Ownership and Innovation in Chinese Solar Photovoltaic Firms:

An Analysis of the Effects of State, Private, and Foreign Shareholding on Patenting Performance

Radomir Tylecote

Thesis submitted for the award of Doctor of Philosophy (Ph.D.)

Abstract

This thesis is a quantitative study of the effect of ownership – by state, private and foreign shareholdings – on innovation by China's solar photovoltaic (PV) firms. Using the country's solar PV industry, I seek to explain the impact of proportions of these different types of shareholding (and within the state category shareholding by central, provincial, and municipal governments) on innovative capacity. This capacity is measured by firms' rates and qualities of patenting.

As Chinese economic growth falters, amid the "re-shoring" of certain manufacturing capabilities, the role of the state, and whether it is helping or hindering its economy's – and Chinese firms' – technological upgrading, is a vital question. This is particularly true in high-tech sectors, including solar PV, which the Chinese government deems essential for the country's continuing economic growth. Through the solar PV industry, we investigate the role of the state, and how it is helping or hindering Chinese companies' innovation.

We employ a dataset covering 150 solar photovoltaic firms. This combines current and historical shareholding data for each firm, R&D expenditure data, and the firms' patent output (all Chinese-registered patents and their related foreign registrations).

The thesis employs a principal-agent theoretical template for the unique Chinese politico-economic context, developing this theoretical approach for the particular "multi-principal" scenario in Chinese high-tech firms (here we refer not only to the combinations of private and state principals, but also to the impact of local against central government). We demonstrate that higher state shareholding leads to higher R&D spending relative to the size of solar PV firms; among state shareholding, local state ownership is shown to be better than central state ownership at generating innovation (which we measure as patent performance). Firms that combine private and state shareholding, especially minority state-owned firms, are superior innovators than purely private or purely state-owned firms.

For particularly innovative patenting, foreign shareholding was found to be beneficial, and finally, central state ownership was more likely to lead to the generation of the less challenging types of solar PV technologies, whereas local state ownership was more likely to lead to "core" PV technologies being patented.

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Declaration

I hereby declare that the entire contents of this thesis are my own work, unless they are otherwise cited as external sources.

Radomir Tylecote

3rd October 2014

Acknowledgements

I was able to embark upon and complete this thesis because of the belief, support, and particularly the tremendous patience of my supervisors, Professor Erkko Autio and Professor Paola Criscuola. I am truly in their debt. My mentor Ian Harvey, Adjunct Professor at the Business School, was a source of constant wisdom and assistance, and has provided great enlightenment about the subjects at hand. Although Dr Cai Jing's assistance appeared later in the research process, it was also vital. I will always be grateful to them all.

I would also like to thank my father and mother, and my brothers, whose support and kindnesses were unflagging.

My data gathering was made possible by Dr Ilian Iliev, Quentin Tannock, Sarah Helm, Frazer Fisher, and Ben Pellegrini at Cambridge IP Ltd, as well as Thomas Oldham, Yu Huijin, and Dr Liu Jiajia in China and the UK. Their help and advice over many months was vital to the completion of this thesis.

When based in Beijing, Professor Gao Xudong and Professor Xiao Yanggao in particular provided me with the advice, insight, and numerous contacts through which I could understand the context and sector in real depth. For this I am also grateful to Manuela Zoninsein, Victoria Wang, as well as Luke Minford and Chris Bailey at Rouse Legal for their support and insights.

Finally, I wish to thank my fiancée Miss Sidsel Rytter Bockhahn for many things, not least tolerance.

Abbreviations

863	National High Technology Research and Development Programme ("863" for its March 1986 founding)
973	National Basic Research Programme ("973" for its March 1997 founding)
a-Si	Amorphous silicon
CAS	Chinese Academy of Sciences
CDB	China Development Bank
CPC	Central Party Committee
CPPCC	Chinese People's Political Consultative Committee
CRS	Cadre Responsibility System
CSRC	China Securities Regulatory Commission
c-Si	Crystalline silicon
EPO	European Patent Office
FYP/5YP	Five Year Plan
GPA	Government Procurement Agreement
GWp	Gigawatt peak
ICT	Information and Communications Technology
IP/IPR	Intellectual Property/Intellectual Property Rights
kWh	Kilowatt hour
MASOE	Majority State-Owned Enterprise
MIIT	Ministry of Industry and Information Technology
MISOE	Minority State-Owned Enterprise
MLP	Medium- to Long-Term Plan
MNC	Multinational Corporation
MOF	Ministry of Finance
MOST	Ministry of Science and Technology
NDRC	National Development and Reform Commission
NIS	National Innovation System
NPC	National People's Congress
PAT	Principal-agent theory
POE	Privately-Owned enterprise
PRI	Public Research Institute
PV	Photovoltaic
R&D	Research and development
RMB	Renminbi
SAMB	State-Owned Assets Management Bureau
SASAC	State-Owned Assets Supervision and Administration Commission
SDPC	State Development and Planning Committee
SEI	Strategic Emerging Industries
SIPO	State Intellectual Property Office
SOE	State-Owned Enterprise
SOECG	State-Owned Enterprise affiliated to central government
SOELG	State-Owned Enterprise affiliated to local government
TRIPS	Agreement on Trade-Related Aspects of Intellectual Property Rights
USPTO	United States Patent and Trademark Office
WIPO	World Intellectual Property Organisation
WTO	World Trade Organisation

The man of system, on the contrary, is apt to be very wise in his own conceit; and is often so enamoured with the supposed beauty of his own ideal plan… that he cannot suffer the smallest deviation from any part of it.

Edmund Burke

1. Introduction

1.1 Background to the thesis

China, for the first time in its history, is investing huge sums in innovation in an attempt at technological catch-up with the West. Whether and where it is succeeding is a question of the foremost importance for us all. So too is how its political structure may be affecting this catch-up.

Despite China having embarked on the process of reform from the latter half of the 1970s, the Chinese state still has more control over the economy – and more ownership of the economy – than any previous successfully developing economy. Perhaps the most important question to ask therefore for China's prospects of "catch-up" is how this power is exercised, or more exactly what effects it has, on the prospects for China's economic development, through its impact on the outcomes of Chinese firms, seen through different levels and types of state ownership.

As we will discuss, the sector that is most vital to China's catch-up is its high technology firms, a fact recognised by its government at the highest level. However, while China's development is highly dependent on it, achieving innovation in high-tech sectors is also widely recognised as being the greatest challenge for Chinese firms.

As a sector through which to study these dynamics, solar photovoltaics provides a field in which Chinese firms have become successful volume manufacturers on international markets. This provides a reasonable number of firms with different underlying levels of innovation. It also includes a considerable variety of ownership types, providing us with an unusual opportunity to assess their different results for innovation.

We will see that China's process of industrialisation has not yet created strong innovation capability in Chinese firms, in contrast with Japan and South Korea where bulk manufacturing-led periods preceded the successful creation of innovation-led economies. China still specialises in low value-added manufactures, frequently with profit margins of 2-5% or less. Failure to increase the capacity for in-country innovation is seen as a particularly important factor where middle income countries have proven unable to enter the developed country bracket (Vivarelli, 2014; Kang *et al*, 2015). Should this remain the case in China, it is doubtful the country will be able to escape the "middle income trap".

The rationale for this study is manifold. First, a quantitative dissection of a question of the effects of financing and corporate governance on innovation output cannot be undertaken in a national context such as China without understanding how the effects of ownership are determined by the mechanics of the state. With this in mind, the theoretical framework is informed by detailed analysis of China's state apparatus and policy framework in this area. Although much western scholarship addresses crude distinctions between "private" and "state" ownership, in fact the proportions of state and private ownership vary on a continuum from 0 to 100%, allowing the emergence of a large number of hybrid firms. Furthermore, within state ownership, the effect of different levels of the state (central government, followed by the provinces, the provincial-level "super-municipalities" such as Beijing and Shanghai, and the smaller municipalities) on the innovation success of China's high-tech firms remains virtually unaddressed. Although the industry is now the subject of a considerable trade dispute, the role of foreign shareholding in Chinese solar PV firms in particular has been little discussed.

1.2 Innovation and entrepreneurs in the Chinese economy

Since the beginning of economic reform in 1979, China's economic growth has been founded on the labour-intensive bulk manufacturing of products for export. Numerous reports, including from the Chinese government itself, now suggest that this scenario must change if China is to become an economically developed country in the foreseeable future (discussed below). Rising labour costs, competition from other emerging markets, unstable demand from developed countries since the financial crisis, plus other factors such as the appreciating renminbi (RMB), suggest that the point is being reached at which China must fundamentally change its economic model.

In 1957, Robert Solow calculated that labour and capital, the two factors which had been assumed to drive economic growth, together accounted for only 13% its total, and that 87% of growth per worker in fact came from "technical change" (Solow, 1957). Studies of South Korea and Japan (below) demonstrate that to avoid the middle income trap, innovation *within* economies is needed, which requires conducive institutional conditions. Meanwhile it appears China's new Premier Li Keqiang wishes to continue the transition to "market mechanisms", meaning in effect breaking state control over industry. Li published a report in 2012 arguing that China must embrace a free market model, stating: "innovation at the technology frontier is quite different in nature from catching up technologically. It is not something that can be achieved through government planning" (Li Keqiang, in McGregor, J., 2012b).

However, while economic reform from the 1980s allowed the growth of private firms and closed many state-owned enterprises (SOEs), private entrepreneurs continue to face obstacles to growth (McGregor, J., 2012b). SOEs still employ a large proportion of the workforce, private firms face higher interest on loan repayments, and SOEs are favoured for infrastructure contracts, receiving various subsidies and benefiting from government *guanxi* (networks).

Indeed in Chinese techno-economic studies, the decade to 2012 has been described as *guojin mintui*: "while the state advances, the private retreats", a reversal of the economic trend of the 1980s and 1990s. We will describe the relationship between reform, innovation, and the generation of patent intellectual property (IP) in greater detail; since around 2003 however, in fields of strategic technological importance including in alternative energy, defence, water, and biotech, China appears to have concentrated investment into the largest SOEs. A June 2011 study by independent Beijing think tank Unirule stated that the "total profits of China Mobile and Sinopec [two large SOEs] in 2009 surpassed the combined profits of China's 500 largest private enterprises" (Unirule Institute of Economics, 2012). It also found that if the subsidies are deducted from SOE profits between 2001 to 2009, their real average return on equity becomes minus 6.29%, and these "soft budget constraints" may disincentivise innovation. SOE managers meanwhile may frequently be promoted elsewhere in the state in a short time period, harming their incentives to invest in innovation for later pay-offs.

Lacking these constraints, the managers of private firms appear to have a greater financial incentive to innovate. However, despite China's broadly modern patent system, evidence suggests that numerous factors are hindering firms' ability to protect patents, and to profit from them through sales, factors which may disincentivise innovation generally. A recent example, Cathay Industrial Biotech, was a private firm established in 1997, which became a leading nylon producer using a proprietary bio-fermentation method. A competitor, Shandong Hilead Biotechnology, began producing the same product more cheaply; Cathay suspended its planned listing to file a lawsuit, alleging an employee had stolen intellectual property, founding Hilead with a retired member of the Chinese Academy of Sciences and an entrepreneur with provincial government links. Hilead gained over $150m investment and a $300m loan from the China Development Bank, taking over 10% of the global market in a year (New York Times, 2011). With Hilead's factory given "national security status", Cathay cannot gather evidence.

In his magnum opus *Science and Civilisation in China*, Joseph Needham (1954) suggested that China's relatively poor technological progress was caused by the phenomenon of "bureaucratic feudalism", whereby the state has hindered innovation since at least the fourteenth century. Qualitative reportage also suggests the dominance and hindering of innovation and growth by the contemporary state. Using solar PV firms as our study, in this thesis we will formally examine to what degree, if any, this may be the case today.

1.3 The international market for solar photovoltaics and the position of Chinese firms

Solar PV is not simply set to be a major component of the energy mix in China and globally, or a technological field in which the Chinese government wants its firms to succeed. Solar PV is an excellent field for the study of Chinas' high-tech firms' innovative success or otherwise. Although photovoltaic processes have been known since 1839 (when Alexandre Becquerel observed the photovoltaic effect in an electrode under a conductive solution when exposed to light), the field continues to show a very high rate of technological learning (Stone, 2012), combining mechanical, physical, and chemical advancements. Solar PV thus provides us with a particularly accurate means to assess the innovative capability of firms in a national innovation system, and of assessing the state's relative success in managing this system.

Having benefitted from forms of subsidy designed in part to increase the Chinese global market share, the solar PV sector is now at the centre of a trade dispute involving European and US tariffs on Chinese imports. Non-Chinese firms meanwhile must adapt to an environment in which the best route for the uptake of their technologies is now by predominantly Chinese "systems integrators" (Nolan, 2012), the makers of cheap finished products for installation. Most Chinese firms lack much patented IP however, with most of the technologically advanced firms in the solar PV sector being in the US, Germany, the Benelux countries, Japan, and South Korea.

The manufacture of solar PV products has been driven thus far primarily by developed-world demand, mainly in grid-connected installation (de la Tour *et al*, 2011). Developed-world subsidies have helped create a large market for PV modules, while Chinese firms have increased production capacity to dominate these markets with cheaper products. Subsidies in the main consumer nations are now being cut, and innovation encouraged by the introduction of higher technical standards (such as in Japan), with demand for higher-specification products therefore set to grow. To both maintain market share and drive indigenous innovation to increase profit margin, Beijing now favours producers with higher technological capability, encouraging patent registration as a means of fostering, protecting, but also rating Chinese firms' technological innovation.

Thus competition in solar PV increasingly revolves around who can produce modules (and module *components*) that convert photons to electricity both efficiently and at competitive prices (allowing kit purchasers to produce electricity either to sell to consumers, or for households and businesses with solar equipment to sell it back to the grid). Manufacturers are competing to reduce "balance-of-system cost" (which includes maintenance and components), to reach grid parity (equal to or less than the price of conventional electricity from the grid) and drive uptake. This is the cost per delivered kilowatt hour (kWh), and varies depending on life of the system, both on installation costs and the amount of electricity a module produces. This price ultimately determines the uptake of solar products. The producers who win market share must also provide innovations for environments varying in light intensity, heat, cloud cover, safety requirements, and taste in appearance. Although China currently dominates manufacturing market share, as other countries compete to produce solar PV modules, and in the innovations that differentiate them, Beijing has recognised the need for Chinese firms to move up the value chain from cheap bulk manufacturing to patent-based innovation.

This introductory section began by placing the research in the proper context, this being China's particular "moment" in economic development, giving the beginning of an understanding of China's challenges for growth, and the place of China's technology firms in these challenges. We have also discussed the gaps in current knowledge that we aim to address. Before a more detailed analysis later in the thesis, we have also begun to discuss both the development of the Chinese solar PV industry in particular, and the place of entrepreneurs in China's technology economy in general. In doing so we have highlighted what Chinese economic growth has not yet achieved, and what may be the relevant institutional constraints on innovation and growth generally, and particularly within our chosen technological sector of solar PV firms. The structure of the thesis to come is as follows.

The literature review below will outline the theoretical template through which we seek to understand the Chinese state's influence on innovation outcomes among solar PV firms, analysing principal-agent theory in particular. This theoretical approach will allow us to better understand the effects of the reform of China's national innovation system, detailed in the section following the literature review. As such we will build an understanding, through principal-agent theory, of the impact of China's national innovation system on solar PV firms' management and thus innovation outcomes, in particular its impacts on managers' innovation investment decisions. These will be assessed by category of firm, these categories being defined by their relative levels of shareholding (by shareholding by central versus sub-central, plus different levels of the state, private, and foreign shareholding).

The thesis asks how share ownership of firms in the Chinese system influences innovative output, through its impact on the innovation decisions of company managers. It does this through an understanding of how the principal-agent relationships between shareholder principals and manager agents vary, dependent on the relative proportions of these ownership types, in China's politico-economic system.

This study does not use straightforward distinctions between entirely state and entirely private ownership, but investigates the results of the continuum of state and private ownership, which vary from 0 to 100% of shareholdings. It also investigates the impacts of different levels of the state (by central government, then provincial, then provincial-level "super-municipalities" including Beijing and Shanghai, and finally the smaller municipalities themselves) on innovation quality and direction.

The thesis aims to contribute to principal-agent theory within institutional contexts, not simply by applying this theoretical template, developed in and for western contexts, to a general Chinese context, but through developing it for a more specific politico-economic theoretical instance. The agent-managers with whom we are concerned act in a multi-principal environment, combining state, private, and foreign shareholding. While some foreign and private shareholder principals exist and act privately, without owning firms in tandem with the state, others are combined with state principals, while state principals also act alone in entirely state-owned firms. This spectrum of principal-agent relationships, in a politico-economic environment in which principals employed by various levels of the state are also employed by the legal arbiter of disputes, and the owner of most financing institutions, is a very particular context for principal-agent theory; in analysing outcomes for firms attempting to innovate in a new technology industry, we seek to create a novel development of principal-agency theory.

Having applied a principal-agent theoretical understanding to the Chinese national innovation system to discern the management outcomes of different shareholder categories, we will discuss what firms are trying to achieve in terms of their patenting, and in which types of solar PV technology they seek to innovate. We will then generate the theoretical framework, which allows the theoretical literature and technical knowledge of the field to generate the hypotheses.

Next, we will outline the methodology, including how the qualitative and quantitative data was obtained, the different types of quantitative data, and the construction of variables. The methodology section will outline the data types used, but we should describe here how the choice of data, between qualitative and quantitative, changed as the research progressed. The intention as the study began was to base my research on interviewing, including within the Chinese solar industry, for predominantly qualitative research. However during my early fieldwork in China it became clear that this method would not bear fruit, due not just to the relatively low-trust business culture, and other factors. I changed my methodological approach radically as a result. This required interviewing in and outside China in order to generate a strong background to the national innovation system and general strategy in the solar PV industry, but also a core quantitative dataset with which to demonstrate my hypotheses. The dataset I chose was broadly divisible in two, involving the assembly of data on the current and historical shareholding of a sample of China's solar PV firms, and on the patenting outcomes of the same firms.

The different types of evidence used to inform each chapter of the thesis are broadly as follows. Chapters 3-5 are underpinned by qualitative sources and information. Chapter 2 details qualitative information gathered on the functioning of innovation systems, their understanding through principal-agent theory, and draws the two areas together to analyse how these power structures and relationships, the information phenomena they create, help us understand high-tech innovation. The qualititaive information in Chapter 3 consists of an analysis of the Chinese structure of state, detailing the relevant principals and agents, and employs legal and economic research to understand what the impacts of state demands, standard-setting, and cadre observation and management are likely to be on innovation outcomes. This chapter also uses evidence about R&D spending patterns and the functioning of China's patent system to describe as completely as possible the role of the state in the development of China's technology firms. Chapter 4 applies the most qualitative sources – the theoretical literature from chapter 2 – to China's innovation system specifically, using the evidence gathered about the working of the Chinese system, and state, to describe what this will mean for principal-agent relationships, for the management of technology firms, and for the country's innovative output (including quantifiable outputs). Although most of the evidence in chapter 5, on China's solar PV industry, is qualitative, this chapter also places the thesis in the context of this particular industry by detailing the scale, technological level, and growth trajectory of this industry. Chapter 6, the methodology, outlines all the other areas of evidence that are used to research this thesis. The qualitative area, data from interviewing, meant evidence from semi-structured interviews carried out in the early stages of research, that guided both the formulation of my research question, and the quantitative data I used to research and demonstrate the hypotheses. This quantitative data is divisible into four areas: patent data, shareholding, R&D data, and control data. The chapter describes why they were chosen, how they were obtained and processed, the construction of variables from the data, and their treatment in regressions (limitations are discussed in the final chapter).

The methodology section is followed by the description of the specific hypotheses themselves, and the hypotheses-specific data analysis in preparation for the hypotheses regressions. The output from each regression is then set out. This is followed by the concluding section, which discusses the results, their limitations, and future avenues for research. We begin with the literature review.

2. Literature Review

2.1 Aims of the literature review

The literature review that follows aims to describe the relevant theoretical literature as it stands; to discuss what the literature has to say about the research question; and to discuss where our approach lies in the general conversation that the literature constitutes, summarising how this literature has informed the theoretical template that follows (in other words helped us understand which "inputs" lead to which "outputs").

This review is divided as follows. The first sub-section addresses the institutional-theoretical area of national innovation systems; the second is a general introduction to principal-agent theory in general; and the third sub-section discusses principal-agent theory in high-tech innovation. Next, there follows Section 3 of the thesis, the analysis of China's own innovation system. Following this we return to the theory to analyse principal-agent theory in high-tech innovation in China. Ultimately, we will explain how we adapt principal-agent theory to a non-western, state-led innovation system, featuring a specific high-technology. We will analyse how the literature overall has helped inform the hypotheses (explaining what the theory has to say about these specific governance questions, explaining for example why career bureaucrats may differ to other managers in decision-making around investing in innovation). We then generate the theoretical framework.

The review aims to be critical of research findings and to highlight gaps in knowledge as it stands. Although we cannot cover every work that comments on the subject, we aim to cover the widest relevant sweep of scholarship, including demonstrating what is not sufficiently understood. Categorising literature thematically, the review is qualitative and discursive, not a list of sources.

2.2 National Innovation Systems

In the following subsection, we will discuss the origins of the area of institutional theory broadly known as "innovation system" theory, outlining the main different approaches to this institutional field; how they see the role of the state (in particular its positive and negative role in innovation outcomes); these approaches' perceptions of "institutions" (especially "hard" formal institutions, or "soft" institutions in the more conceptual sense); and we will explain which conception of innovation system we apply for our case, and the rationale behind this.

Questions of "institutions" have in recent decades become gradually more important in theoretical approaches to innovation. Indeed, having been a peripheral concern to economists, the role of institutions has arrived at the centre of dissections of how innovation occurs. Nonetheless, institutions can be seen as helping or hindering innovation, and as existing in a better or worse match with the relevant technologies.

Renewed interest in institutions in innovation has followed the renewal of attention to institutions in economics generally. According to North (1990, 3), "Institutions are the rules of the game in society or, more formally, are the humanly devised constraints that shape human interaction. In consequence they structure incentives in human exchange, whether political, social, or economic". Innovation systems theory can thus be understood as consisting of attempts to deduce the outline of the relevant institutions shaping innovation, be this in a particular state, region, or technological sector.

The concept of innovation system specifically was moulded out of institutional theory in an attempt to establish which "institutions" are the important factors in innovation processes. Systems of innovation approaches therefore need to take into account all the necessary factors that influence innovation, to grasp the dynamics within the structure. The "national system of innovation" approach was first coined by Lundvall (according to Freeman, 1995; and Edquist, 1997), while it was first published in Freeman (1987) (in another East Asian study, of the Japanese economy and technology policy).

Freeman (1987, 1) defined a national innovation system (NIS) as a "network of institutions in the public and private sectors whose activities and interactions initiate, import, modify, and diffuse new technologies"; Zhong and Yang have defined it as "a network of institutions, policies, and agents supporting and sustaining the scientific and technical advance" (Zhong and Yang, 2007, 2). However different approaches to national systems of innovation soon emerged, and to place our contribution we need to appreciate their differences. Lundvall (1992) and Nelson (1993) edited two particularly influential studies, to which we can also add Carlsson (1995). The core differences between the approaches are as follows.

2.2.1 Core approaches to innovation systems

Lundvall's approach, crystallised in *National Systems of Innovation: Towards a Theory of Innovation and Active Learning* (1992) is more "thematic" (Edquist, 1997) than geographically- or country-oriented. Emphasising learning processes and interactions between users and producers, Lundvall analyses specific innovation themes *across* national boundaries, instead of how a nation state in isolation deals with that question (while also dealing with specifically theoretical questions in relative isolation). Finding that a NIS cannot be strictly defined, Lundvall states that it means, broadly: "all parts and aspects of the economic structure and the institutional set-up affecting learning as well as searching and exploring – the production system, the marketing system and the system of finance present themselves as subsystems in which learning takes place" (Lundvall, 1992, 2). The implication is even that "technological trajectories and paradigms", which guide the activities of individual innovators, should be seen as "one special kind of institution" (Lundvall, 1992, 2).

Lundvall suggests that we also seek to understand the historical causes of these cross-national phenomena: "Determining in detail which subsystems and social institutions should be included, or excluded, in the analysis of a system is a task involving historical analysis as well as theoretical considerations [which means] a definition of the system of innovation must be kept open and flexible regarding which subsystems should be included and which processes should be studied" (Lundvall, 1992, 14).

Although Freeman (1987) describes the Japanese national innovation system's four central pillars as being the Ministry of International Trade and Industry (MITI); company R&D, particularly around technology imports; education; and industry's conglomerate structure, Nelson (1993), delineates more clearly the exact institutions, country by country, responsible for innovation in an active and political sense, stressing empirical evidence-gathering and creating a national case study-based approach. It is worth highlighting tendencies evident in this approach. Nelson (1981) discussed evolution-based approaches to technological change as superior methods of understanding processes of innovation than established neoclassical economic theory. Although Nelson (1993) does not describe evolutionary theory in this work on NIS, he had argued previously that "in capitalist countries, technical change is set-up as an evolutionary process" (Nelson, 1988, in Edquist, 1997).

Yet the idea that the evolutionary process of technical change is "set-up" itself demonstrates two assumptions: intentionality on the part of institutional actors, especially those in higher positions of power, and that any evolutionary process can be set-up at all. This assumption is repeated: "This book is about national systems of technical innovation [and] the studies have been carefully designed, developed, and written to illuminate the institutions and mechanisms *supporting* technical innovation in the various countries" (Nelson and Rosenberg 1993, 5; my italics. This is an assumption that is common to much work using this perspective). However it is possible that institutions may not support, but hinder, innovation.

Nelson and Rosenberg also differentiate quite clearly not only between different nations' systems, but different sectoral systems within nations: "The system of institutions supporting technical innovation in one field, say pharmaceuticals, may have very little overlap with the system of institutions supporting innovations in another field, say aircraft" (Nelson and Rosenberg, 1993, 5). That this can be a useful approach for a specific sectorial focus is demonstrated in studies such as Sagar and Holdren (2002) on energy innovation systems. No clear definition of a NIS is given by Nelson and Rosenberg however. Neither do they address organisational, social, or institutional innovations in great depth (which is challenging when dealing with reform). While the authors above do not give a clear definition of "institutions", Edquist (1997) suggests that firms and industrial research laboratories are the most important institutions for innovation. Edquist also suggests that there are good reasons to discuss systems in the national sense, with clear differences even within regions (such as East Asia, or Northern Europe), such as in R&D investment, institutions, and overall performance (Edquist, 1997). Edquist and Lundvall (1993) give the example of Denmark and Sweden, whose differences are "remarkable". Furthermore most innovation policies are made nationally, so the rationale for these policies, and their impacts nationally, must be understood: "the state, and the power attached to it, is also important" (Edquist, 1997, 12).

According to Edquist (1997), a third approach is seen in Carlsson *et al* (1992), whose "technological systems" perspective addresses theoretical questions of technological systems, which they suggest are specific for different areas of technology, emphasised above the national. Hence Carlsson's "technological system", rather than strictly national, is "a network of *agents* [my italics] interacting in a specific economic/industrial area under a particular institutional infrastructure or set of infrastructures and involved in the generation, diffusion and utilisation of technology" (Carlsson, 1995, 14; the later sections in this literature review will delineate this). The infrastructure affecting a sector, according to Carlsson *et al* (1992), can be divided into four: industrial R&D, academic infrastructure, other institutions, and state policy.

The "institutional infrastructure" of each technological system refers to the "institutional arrangements (both regimes and organisations) which, directly or indirectly, support, stimulate and regulate the process of innovation and diffusion of technology" (Carlsson and Stankiewicz, 1995, 45) (we note that this is implies assistance to, rather than hindrance of, "the process of innovation"). This means a wide range of institutions: "The political system, educational system (including universities), patent legislation, and institutions regulating labour relations" (Carlsson and Stankiewicz, 1995, 45), which in our case includes governmental and patent-related institutions.

More recently, various scholars have analysed the mechanisms for the diffusion of renewable energy technology specifically, and innovation systems' role therein. At the end of the 1990s, Jacobsson and Johnson (2000) presented a framework to analyse renewable energy technology diffusion (other scholars include Wang, Qin and Lewis (2012), to be discussed below). This context already seems very different from today's however, with the authors analysing an increase in nuclear power installations from 1980, adding that of the small increase in renewables installations, "it is primarily the renewable energy sources that were already established at the beginning of the period (hydro power, geothermal power, and combustible renewables and waste) that have contributed to this increase", and that "new renewables (wind and solar power, etc.) have not yet reached a widespread market" (Jacobsson and Johnson, 2000, 626). Wind energy at the time was "probably the fastest growing renewable energy source in the world", although "it seems possible that solar cells will become attractive in one (or several) larger market segments(s) in a not too distant future" (Jacobsson and Johnson, 2000, 626-8). The diffusion of solar PV in particular was hindered at the time partly by high cost, unlike in the current paradigm.

Within innovation systems generally, Jacobsson and Johnson (2000, 629) proposed certain "elements" to help understand the transformation of an energy system. Taking into account the neo-classical economic approach, which sees technology choice influenced by relative prices, and the individual firm perspective in which "the entrepreneurial act is the central feature of innovation and diffusion", they emphasise, first, an "innovation and diffusion process [which] is both an individual and collective act" (Saxenian (1994) in Jacobsson and Johnson, 2000, 629), and second, the determinants of technological choice being found in an "innovation system" as well as in individual firms (Jacobsson and Johnson, 2000, 629). As this system includes "a large number of variables apart from prices", firms respond to price, but also many other factors.

Jacobsson and Johnson (2000) also draw on the technological specificity of Carlsson and others, especially Carlsson and Stankiewicz (1991, 111): "networks of agents interacting in a specific technology area under a particular institutional infrastructure to generate, diffuse, and utilise technology. Technological systems are defined in terms of knowledge or competence flows rather than flows of ordinary goods and services. They consist of dynamic knowledge and competence networks". Some actors however will be "prime movers", so "technically, financially and/or politically" powerful that they have a considerable influence over a new technology's development or diffusion. Meanwhile "networks" of firms influence the perception of "what is possible and desirable", which "guides specific investment decisions" (Jacobsson and Johnson, 2000, 630). Finally, as discussed by Edquist and Johnson (1997), institutions affect the path a technology takes. So any new technology system increases technological "diversity", but is "path-dependent" (David, 1988) on both actors and associated institutions. Jacobsson and Johnson (2000, 630) suggest this is especially true for renewable energy, where new technologies "substitute rather than complement" existing technologies, threatening the real or perceived interests of dominant actors, in the state or elsewhere.

Among innovating firms themselves, Dosi (1988, 225, in Jacobsson and Johnson, 2000, 631-2), points out that “the search process of industrial firms to improve their technology is not likely to be one where they survey the whole stock of knowledge before making their technological choices. Given its highly differentiated nature, firms will instead seek to improve and to diversify by searching in zones that enable them to use and build upon their existing technological base”. Thus in any system, “firms, which are aware of a new technology, may pursue risk assessments that are biased in favour of the prevailing technology” (Jacobsson and Johnson, 2000, 632). A system can therefore exacerbate firms’ tendency to the pursuit of particular technological fields.

To summarise these more recent approaches to adjusting innovation systems for renewable energy development, “the rate and direction of technical change – the process of technical choice – is decided in competition between various technological systems” (Jacobsson and Johnson, 2000, 633), but the authors add that “the construction of a new system often involves the destruction of an alternative system”. With institutional change and policy closely related, in adjusting an institutional system to favour an emerging technology, “policy makers need to be patient”.

Johnson and Jacobsson (2001, 95) suggest that if they are not – or if they are influenced too strongly by interests that have become dominant in an industrial system – institutions may fail to usefully shape a new one. For instance, legislation can direct the “search process” in the direction of an ‘incumbent’ technology by influencing the prices of the alternatives, and as a result capital markets may not respond to a new technological system’s needs (Carlsson and Jacobsson, 1997b). This is likely to affect the supply of “capital and competence” (Johnson and Jacobsson, 2001, 95); a new technological field may also have badly organised actors, which may mean limited ability to advocate legislative change and a lack of organisational nous which may retard acceptance of a new technology. (The scholars thus present a solid framework of institutional problems, but mine is both a new field with particularly dominant politico-economic interests which both ‘own’ the legal system and parts of economic production, and in which the power relationships can be much more clearly understood through a principal-agent framework).

Meanwhile Johnson and Jacobsson (2001, 96) describe a case where the “technological strength of Sweden is now negligible, however”, as opposed to a country become technologically more advanced. And although, like in China, some actors had weaker “organisational power”, with more power with bigger firms, the state’s actions were different, with government putting money into a specified area: large-sized wind turbines. Different forms of “unlocking” were also needed in Sweden (Johnson and Jacobsson, 2001, 106), specifically the need to unlock the “nuclear trauma”, i.e. the influence of the nuclear industry.

However in their continuing analysis of the failure of the Swedish institutions and innovation systems to help build a strong wind turbine industry, Bergek and Jacobsson (2003) provide a useful supplement. Although neo-classical economics uses the phrase “market failures”, Johnson and Jacobsson (2001, 93) suggest “it is not meaningful to refer to deviations from a (neo-classical) “optimum” in an uncertain, dynamic and complex world”. Their objective instead is to study “obstacles” to development, or factors that “tilt the selection environment in favour of incumbent technologies” (in our case however this may mean simpler PV technologies, as we will discuss). Johnson and Jacobsson (2001, 95) suggest these obstacles may come in the form of legislation, the education system, the capital market, and weakly organised actors, but our analysis requires an understanding of other obstacles that we will discuss, and ultimately of agency relationships in the politico-economic system itself.

Scholars have approached national innovation systems from numerous other perspectives. These include Thailand's NIS as a case of a "less successful" developing country (Intarakumnerd, Chairatana and Tangchitpiboon, 2002); outlining, for the Indian case, the main elements of the NIS (Herstatt *et al*, 2008); analysing specific elements in national systems, such as biotechnology in Taiwan (Dodgson *et al*, 2008) or R&D laboratories in general in the US (Crow and Bozeman, 2013); regional systems as elements in the national system (Cooke *et al*, 1997; Chung, 2002); global interdependence of national innovation systems (Niosi and Bellon, 1994; Carlsson, 2006); and the historical approach to national innovation systems in general (Godin, 2009). We will draw on various China-specific studies written from such perspectives in the following section.

For our purposes the differences between Nelson's and Lundvall's approaches are, first, in the organisation of central actors. Lundvall's approach allows more discussion not simply of how a system is managed effectively state-by-state, but at how it may be managed to malign effect (which includes dealing with finance for example). The thematic rather than geographical approach (of both Lundvall and Carlsson) also allows more breadth than Nelson *et al*.

2.2.2 Innovation systems, the state and reform

We have established that some institutions regulate and control competition and conflict among groups. For our study, we need to understand the actions of state institutions, because the presence of state management does not necessarily imply success, even if this fact has not always been emphasised. Edquist (1997) has suggested institutions may be "obstacles to innovation". Therefore a "historical perspective", as Edquist (1997) states, "is natural". This is how we appreciate the current form of the relevant institutions in any given NIS, then uncover their impacts. As we have discussed through Solow (1957), an economy being capable of continued growth depends on its capacity for technical change, which means it depends on its ability to "adapt and renew its institutions to support... innovation" (Edquist, 1997, 55). Thus national economic stagnation can be caused by the institutional structure's failure to adapt (Freeman and Perez, 1988). This mismatch of "radical technical change" with the institutional structure "may lead to periods of economic stagnation until new institutions and institutional restructuring establish a new match" (Edquist, 1997, 55). Although Edquist uses the phrase "institutional drift" for institutions' attempts to carry out new tasks, in our case this means Marxist-Leninist institutions being applied to attempts to drive innovation in high-tech firms for the purpose of economic renewal. As such "institutional mismatch" may be a better description here.

Lipsey (2009, 3) states: "invention and innovation are risky and costly; people will usually only engage in these activities if they anticipate a gain that exceeds the expected personal cost", or in our case in the absence of "institutional disincentives to growth". These are not "either-or characteristics but matters of degree... as long as some innovation is tolerated and rewarded, there is a wide range of institutional arrangements that are compatible with growth", including the various innovation policies in "market economies that are currently growing". However according to Lipsey (2009, 6), "new technologies require new institutions to support them. Wu and Tu (2007) demonstrated how managers perceive considerable downside risk associated with R&D investment; it thus takes the right institutional innovations to prevent growth slowing to a halt, because, if new technologies are not exploited, further inventions and innovations that build on them are unlikely to occur". This means that "technology and institutions are linked in a system of mutual interaction".

This question has been addressed by scholars such as Lundvall, Intarakumnerd and Vang (2006, 1, 2, 8), who describe Indonesia as one case where "the need for a transition is obvious but where it remains blocked by established power structures and institutional inertia." They agree that analysis of innovation systems may be at its most valuable in countries attempting to escape the middle income trap, as "the transition perspective may be seen as a necessary complement to prevailing ideas of *catch-up economic growth*". Growth can only be maintained if systems within nations "from time to time [go] through a process of qualitative change affecting institutions, organisations, and relationships between organisation." They add that: "In China [the challenge] is to build institutions that help firms out of an imitative mode in many fields of technology but also to build institutions that make growth sustainable". While some suggest that it is more important to study technological globalisation *per se*, the very fact that firms must compete in a globalised technological marketplace means the impacts of national innovation systems on their success within it is more important than ever.

Lundvall, Intarakumnerd and Vang (2006, 2) suggest that the NIS concept is "dialectical", given that "innovation signals discontinuity while "system" tends to be associated with a stable structure", resulting in more attention to current institutional setups than to changes therein (the continuation of Marxist-Leninist institutions and their impact is one of the themes that runs through this thesis). Lundvall, Intarakumnerd and Vang (2006, 4) add that: "contingency mismatch" exists where "situations where the environment changes so that the prevailing institutional set-up becomes ill-suited for the problems that the environment raises", such that a limit to growth emerges (which may necessitate more radical change). We will return to Lundvall (e.g. Lundvall and Gu, 2006) and other innovation system scholars in analysing the Chinese innovation system, its organisation by the state, and its reforms, in the following section.

Some critics of the NIS approach have suggested that regional entities have become more important than national, as "sub-national entities", including provinces, cities, and districts become more important than the nation state, with Silicon Valley a case in point (Sun and Liu, 2010). However this also reveals why we need to understand the specifics of the Chinese example. Reforms to the Chinese NIS have been "controlled and directed" by the central government (Sun and Liu, 2010, 1311), meaning the concept of the state "is far more complex than that of a geographical space, as it also embraces the prime unit of public policy" (Sun and Liu, 2010, 1312). However one should not neglect the regional dimension, and we will return to the role of Chinese regions in discussing the innovation effects of central versus non-central governments, and of regional industrial agglomeration.

This innovation system in China differs from most developed countries' equivalents in various aspects. The first is the context, specifically the level of marketisation. More developed nations will usually see the NIS in a market context, with interactions between innovative actors, and with government policy promoting the interactions (Sun and Liu, 2010). China's NIS however emphasises the leading role of the state in the "transition process from a planned to a market-oriented economy" (Sun and Liu, 2010, 1313). Furthermore, although an "enterprise-centred innovation system" is Chinese policy-makers' stated aim (Sun and Liu, 2010, 1313), many of these enterprises remain wholly or partly state-owned, with the rules governing how this transition takes place also decided by the state.

The next difference is how states govern interactions in the system. While developed country governments may usually aim to optimise interaction between the systems' actors, in China the government aims to build an innovation system that is "enterprise-centred" but with the state as a major spender (Sun and Liu, 2010), establishing R&D laboratories, centres, and suchlike. Finally, Sun and Liu (2010), suggest that the Chinese state's leading role in restructuring the innovation system differs from the more autonomous, market-led phenomena in developed countries.

2.2.3 Innovation systems and agency theory

The idea of institutions can be further developed by seeing them as "routines". Lundvall (1992, 10) states: "institutions may be routines, guiding everyday actions in production, distribution, and consumption", a clearly different meaning to the more strictly organisational delineation of Nelson and Rosenberg, referring to organisational structures. Edquist (1997) suggests that Nelson and Rosenberg's approach may require more focus on "things that pattern behaviour". But to Lundvall's perspective "more weight to organisations" could be added (Edquist, 1997); these are questions we seek to address in this thesis.

All perspectives agree that actors' behaviour is influenced by a "network of institutions" (Freeman, 1987), these institutions being "crucial" to understanding the innovation process (Edquist, 1997). But it is this "system" that means we look at an NIS in particular, not institutional theory in general: we follow Edquist's (1997, 15, 13) definition of system as "including all important determinants of innovation", and more exactly as a "set of institutional actors that, together, play the major role in influencing innovative performance". In other words the NIS is a system in which the principal-agent relationships we discuss below exist, and a system that is capable of directing them.

This cuts to the quick of what kind of theory the systems of innovation approach is. *Appreciative* theory involves an empirical focus and uses explicit causal arguments (Nelson, 1995), while *formal* theory is expressed in stylised form (Edquist, 1997), and can be used to "discipline and sharpen" theories such as appreciative theory (Nelson, 1995, 5). The systems of innovation approach is not a formal theory, lacking "convincing propositions as regards established and stable relations between variables" (Edquist, 1997, 28), and is simply a "conceptual framework". Although the NIS approach suggests a "structure", it lacks focus on actor orientation within this structure. Edquist (1985, 1997) suggests that an approach that combines this structure with actor-orientation is needed: the conceptual framework needs to be "disciplined and sharpened" by this explanation of why actors behave as they do within it. We suggest that without this it is liable to give the impression of the existence of institutional "black boxes" within the institutional framework, leaving "causal gaps". The gaps thus need to be filled by an explanation of the patterns of behaviour within the institutional framework, hence our choice of principal-agent theory, which we will describe in the following sub-section.

2.3 Principal-Agent Theory Introduction

2.3.1 Principal-agent theory

This subsection will plot the outlines of principal-agent theory in some detail, to explain how these relationships operate in, and impact, the Chinese national innovation system. We will begin by describing the functioning of principal-agent relationships, and the types of phenomena they can create. This includes the possession of information between the partners in these relationships, how imbalances in information possession affect behaviour, and the incentives that principals attempt to set to rectify this, with varying degrees of success.

Defining an agency relationship as a contract whereby one person or more (the principal/s) hire another (an agent) to carry out a task on this principal's behalf, this implies the delegation to the agent of some level of decision-making authority (Jensen and Meckling, 1976). Thus the principal-agent problem typically involves one party, an agent, acting for another party, a principal. Traditionally used as an analytical tool to study questions around western shareholding, the central problem addressed is how to induce or motivate the agent to behave in the interests of the principal. (Outside the western shareholder-principal and manager-agent context, principal-agent questions in general have mainly been analysed in insurance provision, and in political contexts of relationships between voter-principals and elected politician-agents). Indeed, Arrow's (1963) insurance industry research is regarded as the classic principal-agent study. Having paid for insurance, patients chose doctors based on their ability to provide services, with insurers picking up the cost. This may include each of the core concepts of: informational asymmetry (between patient and insurer), adverse selection (with people more prone to illness more likely to seek insurance), and moral hazard (when the agent, in this case the insured patient, in taking more risks with his or her health, carries out actions which are not optimal for the principal, here the insurer).

Moral hazard therefore refers to the insured person taking more risk than he would were he not insured, which may mean more risk than is optimal for the insurer and insured together (i.e. *post-contract hidden actions*). *Adverse selection* is when people who know they are highly risky are more likely to insure themselves than people who know they are low-risk (a *pre-contract hidden situation*). So if principal-agent questions address one party acting for another, incentives questions ask how this agent can be *incentivised to act in the principal's interests*. Asymmetric information meanwhile exists between principal and agent (as to the actual behavior of the agent, and *how he uses the resources* he is provided); the specific *actions that may be hidden from the principal* as a result therefore constitute the moral hazard.

The indirect origins of principal-agent analysis appear in Adam Smith (1776, 44). Seeing the need for delegation within firms, in the contractual relationships between masters and workers Smith noted conflicting interests, and the uneven distribution of bargaining power (here the masters were principals and the workers agents). To Smith the masters usually had most of the bargaining power:

"What are the common wages of labour, depends everywhere upon the contract usually made between those two parties, whose interests are not the same. The workmen desire to get as much, the masters to give as little as possible" (Smith, 1776, 44).

Smith also appealed to noneconomic motives: "The pride of man makes him love to domineer, and nothing mortifies him so much as to be obliged to condescend to persuade his inferiors" (Smith, 1776, 89). Thus Smith understood that the aims of principals and agents should not be seen in purely profit-oriented terms, and they may have other goals for which they direct their choices.

The concept that the growing complexity of specialised labour relations defines economic development (and that applying knowledge also grows more complex) can be traced back to Smith (Gu and Lundvall, 2006), so any discussion of principal-agent theory must also trace these roots. For Smith, the most serious problems that arose were lack of investment by tenants in the land, and in the (unmonitorable) misuse of farming instruments: "In France [proprietors] complain that [tenants] take every opportunity of employing the master's cattle rather than in cultivation; because in the one case they get the whole profits for themselves, in the other they share them with their landlords" (Smith, 1776, 277), in Laffont and Martimort, 2002. In other words the optimal use of resource differs between principal and agent, which may lead to conflict between them. In this way is misalignment between the aims of principal and agent created.

Smith (1776, 124) also explained the general result of these situations, by which we mean moral hazard, suggesting that within the joint-stock company, in which management and shareholders are separate: "[the] directors of such companies, however, being the managers rather of other people's money than of their own, it cannot be well expected, that they should watch over it with the same anxious vigilance with which the partners in a private copartnery frequently watch over their own". Smith deduced that "Negligence and profusion, therefore, must always prevail, more or less, in the management of the affairs of such a company" (Smith, 1776, 239). The "agency problem" occurs because principal and agent have different goals, and principals cannot know for sure whether agents have behaved "appropriately" (Eisenhardt, 1989).

We will thus create a proper understanding of principal-agent theory by discussing first the types of "post-contract problems" that principal-agent relations can create. Understanding principal-agent relationships as contractual relationships involving a principal attempting to induce agent behaviours that meet the requirements of a principal's own interests, we go on to analyse the core phenomena these relationships generate, and the reactions they require. The central questions then, are: the structure of principal-agent relations themselves, which create information asymmetry, leading to moral hazard, which principals attempt to address by giving incentives, but which may have side-effects depending on their rewards and time-horizons[1].

Before considering the question of using incentives to align principals and agents, we should ask the nature of the costs agency problems can impose, as discussed by Jensen and Meckling (1976). The assumption that each party is a "utility maximiser" (Jensen and Meckling, 1976) means agents will not always act in principals' interests. As we discuss in the subsection below, principals *may* be able to control departures from their interests through giving agents incentives, and/or taking on "monitoring costs", which *may* limit agents' undesirable behaviour. Jensen and Meckling (1976) state that it is

[1] Eisenhardt (1989) suggests that many researchers work almost entirely on the particular principal-agent relationship involving the owners and managers of large public corporations (leaving much work to be done on cases such as ours). For example Jensen and Meckling (1976) analysed corporate ownership structures, with equity ownership aligning manager and owner interests, with "positivist writers" almost exclusively interested in the example of owner-CEO relations in corporations.

impossible to optimise agent decisions from the principal's point of view at "zero cost": there will be financial or non-financial "monitoring and bonding costs", besides which there must still be "some divergence" between decisions optimal for agent and principal welfare.

Thus they define these agency costs as the combination of: principals' monitoring expenditures, including attempts at controlling agents' behaviour via spending controls and suchlike; expenditure on "bonding"; and any *residual loss*. But it is the desire of each party to maximise utility, in particular the agent, and the presence of information asymmetry that makes moral hazard itself possible.

Eisenhardt (1989) therefore summarises agency theory as being concerned with relationships whereby one party (the principal) delegates work to another party (the agent). The theory then attempts to address the two obstacles that can arise in these relationships: the *agency problem*, when the goals or preferences of principal and agent come into conflict, and that it is difficult and/or expensive for principals to check on *what agents are actually doing*, in other words moral hazard.

2.3.2 Moral hazard

Problematic private information involves an agent taking actions unseen by a principal. This means hidden action, or *moral hazard*, springs from this asymmetric information problem. Thus moral hazard is a consequence of information asymmetry, expressed in actions by the agent which are not optimal for the principal. It can also be the result of one party in a relationship or transaction having more information than the other, with the party with the information making himself more insulated from risk, with the latter more likely to pay for the consequences; shirking, or "negligence and profusion" can also arise through this scenario, as can excessive risk avoidance by agents, and short-termist behaviours that are costly in the long-run. Thus we aim to describe what we mean by moral hazard itself, the part it plays in the principal-agent context, and how it relates to our case.

The origin of moral hazard theory, despite its development through insurance analysis in the 1960s, may in fact be in Hume (*A Treatise of Human Nature,* 1738, 239). "Two neighbours may agree to drain a meadow, which they possess in common; because it is easy for them to know each other's mind". This meant "that the immediate consequence of his failing in his part, is the abandoning the whole project. But it is very difficult, and indeed impossible, that a thousand persons shou'd agree in any such action; it being difficult for them to concert so complicated a design, and still more difficult for them to execute it; while each seeks a pretext to free himself of the trouble and expence, and wou'd lay the whole burden on others". This is the core moral hazard problem: in the presence of ignorance, one party may carry out non-useful (or risky, or detrimental) actions when they will not feel the results of these actions, but instead the other party will.

The moral hazard area has been studied in the contexts of team management, team production, contract design, and more recently risks in financial products. In contracts though, moral hazard arises in situations involving "hidden actions" (asymmetric information), specifically shared risk under conditions whereby actions taken privately affect the probable "distribution of outcomes" (Holmström, 1982), and managers can shield higher-ups from the results of bad decisions. Yet moral hazard is also visible in other contexts. Holmström (1982) suggests that these include when managers' success, real or apparent, is unconnected to how the business really fares; when a failure has limited effect on the company; when managers have secure tenure and are hard to remove; when they are connected nepotistically to "higher-ups"; when employees below managers may be blamed; and when it is unclear who is really responsible for successes.

The phrase itself also appears first to have been used in insurance, specifically Britain's early nineteenth-century insurance industry (Baker, 1996), during the study of probability in marine insurance. For insurers, moral hazard meant the combination of bad character and/or temptation that needed to be prevented in contracts (the moral element implied contracts that would discourage the bad-intentioned from applying, and not tempt the good to do wrong for financial gain). Moral hazard became a question for economics generally in the 1960s when economists analysed how the very existence of insurance may, through moral hazard, *increase* the occurrence and cost of the phenomena insured against (Baker, 1996). As we have seen, this began in Arrow's 1963 analysis: the "adverse selection" meant taking out insurance if you know you are "riskier" than others in your category, and "moral hazard" referring to those insured possibly taking less care. Pauly suggested that moral hazard applied to all forms of insurance, yet Arrow realised that moral hazard may exist in any principal-agent situation. Later scholars have developed greater analytical sophistication. In his most detailed moral hazard study, Stiglitz (1983) stated that virtually all economic relations "are affected by risk and by the problems of insurance and incentives to which this gives rise" (which for our purposes includes the risk of innovation failure when "insurance", in the form of future state employment, is given to those agents who are making R&D investment decisions).

This information problem gives rise to the principal's desire to monitor agents' behaviour. Following Smith, Babbage (1835) studied both such conflicts of interest, and how the monitoring of agents they necessitated might proceed. Babbage (*On the Economy of Machinery and Manufactures*, 1835) developed Smith's understanding of contract problems, suggesting that precise performance-measurement was needed for profit-sharing contracts, i.e. the monitoring of agents to make sure they did what principals wished. Babbage wondered that "It would [be] of great mutual advantage to the industrious workman, and to the master manufacturer in every trade, if the machines employed in it could register the quantity of work which they perform, in the same manner as a steam engine does the number of strokes it makes". Removing disagreement between parties by mechanically recording work, reducing disagreement between them, Babbage thought, would give "a greater stimulus to honest industry than can readily be imagined" (Babbage, 1835, 297)[2]. (Asymmetric information may not only affect a relationship between a principal and his agents but also "plague the relationship between agents" (Laffont and Martimort, 2002, 5), highlighting a multiple-agent, if not yet a multiple-principal context.)

However effective monitoring must deal with time horizons, in other words whether the principal only monitors behaviours effective in the short-term, or understands which agent behaviours are actually in their long-term interest. Aulakh and Gencturk (2000) suggest behavioural controls reward long-term outlooks, as they remove the pressure to jeopardise long-term success for short-term results. If the desired agent behaviour is monitored by the "mechanisms of social pressure", the ability to achieve long-term economic targets may be enhanced (Aulakh and Gencturk, 2000). Yet this requires principals to know in advance the best means towards an end, in other words what behaviour they

[2] By 1822, pursuing the recording of such information by a machine, Babbage had already begun developing the Difference Engine, arguably the first mechanical computer.

should be seeking. And in China, mechanisms of social pressure over state agents are likely to impose other social goals, such as maintaining employment, or the quantitative patenting we shall discuss, which may not be enhancing to firm economic outcomes. Ultimately, we shall examine a clash of time-horizons in our case: although innovation requires long-term investments with delayed payoffs, managers may be assessed such that they are more likely to make investments with faster – visible – payoffs.

2.3.3 Incentives

According to Miller (2005) for example, principal-agent models should have six features. *Agent impact* means agents take independent actions impacting principals' payoffs; *information asymmetry* has principals observing outcomes, but not agents' actions; *asymmetry in preferences* meanwhile sees agents and principals having different behaviour preferences for their respective wellbeing. But Miller adds *a unified principal having initiative*, i.e. principals acting rationally based on coherent preferences, and acting first by offering contracts; *backward induction based on common knowledge* means principal and agent share knowledge of effort costs, other parameters, and agent rationality. Finally *ultimatum bargaining* assumes the principal has all the bargaining power, so can make a "take-it-or-leave-it" offer to an agent. To Miller (2005) these assumptions lead to two "primary results". Principals use outcome-based incentives to partly overcome moral hazard problems, so despite having an informational disadvantage they transfer risk to the agent; but an e*fficiency tradeoff* sees agents demanding higher compensation for this risk, cutting principals' profits. So the best trade-offs see risk-averse agents paid an outcome-based bonus.

We note however that our case may have differences to this more conventional formula: although outcomes may be observed as suggested, this observation can only be in the short-term, and this can lead to the creation of incentives that create problems later on. Regarding backward induction, the relevant form of agent rationality may be hard to ascertain, rationality being focused towards different goals, which makes this assumption too strong to be realistic. Finally, the assumption of a unified principal requires a majority shareholder, otherwise "take-it-or-leave-it" offers are impossible. We now address the possible side-effects of these tactics in general in our discussion of incentives.

If an agent had some different objectives, but no private information, principals could propose contracts that perfectly control the agent, so incentive questions would not arise (Laffont and Martimort, 2002). But given both regularly different objectives, and private information, incentives are often necessary. Yet delegating tasks to an agent in the presence of some lack of information about them is problematic, which means *decentralised information* can create incentive conflict. Akerlof (1970), Spence (1974), and Rothschild and Stiglitz (1976) demonstrated how asymmetric information created a problem for incentives, given that the unknown aims of agents make providing appropriate incentives difficult (i.e. the problem of incentives with asymmetric information).

In other cases however, agents may have different aims to principals, and stand to gain less from the investments the firm needs, making them liable to "shirking". In such cases, profit-related bonuses can be used to reduce shirking problems.

Agents' rewards can be decided, at least to a degree, by whether they reach set standards, as Babbage (1835) demonstrated (and patent measures may be one of these). But another question is the degree to which these outcomes can – or should – be measured (we shall discuss how patent measures may be an example of a poor proxy for what may really interest a principal). Indeed, far from being simple to measure, many tasks take a great deal of time, require team effort, or produce "soft" outcomes that are difficult to measure effectively (Eisenhardt, 1989). Incentives can also worsen the problems that they are established to combat. A clear case of this is when the tight monitoring of behaviour produces short-termism, for example through the use of short-term weighted profit-related bonuses mentioned above. In innovation, we will see examples of how attempts to deal with shirking can cause other moral hazard problems. A more conventional instance is the use of stock options to incentivise managers (meaning a manager has the right to exercise the option, and own stock in the firm, if the share price rises above the call price in the future, giving them an incentive to help boost the firm's value). However unless stock options are both sufficiently long-term they are liable to create short-termism (Smithers, 2013). Despite being designed to deal with shirking and risk avoidance, stock options are liable to exacerbate the short-termism problem, by intensifying the drive to increase immediate profit. Dealing with short-termism, shirking, and risk avoidance can arguably be seen as the three central concerns of the incentives literature, and we shall return to them in discussing their impacts on innovation.

Although the intensive scholarly study of incentives is relatively recent (and Schumpeter (1954) did not mention incentives in his history of economic thought), today for many economists the discipline is largely a series of incentive questions, such as how to design institutions that "provide good incentives for economic agents" (Laffont and Martimort, 2002, 1). This is why the incentives field appears with Adam Smith's division of labour and exchange, and the need to delegate (the first contracts appearing as landlords contracted with tenants in agriculture). Babbage himself suggested two principles to remunerate labour such that agents would act in principals' interests. First, a considerable part of each person's wages should depend on the profits made by the firm; and second, that every person within it should derive more advantage applying any "improvement he might discover" than he could by any other course (Adam Smith, 1776, 177).

In the round, in principal-agent scenarios, incentive questions ask how it can be made in agents' interests to behave as the principal desires, in other words how a system of rewards can be structured so that an agent gains from doing so. But if an agent responds to incentives such as Babbage (1835) suggested, it does not necessarily follow that the principal's desired outcome – such as improved innovation – is met, simply that the agent is persuaded to act as the principal *believes* will help achieve that end.

We will see how with (sometimes innovative) tasks too complicated or costly to do oneself, principals hire particular agents (with specialised skills) to carry them out. The core question is how this principal can *best motivate the agent to perform as preferred*, despite difficulties in *keeping track of this agent's activities*. These are the fundamental incentive problems – the need to motivate and monitor – arising both in the simplest agency relationship and more complex organisations such as corporations (and we will structure our theoretical framework by asking how this incentive problem informs the outcome of each hypothesis). Therefore without considering incentives, the firm may still remain a "black box", without appreciation of how owners align the objectives of various members, "such as workers, supervisors, and managers" with profit maximisation (Laffont and Martimort, 2002, 2), in particular over the long-term. (Although we rarely describe stock markets as individuals, we frequently describe firms as if they were individuals with “motivations and intentions” (Jensen and Meckling, 1976). To understand outcomes, we need to consider the agents in these organisations.)

Thus incentives also represent a way of dealing with informational asymmetry, and the moral hazard that as we shall see is at the centre of concerns for innovation in China. If the asymmetric relationship is one where authority is on one side and information on the other (Weber, 1925), principal-agency studies mean this asymmetry exists in a relationship where agents have an *informational advantage* over principals, then analyses an area where the principal has *authority*, namely the ability to impose incentives on agents. So the incentives should give informationally disadvantaged principals leverage, inducing the (more informationally expert) agents towards actions the principal would have them take. By manipulating agents’ incentives, principals seek to minimise *agency costs*, or the losses imposed on them by any inability to align an agent’s self-interest with his own (Miller, 2005). These “losses” typically mean reductions in profit, but in our case, as we will see, will imply innovation failure.

Having discussed the problems of principal-agent theory as it stands, we will apply principal-agent theory first to high-tech innovation in firms, before then going on to discuss the application of these phenomena to Chinese high-tech innovation in particular. In particular, under principal-agent theory we will apply the concepts of information asymmetry and moral hazard, the use of incentives to affect the choices of agents, and the possible side-effects of these incentives, and the impact of cases where instead of a unified principal, mixed principals exist.

Arising with the context of the landowner-tenant relationship in an agricultural economy, principal-agent questions are becoming increasingly important as more complex organisations work on innovative tasks, requiring distant management of teams, and investment by large organisations or shareholder groups, who cannot constantly check on individual behavior. Thus successful innovative output depends a great deal on successfully structured principal-agent relations. In other words, while Sappington (1991, 45) suggests that the phrase “if you want something done right, do it yourself”, encapsulates the major concerns of incentive theory, how to get something done right if you cannot do it yourself is the real question at hand.

2.4 Principal-Agent Theory in High-Tech Innovating Firms

Before we consider the way in which an agent is tasked with carrying out innovation activities within a firm, we should pause to consider how firms generate knowledge, and the theoretical understanding of the rationale behind this.

2.4.1 The generation of capabilities by firms

Although many mainstream twentieth century economists saw companies as institutions that were straightforwardly defined by their obvious production capacities, it became clearer that these production functions did not explain the behaviour and direction of these firms, or indeed their limits.

A newer literature of dynamic capabilities began in the evolutionary and behavioural theories of Cyert and March (from 1963), and Nelson and Winter (1982).

In the *Behavioural Theory of the Firm*, Cyert and March's (1963) refined definition of firms saw companies as unique entities distinguished by hard to imitate "standard operating procedures", or heterogeneous characteristics, making the performance of any given firm broadly determined by its capacity to match operations to its environment, and to changes within its environment. Yet in their *Evolutionary Theory of Economic Change,* Nelson and Winter (1982) advanced a more dynamic approach to company strategy, asking how firms were capable of evolving in line with their environments. In describing their "standard operating procedures" as "routines", Nelson and Winter stated these routines governed a company's adaptation to its environment, as its "genetic material". Subsequently Teece *et al* (1994), among others, built on this dynamic scenario for firms' strategy.

However the still dominant neoclassical view implied that firms had both perfect information and certainty of environmental outcomes, and lacking problems of adaptation or of internal resource allocation were able to straightforwardly maximise profit. Firms' internal workings were therefore left neglected. Cyert and March's theory however took first, "the firm as its basic unit; second, the prediction of firm behaviour with respect to such decisions as price, output, and resource allocation as its objective; and third, an explicit emphasis on the actual process of organisational decision-making as its basic research commitment" (Cyert and March, 1963, 19). This depiction of the firm as an entity constituted by its own goals and standard operating procedures allowed a fundamental understanding of the firm's heterogeneity. It was this heterogeneity which created disparities in firms' performance over the long- and short-term. Some routines in turn change firms' operating procedures over time. According to Nelson and Winter however, "search routines" direct firms towards innovation, but innovation that will be compatible with their current knowledge or approach.

Drawing on Nelson and Winter, Teece's (1988) resource-based approach sees firms as collections of both tangible and intangible assets, competencies, or resources, which are hard for other firms to imitate, and are the foundation of firms' respective competitive capabilities. So should a competitor be able to uncover and copy a "competence-forming routine", the originator company may be able to use IPRs in order to protect itself. The capacity of firms to develop the appropriate resources however is in considerable part dependent on the ability of the firm to find, then assimilate, the necessary information from its environment (Amit and Schoemaker, 1993).

Firms must also find new pathways in both their own research and the research of others (Teece, Pisano, and Schuen, 1997), and as we will see, the relevant managers need to have an incentive to find and act on them. Much research has been undertaken on the impact of systems of management, and systems of management within particular national innovation systems. Their impact on firm innovation outcomes specifically, some of which can be placed in a principal-agent framework, we discuss in the following subsection.

2.4.2 The role of the principal-agent relationship in innovation in high-tech firms

We have asked about the core principal-agent dynamics of firms in general, of which we shall now remind ourselves; following this, we shall enquire about the peculiarities of principal-agent dynamics in innovating high-tech firms in particular.

Principal-agent relationships involve information asymmetry, as to goings-on within a firm, between agent and principal, which helps create moral hazard. Principals use incentives to push agents towards certain choices the principals prefer, but these incentives can have side-effects.

The peculiar categories of phenomena that apply to high-tech innovating firms are as follows. Agents need to have or learn some technological expertise to be effective managers of high-tech firms, but this expertise among agents is liable to create a particularly pronounced information asymmetry between them and principals. As a result, high levels of moral hazard are possible, because there are more ways in which an agent, potentially, could misspend without the knowledge – or understanding – of the relevant principals. Other special factors also create a high level of moral hazard, such as the complexity of innovative activity and the need for constant work within teams, the nature of which cannot always be communicated upwards. We will explore below tactics principals dealing with high-tech firms employ to deal with this risk. There are also particular peculiarities that arise for incentives and assessment of agents.

In technological innovation, manager success can be difficult to measure: the first area of this is simply measuring the technical achievement itself. Assessing technical outcomes not only requires skill on the part of principals, but establishing a level of what constitutes quality technical output can be arbitrary to some degree. Second, it may require knowledge of the market to compare one's agent's technical achievements relative to the market in which they compete. Third, short-term assessment of agents may both ignore their likelihood of more important long-term success, and the side-effects of measuring agents in the short-term may even harm their management over the long-term (a question we will analyse in the Chinese context). The implication of these challenges is that it is hard for principals to use incentives if it is hard to find appropriate assessments against which to measure agents.

2.4.3 Information asymmetry and moral hazard

As investment in R&D is a vital element of technology firm growth – and economic growth (Malecki, 1997; Guellec and van Pottelsberghe, 2004; Griliches, 2007) – it is vital to appreciate how firms' governance affects their R&D investment, with considerable new research analysing this impact (Munari *et al*, 2010; Driver and Coelho Guedes, 2012). The high information asymmetry of innovative firm cases, and the resulting moral hazard, means that principals are less likely to know how R&D investment is carried out.

In innovation cases, where an agent is charged by a principal with successfully carrying out innovation activities in a firm, strong informational asymmetry usually stands out because of the complexity of the activities required in any innovating unit, whereby a number of opaque technical processes imply a principal cannot know exactly how innovation investment is spent. Indeed, the situation may be worse. Principals cannot usually know that money has been spent on innovation at all, as even R&D staff may carry out tasks like fixing products or processes, which is not actually innovation. Shareholders may thus suspect management are wasting money that they say is being spent on R&D. The moral hazard lies in the principal being unable to know precisely what a manager will do with this investment. As we will see in the subsection below, this can result in wasteful expenditure. For an investor of any type, the two other problems caused by informational asymmetry, after moral hazard (that one cannot know what managers are doing with money), is the adverse selection problem. Management has different responses to this, including the monitoring of agents.

Nooteboom (2010, 1) finds that "trust is especially needed as well as especially problematic. One needs trust under uncertainty and in innovation uncertainty is high". More precisely, trust implies a lack of information, since it involves risking vulnerability to others' actions; in the presence of certainty about them there will not be risk. As such, uncertainty is particularly high in early exploration, where trust is thus "incalculable". At this point, being unable to know what may happen, one often cannot know what actions one would carry out oneself. By implication where trust ends control is needed. However if, lacking trust, one imposes contracts on agents, this will limit improvisational scope and the changes of direction that innovation may need (also, when it comes to innovation, regarding contracts or hierarchical control, Nooteboom finds monitoring "relatively difficult"). By implication trust can reduce moral hazard, and it may be found where principals and agents already know each other better, such as in a smaller local community, where moral hazard may be controlled by reputational concerns. To a conventional single principal-agent model we can add the consideration of relationships between principals and agents changing over time, so that understanding how their politics change gives a more reliable understanding (Waterman and Meier, 1998).

There is also the difficulty of assessing innovation outcomes however. For example, principals may sometimes be able to detect systematic shirking by agents eventually, by comparing average output with that predicted for the best effort level per period (Radner, 1980; Rubinstein and Yaari, 1983). However this approach assumes information on agents is constantly available, output is predictable, and sets out a straightforward contract in which agents are offered the best sharing rule in the final period if average performance from the first to the final period has been acceptable, or a penalty sharing rule if performance has been unacceptable (Lambert, 1983). However there are two other moral hazard problems related directly to innovation: managers' tendency to underspend on high-risk investments, and their tendency to underspend on longer-term investments, notably intangible ones like R&D. (Agency theory tends to regard shareholders as being "risk-neutral", in that they should be able to spread investments around various firms; managers however are seen as being "risk-averse", given that they have only a single job. In innovation, this means averse to the risk of spending money on long-term projects from which they may not gain.)

To deal with difficulty assessing outcomes, or the wisdom of investment in various types of innovation process, contract-design may require applying an "informativeness principle" (Holmström, 1979), stating that any performance measure that reveals information on agents' chosen levels of effort should be mentioned in pay contracts. Yet making incentives as tough as possible is not always in employers' interests. A problem in achieving innovative outputs, in western contexts at least, is that creating reward systems for managers will in the real world always imply rewards for various different targets, whereby innovation, if encouraged at all, must be balanced against other (often shorter-term) achievements and metrics. Financial performance-based remuneration for managers has been found to be negatively correlated with intensity of R&D (Hall, 1993). In these contexts, the mechanisms that are designed for financial markets' short-term demands appear to be harmful to longer-term R&D investment. In other words, capital markets systematically undervalue investment in R&D, thus denying managers sufficient investment incentive, pushing them to make more "noticeable" investment choices that may have little or nothing to do with innovation; we shall return to a fundamentally similar question in the radically different managerial context of China.

2.4.4 Measurement responses and incentives

The implication of the high-tech innovating firm context is that principals will want to give particular attention to either reducing the asymmetry of information, or creating incentives for management behaviours that – they intend – will compensate for the asymmetry. The first tactic means principals providing themselves with more information about the firm, with information on particular agent behaviours around R&D investment and activities that lead to successful innovation. The second, which may be complementary or done in the absence of this information, means that managers will be rewarded for the behaviours that managers believe lead to better innovation.

High-tech innovating firms have particularly high demands in terms of the level of technical understanding within them, which can create a severe "gradient" of information if principals are relatively lacking in technical understanding (agents are either selected for, or expected to apply, specialised knowledge or management skills, so "the principal can never hope to completely check the agent's performance" (Arrow, 1963a, 147)). If principals lack information and/or technical expertise, the alternative is that one needs to have the expertise required to pick the appropriate people *with* the expertise, i.e. those who can be effective agents. This is the method of one form of technology investor in particular, venture capitalists, as they structure management to possess the needed expertise. However, venture capital firms will also reduce information asymmetry by placing their own members in the management of their portfolio firms as a monitoring device, reducing the moral hazard that can occur through the wasteful spending of principals' resources.

If principals cannot reduce the information gap in this manner, they may make efforts to measure agents, such as creating measures of successful innovation (in China this can take the form of measuring patent output, but this risks creating various side effects as we will discuss). Some contexts have revealed the problems that poorly-conceived agent assessment creates, and why innovation is hard to assess. Prendergast (1999) found that the one-time practice at AT&T of compensating programmers per line of code created excessively long programmes, a "multitasking" problem whereby some tasks were neglected simply because others were rewarded (Holmström and Milgrom, 1990). (We shall see that China may face a similar problem: once patenting *per se* is rewarded, firms may patent uselessly.)

Drago and Garvey (1998) found that placing agents on individual performance-related pay structures led them to help colleagues less than previously, an effect that seems especially strong amidst "team production" (Alchian and Demsetz, 1972). With teams, output results from numerous actors, and performance-related pay raises the free-riding incentive, raising positive externalities of individual team members' work while lowering returns to individuals (Fama (1980, 301) suggested that "in the team or nexus of contracts view of the firm, each manager is concerned with the performance of managers [both] above and below him since his marginal product is likely to be a positive function of theirs"). And although Kandel and Lazear (1992) suggested that peer pressure can help deal with the problem, this relies on oversight by peers having low costs. While some have found that performance-related pay has positive effects when work involves repetition (for example the work of Groves *et al*, 1995), for tasks requiring creativity, its effects appear to be negative. For instance, there appears to be little correlation between CEOs' performance-related pay and their firms' success (Drago and Garvey, 1997).

Various examples for principal-agent theory assume that principals have knowledge of an agent: Sappington's (1991) example of principals making "take-it-or-leave-it" offers to agents is one, and the principal taking most of the resources is subject only to agents' rationality constraints; Holmström's (1979) "informativeness" solution requires contracts to cover "relative performance evaluation", measured against similar employees (or agents). Not only does the knowledge assumption sometimes fail (Fehr *et al*, 1997), but principals often do not expect agents to behave rationally, and many agents do not (state Miller and Whitford, 2002). Some studies have experimented with principals offering outcome-contingent bonuses to deal with the irrationality of agents, designed to transfer enough risk to these agents to make it in their interests to give high effort, although in many cases principals offer bonuses too small to eliminate moral hazard (Miller and Whitford, 2002).

Incentives are created through rewarding agents for meeting various forms of target. Because innovation projects' value will be uncertain at first, with more information arriving as they develop (Bergemann and Hege, 1998), in the venture capital example, entrepreneurs control fund allocation, so investors cannot see "investment effort". As entrepreneurs control the flow of information in the project, so an "optimal contract" should reward entrepreneurs only following successes, with the investor keeping a "hard" claim in case of failure. Introducing incentives is only sometimes possible however.

Incentives will typically include managers owning a significant number of shares in a firm for a minimum time, whereby they are paid partly in shares that they are not allowed to sell for a specified time. Managers may also have stock options. These incentives are optimal if the share price when the managers are allowed to sell accurately reflects the firm's value including the innovations in which they have invested. But it is improbable that the value of these innovations will yet have been fully realised, so this requires shareholders to monitor, and to understand, their remaining future value. If this does not happen (because of low "monitoring intensity", or monitoring quality) then the managers will be incentivised to neglect innovation as this point approaches, squeezing out profits in a more short-termist manner. This means intensive incentives require intensive monitoring (or high quality monitoring). (The "incentive-intensity principle" of Milgrom and Roberts (1992), sees incentives' optimal intensity resting on four elements: incremental profits made by additional effort, accuracy of assessment of desired activities, the risk tolerance of agents, and how they respond to incentives.)

We shall return to how our particular principals try to guide agents towards various types of activity; in innovative activities however, even if information on within-firm agent behaviour is available, profits for additional effort are always uncertain. This can mean that if agents are to be guided more effectively than they would be able to direct themselves, considerable sectorial or technical expertise may well be required.

Should shareholders desire improved R&D investment (by volume or efficacy), they will need corporate governance mechanisms which incentivise managers to maximise the investment's value (Agrawal and Knoeber, 1996). Some managers may otherwise opt for efficiency-seeking, shorter term behaviour, instead of – or even at the cost of – longer term firm success. Venture capitalists also use incentive measures, which include making sure their agents have "skin in the game" (or stand to benefit personally from later firm success), creating high incentive-intensity (a subject we will address in the Chinese context). When the external markets around corporates are highly developed, these selected outside directors should also be disciplined by the market, which can price them according to their performance. Fama (1980, 288) suggests: "the market for outside takeovers [provides] discipline of last resort", and agents are incentivised by the quality of future employment should they manage innovation well (however, as we will discuss, the Chinese context may not follow this pattern, with other state employment opportunities for many agents regardless or even because of poor investments in innovation).

In summary, the strong informational asymmetry present in innovation contexts is compounded by agents knowing that their investment of funds into innovative activity has very uncertain payoffs, which creates plenty of leeway for the misuse of funds. To compensate, there is dependence among principals on strong technical monitoring capability, or if picking outside managers, using the pre-existence of good labour market incentives to control agents' managerial behaviour, by placing the innovative success of a firm in their interests. We have alluded to the differences in the Chinese context, and the manner in which the institutional structure, and its control system and incentives, may affect the principal-agent relations required for successfully innovating firms. So that we can examine this more explicitly, the next Section (3) will analyse China's innovation system, before we apply the theory we have discussed to this innovation system specifically in Section 4.

3. Discussion of the Chinese innovation system

Before we can create a picture of its interactions with the management of firms, we should outline the origins and development of China's innovation system. Although a system of government, institutions, and laws is not innovation itself, it does largely determine how this innovation takes place, particularly where the state is as powerful as in China.

To better understand how this occurs, we will detail the Chinese innovation system by describing the relevant apparatus of state; the impact of the state's innovation plans (especially the "Medium- to Long-term Plan" since 2006); the state R&D funding system; the State Intellectual Property Office (SIPO) and IP law; the assessment of state cadres as enterprise managers; and government procurement and technical standard-setting. We will then summarise these institutions, before in the following section we bring together this analysis with the principal-agent relationships described in the theoretical literature review, and create a theoretical template for the hypotheses.

3.1 Structures and systems of state control

Although some of our firms will benefit from connections to institutes and universities, the innovators with which we are concerned are Chinese companies, some of which are owned by the state, some of which are private, while others have various hybrid forms. As such, we outline the patterns of state control in the economy, and its impact upon the environment in which innovation occurs.

3.1.1 Proportions and trends of ownership

In starting with the broad proportions of ownership (and trends therein), we note that the state, in both its central and local forms, still directly owns a large proportion of the economy. Although the period since Deng Xiaoping began economic reform around 1979 has been marked by encroachment by private and semi-private companies into an economy that was almost entirely state-owned, authors describe the decade to 2012 in particular as "the state advances, the private retreats", or *guojin mintui* (McGregor, J., 2012a), and report that SOE dominance over private firms has become particularly entrenched in sectors the state regards as strategic.

In 1997, President Jiang Zemin and Premier Zhu Rongji launched the "Grasp the big, let go of the small" (*zhuanda fangxiao*) policy, by which the state let go of 117,000 SOEs, allowing them to sink or swim. This was the peak of the sacking of almost 50 million workers (40% of the SOE workforce) over ten years. The central-state owned urban SOE workforce fell from its 76 million peak to 28 million by 2003, intended by Beijing to allow the "party leadership dream" of turning the large SOEs into internationally competitive "national champions" (McGregor, J., 2012b), technologically able to compete with leading foreign firms (after Hu Jintao and Wen Jiabao came to power in 2003, the number of centrally state-owned SOEs fell from 196 to 153 by 2006).

However, while many foreign scholars saw this 1997 announcement of "ownership diversification of the state sector" as being "a green light to massive privatization", in fact it cemented the dominance of state ownership in Chinese industry. Specifically, decisions of the 4th Plenum of the 15th Party Congress (1997), then the State Development Planning Commission in January 2000 (merged with the State Planning Commission in 2003 to create the National Development and Reform Commission (NDRC), sitting below the Politburo) confirmed that while state ownership would be cut in some sectors, it would stay dominant in "industries of strategic importance" (Atkinson, 2012). Few practical measures for divestiture have since been formulated: the 16th Congress of 2002 called for a new system of managing state assets, "unifying the duty of managing assets, personnel and affairs", but since 2003 the system has reaffirmed the state's controlling role.

State shares in firms are held by central and local governments, which "are represented by local financial bureaus, state asset management companies, or investment companies" (Qu, 2003). In the case of subsidiaries, state shares can also be held by the "parent of the listed company, typically an SOE. They are not tradable". Another form of share, "legal person shares", may be owned by "domestic institutions" including industrial enterprises, securities firms, investment trusts or companies, foundations, funds, construction firms, real estate companies, transport and power companies: these may be SOEs, state-owned non-profits, collectively or privately owned firms, or joint stock companies. However, the important point is that although many SOEs have become PLCs, "*ultimate state ownership* is retained, so they also retain the same flaws of old SOEs" [my italics] (Qu, 2003, 775). This means that even when state-owned enterprises are listed, "controlling authorities", in other words "central government, ministries and local government" have *de facto* ownership rights "over PLCs [and] in reality do not bear any residual risks over control and use" of SOE assets (hence in our study of the effects of shareholding on innovation, we will trace the *ultimate* share owners, classifying shares accordingly).

Within one month of Hu and Wen taking office in 2003, the State-Owned Assets Supervision and Administration Commission (SASAC) was created, bringing central SOEs *apparently* under direct control by a body reporting to the Politburo. SASAC was then ordered to "enhance the state-owned economy's controlling power", concentrating state capital in major industries and fields relating to both national security and "national economic lifelines", speeding the formation of a group of enterprises "with independent [IP] and strong international competitiveness" (McGregor, J., 2012b, 25).

As well as classification by *percentage* of state ownership, state-owned firms can be classified as being at different governmental levels. SASAC's website (August 2012) states that there are now 117 central SOEs, down 14% from 136 in 2009 (SASAC, 2009b); meanwhile, by end 2008, the total number of SOEs in China was 110,000 (SASAC, 2009), indicating that the huge majority of SOEs are owned by some level of sub-central government (Mattlin (2010) however shows that central SOEs account for around 70% of all SOE profits, or 20% of government revenue).

3.1.2 The state's management of its firms

Aware of the faltering performance of many of its SOEs, and amid growing global competition in innovative products, Beijing is placing growing emphasis on the subject of corporate governance (Li, 2003). The diagram below outlines the broad state management of SOEs. Although SASAC is in theory "the world's largest shareholder", according to analysts it functions as "little more than the SOE secretariat". This is because the Communist Party manages all "significant policy decisions" through the *Central Organisation Department* (McGregor, J., 2012b), taking charge of appointing hundreds of SOE bosses, regularly switching them "back and forth between government and party posts" (McGregor, J., 2012b)[3]: we will see how this may deny them a long-term interest in investing in innovation at the SOE to which they are currently posted.

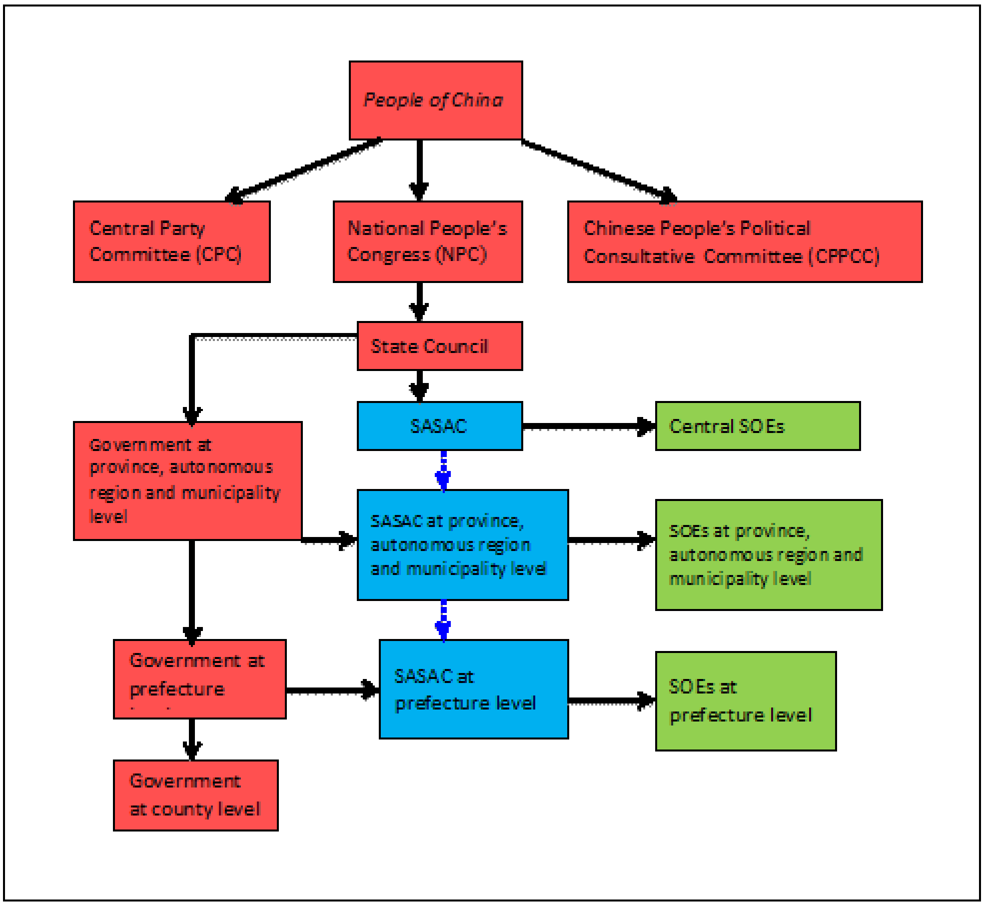

Figure 1: Structure of the State-Owned Assets Supervision and Administration Commissions (SASACs), Government, and state-owned enterprises (SOEs) (sources: SASAC, 2005; State Council, 2003)

SASAC states it is "neither a governmental administrative organ to provide public administration of enterprises… nor an ordinary enterprise or institution, [but] is a special organ of ministerial level directly under the State Council" (SASAC, 2005, 6). Yet despite its high level, official documents demonstrate the limits of SASAC. The *Measures for the Supervision and Administration of State-Owned Assets of Enterprises* (SASAC, 2003) states that central SASAC has a "guiding and supervising"

[3] An equivalent US entity "would oversee the appointment of the entire US Cabinet, state governors and their deputies, the mayors of the major cities, the heads of all federal regulatory agencies, the chief executives of GE, ExxonMobil, Wal-Mart, and about fifty of the remaining largest US companies, the justices of the Supreme Court, the editors of the *New York Times* and the *Washington Post*, the bosses of the TV networks and cable stations, the presidents of Yale, Harvard, and other big universities, and the heads of think tanks like the Brookings Institution and the Heritage Foundation" (McGregor, R., 2011, 54).

relationship for *local* SASACs. Central SASAC only exercises direct ownership over the 117 central SOEs, delineating central SASAC's limits. The *Measures* also make clear that SOEs that are not on the central SASAC list are outside central SASAC control, primarily answerable for their investments and management to local governments (the *Measures* also clarify that provincial and city governments can act as investors).

Meanwhile, of the 53 most important of the 117 central SOEs under SASAC, the Central Organisation Department directly appoints their three highest executives, usually the Party Secretary, Chairman, and CEO. While their deputies are officially appointed by SASAC, its personnel division is not permitted to carry this out, and they are chosen instead by a branch of the Organisation Department within SASAC (also known as the "Party Building Bureau"). Equivalent positions in smaller central SOEs are decided by SASAC's "Second Bureau", first consulting "supervising ministries" and "Party organs" (McGregor, J., 2012a), and must be approved by the State Council (however, at sub-central level, local Organisation Departments are answerable to local government to varying degrees).

Various scholars have therefore asked how much SASAC actually controls central SOEs. One SASAC Vice-Director stated that personnel appointments (and sackings), and payment systems of various central SOEs, are controlled by the State Council and the Organisation Department (Chen, 2013). SASAC's SOE management therefore appears not to be administrative, but involves performing as investor (while higher powers control appointments of managers). As we will describe, this means the oversight of central SOEs is split between various "principals", diluting oversight in a long control chain. Although Wang *et al* (2012) suggest effective investors should have financial return rights, decision rights, and rights to choose managers, the *Interim Measures* demonstrate that SASAC lacks the right to appoint, and ultimately control, managers. Although it is clearly stated that "SASAC appoints and removes the top executives of the supervised enterprises, and evaluates their performances through legal procedures [and] grants rewards or inflicts punishments based on their performances" (State Council, 2003, 4), Wang *et al* (2012) state that the reality also differs at sub-central levels. For instance, some local governments' Organisation Departments do not wish to transfer to SASAC the power to appoint, remove, or assess top SOE executives (the ramifications of which we shall explore). SASAC lacks other powers that should be enjoyed by investors, including unclear investment return rights for SASAC, and unclear rules on supervising income distribution in firms, plus unclear shareholder rights (Wang *et al*, 2012). This introduces the dispersal of both control and responsibility through the state ownership system, and we shall go on to ask the relevance of the dispersed control of these state firms to the execution and outcomes of R&D.

While SASAC also manages "supervisory panels" for firms on the State Council's behalf (SASAC, 2009), these are mainly charged with supervising SOEs' finance, internal supervision, and risk control, but the official investor is given little scope to encourage R&D in firms' day-to-day management (we will describe below how the organs in charge of appointments assess managers' activities). An anonymous official in a provincial SASAC stated that SASAC's investment rules are nominal, and it acts mainly as supervisor, overseeing the operation of state assets, while the upper echelons of state keep political control over its firms, especially in centrally-owned enterprises. Meanwhile, the more profit SOEs generate, the easier it is to channel money into "private coffers", to be spent at the whim of senior employees (Gong, 2013).

With limited, unclear shareholder rights, SASAC lacks leverage over SOE managers; the Organisation Department appointment procedures, especially in central SOEs, imply that even if a manager succeeds in making an SOE innovative, considerations such as "loyalty assessments", as we will discuss, can take precedence, disincentivising such efforts.

3.1.3 Cadre assessment

The methods by which agents are monitored and assessed should thus first be understood, in order to understand innovative behavior in this system, and likely outcomes for our sector. Firstly, China's lawmakers appear to have an "ambivalent" position towards the depoliticisation of firm management: Article 14 of China's Company Law still calls for the supervision of enterprises by "government and masses", while the presence of firms' "three old political committees" (party and labour committees and trade union) continues, meaning the old political organs have not been abolished (Nee and Opper, 2007), and although the "old three" have lost a large amount of their control rights, they maintain some political influence. By implication, their persistence helps the continued political monitoring in the government's assessment of cadres in firms.

Mechanisms of governance among SOEs may have various handicaps specific to technological capability. Most have an arms-length relationship with their supervising officials, but managers maintain *guanxi* with bureaucrats, often for easier access to finance or intelligence on new policy. Few expect officials to go out of their way to monitor firms or oversee their R&D, and most lack the expertise to do this anyway (Da, 2010), while their supervision responsibilities, as we have seen, are split between SASAC and other organs. As state managers' most important relationships are with more senior officials, the attention they can give their firm's innovation (or a competitor's) is limited (Da, 2010). Although Beijing's drive to enhance technological competitiveness has pressured officials to develop the technological capabilities of firms they oversee (indeed SOE managers are sometimes tasked with tech-transfer ahead of profit-making (Haley and Haley, 2013)), lacking engagement or expertise they are often satisfied with technology and rankings that give high and rapid visibility; patenting may have become used to these ends.

Meanwhile, political connections between firms and government appear especially strong when a firm's chief executive is a current or former bureaucrat in either central or local governments (which can also help secure R&D funding). In a survey of 19 listed firms in highways and transportation, 17 had chief executives who were former directors of the transport bureau in their local government (*First Financial Daily*, 2011, in Li and Qian, 2013). These CEOs with ongoing political employment are also incentivised to improve their political record generally for promotion (*zhengji*) (Li and Qian, 2013).

The regulations forming the updated CRS were passed in 1993: principal criteria for cadre evaluation are formulated in general terms, applying across departments, levels and regions. These are political integrity (*de*), competence (*neng*), diligence (*qin*) and achievements (*ji*), with emphasis on "actual work achievements". One handbook states that "work achievements should account for 60 to 70%, and political integrity, competence and diligence should together account for 30 to 40% of the evaluation" (Edin, 2003, 37). Yet the work achievements on which managers are assessed are also blended with rewards such as those for "operational growth" (in the short-term) and "contribution to society" diluting incentives for managers to prioritise innovation. Cadres are graded as excellent (*youxiu*), competent (*chenzhi*) or incompetent (*bu chenzhi*). Edin adds that capacity to control does not necessarily "translate into implementation of all their policies".

Managers' achievements in firms are graded on achievements that may not only distract from, but conflict with innovation. Higher levels of the party-state try to improve monitoring *and* strengthen political control by promoting successful cadres (such as township leaders) to hold concurrent positions at higher levels, "rotating them between different administrative levels and geographical areas" (Edin, 2003, 35). However, the definition of "success" of the units under them that leads to manager-cadres being promoted is complex, with development and innovation forming only 15% of the "Managerial Performance" component of assessment, itself only 30% of the whole. Although local SASACs can make adjustments, this is outlined for *central* SOEs below.

Financial Performance (70%)						Managerial Performance (30%)	
Content and Weight (%)		Basic indices	Weight (%)	Reference indices	Weight (%)	Assessment Item	Weight (%)
Profitability	34	Net asset earnings ratio	20	Sales profit rate	10	Strategic management	18
				the surplus cash cover ratio	9		
		Return on asset	14	Profit/cost of capital (EVA)	8	Development and innovation	15
				Rate of earnings on equity	7		
Asset quality	22	Total asset turnover	10	NPL ratio	9	Operational decisions	16
				Current asset turnover	7		
		Acct. receivable turnover	12	Cash/asset ratio	6	Risk management	13
Debt risk	22	Asset/liability ratio	12	Quick ratio	6	Basic management	14
				Cash ratio	6	Human resource management	8
		Paid interest/debt	10	Ratio of liabilities to interest	5		
				Contingent liability ratio	5		
Operational growth	22	Sales growth rate	12	Sales profit growth	10	Influence in the industry	8
				Growth rate of total asset	7		
		Ratio of value maintenance and appreciation of capital	10	Technological input ratio	5	Contribution to society	8

Table 1: Performance assessment criteria in SASAC central SOEs (source: SASAC, 2010)

Furthermore, according to measures for assessing "persons in charge of central enterprises" (CEOs and COOs) (Li, S. 2007) if in three years a firm does not reach SASAC's target (for these cadres 70% of the target consists of financial indicators and under 5% is based on innovation performance), the CEO or COO is at risk of actually losing his or her job.

Also, according to Li (2007), stock options are extremely unlikely in the cases of central SOEs and fully state-owned firms of all government levels; a core difference for MISOEs however is that these options are very possible for their senior managers. Meanwhile, many senior managers running MISOEs run them for a considerable time. ZTE Corporation for example was founded in 1985, listed on the Shenzhen Stock Exchange in 1997, then Hong Kong in 2004.

Having begun as a wholly state-owned enterprise, with the state share dropping below 50% in 2003, ZTE has long seen a major stake in managers' hands. Four managers led by founding CEO Hou Weigui established a company named Zhongxing-Weixian Telecommunication Equipment Co Ltd (ZXWXT) in 1992, and this took over ZTE's management through a contract stating "that ZXWXT take charge of the business with their assets as mortgage. If they achieve all the goals, they could earn more; otherwise, they would pay for the losses" (internal memorandum, in Li S., 2007).

As "state capacity" (in this case the ability to monitor and control agents at lower political levels) has increased, any failure in innovation outcomes is due more to the centre's conflicting priorities than "inadequate control over local leaders" (Edin, 2003, 36). The contemporary cadre responsibility system (CRS) is not simply a means to improve government efficiency, but a monitoring and incentive method of higher-level political control over agents. By implication, when placed under these political pressures managers may follow aims which conflict with innovation outcomes.

The state may thus be hindering its own innovation aims, by directing innovation resources to SOEs and by providing their managers with contradictory management goals in promoting innovation[4]. Meanwhile private firms have a stronger budgetary need for competitive products as they lack soft-budgets, but appear, as we will discuss, to receive less legal protection by the state regarding their IP.

3.1.4 State listing and management of firms

Since the beginning of reform, Beijing has listed a large number of SOEs, which post-IPO have generally remained in state hands via state-owned funds[5]. We will address the differences between listed and non-listed firms in terms of their innovation outcomes in more depth in the later quantitative analysis; at this stage we should discuss how the mechanisms of state ownership continue to permeate management – and the selection of cadre-managers – in these *listed* state firms, as the achievement of innovation is one area in which the nature of state ownership may prevent listing functioning as expected. As the state relies on these firms to maintain employment and industrial output, their

[4] In considerable part due to this state dominance, unlike elsewhere in Asia, the shareholdings of listed firms in China are characterised by the relative absence of families as major shareholders or managers (Li and Qian, 2013).

[5] Even as 2005 reforms saw state shares become traded on the secondary market, this did not fundamentally change state funds' positions as the firms' largest shareholders.

corporate governance model remains essentially the same as the model of control used for the unlisted SOEs (Li, 2003).

One hindrance is therefore not simply in the cadre assessment discussed above, but in cadre selection itself. Top managers' appointments in these firms are still decided by the different levels of SASACs and party committees. The majority of candidates for the top management roles have also worked previously in connected agencies of the government (Li, 2004), with many having been officials in government departments that have been closed; this means not only a lack of relevant experience, but that they are likely to have other roles available to them regardless of their firms' performance, which many need simply to not fall severely (Li, 2003), at least on their watch.

Taking the board of directors as the highest management level in a given firm, Chinese Company Law of 2006 states that boards take the executive role. Meanwhile the state (Li, 2003) has maintained its control of boards of directors via the appointment procedures described. In general, in listed majority state firms at any level, the chairman, vice chairman, and CEO are appointed by the firm's Party committee. After this, SASACs mandate that the state funds that represent their ownership (often the largest shareholders) will organise firms' shareholder meetings, and draft the shortlist of candidates for these board positions (Li, 2003). (On these boards, it is also commonly required that a firm's chairman must be Party vice-secretary, and the vice chairman be Party secretary, or vice-versa.) Meanwhile, the appointment of independent directors in those listed firms with major state ownership also appears to be under state influence. The *Guidelines on the Establishment of the Institution of Independent Directors in Listed Companies* (China Securities Regulatory Commission (CSRC), 2001) state that independent directors must be elected through listed firms' shareholder meetings, meaning any level of state which is the largest shareholder (even if indirectly through a state-owned fund) effectively decides on independent directors' appointment.

Aside from the board itself, *supervisory committees*' main function is to monitor the top managers' behaviour in line with shareholders' interests.[6] Supervisory committee members are usually hired, first, from the state-owned funds that are state-owned listed firms' biggest shareholders, and recruited through meetings of shareholders. Their backgrounds tend to be similar to the board members, as described, and they will have good relationships with government (we will discuss in our hypotheses why it may be preferable for them to have working relationships with local rather than central government). They also frequently recruit secretaries of the Party committees and "worker representatives" in these firms (Liaoning Securities Bureau, 2012). Thus the committees further the government monitoring of these listed firms' managers methods at all levels (Li, 2003), furthering a model of corporate control over managers, one of whose central goals is the implementation of government policies, the results of which we shall seek to establish.

3.1.5 Government procurement and standard setting

The Chinese government has created demand-side innovation policies to help give indigenous innovators a favourable environment, including procurement preference for domestic innovative products, and technical standard-setting. We will outline the intentions and possible effects of these

[6] Stated in Chinese Company Law, Article 54, 2006.

policies; in the round, the national IPR strategy that they complete aims to "increase patents", using "IPR tactics".

In 1992, Beijing published the *Government Procurement Law*, mandating (with exceptions) that government procurement purchases should be limited to domestic products[7], with support for enterprises used to support those which purchase domestic high technologies (Dewey and LeBoeuff, 2012). In public procurement, the World Trade Organisation's *Government Procurement Agreement* (GPA) does not apply to all government procurement, and GPA coverage to each member state is based on negotiation (WTO members are not yet required to join the GPA, and China is currently negotiating GPA accession, meaning it can include preferences for domestic goods and companies in state procurement practices (US-China Business Council, 2009)).

The Government Procurement Law was updated in 2003, while the *Bidding Law* (2000) states that various construction projects should allow bidding to take place (including for surveying, design, construction, supervision, and procurement of the important equipment and materials). The projects involved are large-scale infrastructure and utilities concerning social and public interests and public safety; those entirely or partly employing state funds; and those using funding or loans from foreign governments or international organisations (thus the Bidding Law affects construction in general and potentially solar PV projects in particular). This extends domestic demand-side preference as an aid to procurement; crucially, it may also mean that within state procurement, projects will see "preference given [to] large companies" (Da, 2010, 41).

Procurement policy was reinforced from January 2005, as the Ministry of Industry and Information Technology (MIIT) issued the *Opinion on Accelerating the Large Company Strategy in the Electronics and Information Industry,* stating that support should be provided "to the leading large companies". Although it is common for governments to set minimum requirements in procurement, China is unusual in stating "large companies" will be given priority (Prud'homme, 2012), which leaves the door open for SOE preference. In 2009 the *Circular on Carrying out the Work on Accreditation of National Indigenous Innovation Products*, (a.k.a. *Circular 618,* by MOST, the NDRC, and the MOF) created a national-level "catalogue" of preferred procurement products in the six high-tech areas of computing and application equipment, communications, modern office equipment, software, new energy, and high-efficiency and energy-saving products (broadly matching the MLP's own list). An upgraded catalogue (from MOST, MOF, MIIT and SASAC) following the Circular listed 240 forms of industrial equipment in 18 areas that Chinese firms are encouraged to manufacture, to upgrade China's manufacturing base (Atkinson, 2012), including solar PV. Participating firms were offered subsidies and tax incentives, alongside priority in procurement. The result of this policy framework appears to have been that a larger market was created for the firms which were already well placed to benefit the most from their connection to the state as manifested in antecedent R&D funding.

The MIIT Planning Release *Restructuring and Revitalisation of Planning for the Equipment Manufacturing Industry* (2009) encouraged using domestic manufacturing equipment, and the structuring of insurance to favour their products. This was followed in November 2009 by the *Indigenous Innovation Product Accreditation Policy*, whereby state-procured products had to contain

[7] Government procurement refers to all purchasing through fiscal funds by organs of state (*guojia ji guan*) at all levels and institutions (*shi ye danwei*), plus social organisations (*tuan ti zuzhi*). Goods, construction, and services are listed in the central procurement catalogue.

Chinese IP. Beijing's municipal procurement catalogue contained 42 products and just one from a foreign-invested manufacturer; Shanghai's had 258, with two from foreign-invested firms; Nanjing's list had none (Atkinson, 2012).

These initiatives have been pursued in different ways by different levels of state. Beijing municipality appears to have taken a particular lead in procurement, with its high-tech Zhongguancun district becoming the proving-ground for indigenous innovation procurement (even before the *Suggestion on the Pilot Testing of Government Procurement of Indigenous Innovation Products at Zhongguancun Science and Technology Park by Beijing Municipal Government* (2008) was published) (Xie, 2011). Beijing's municipal government spent RMB3.3bn to that point on procurement featuring indigenous innovation by Zhongguancun firms (Xie, 2011). Procurement has built a platform to take Chinese firms from early innovation to market entry, and demonstrates a more direct approach among local government, and province-level cities in particular (the four major municipalities of Beijing, Shanghai, Tianjin and Chongqing) in supporting their high tech firms. This is relevant because this combination of creating a demand-side environment, as well as funding innovation, but apparently with the closer monitoring of their managers' firms' product development than among centrally-owned firms, may have made these local firms more inventive than central firms (to which we shall return in the hypotheses).

Indigenous innovation was officially disconnected from government procurement in 2011, but the "essence of the indigenous IP system, in setting out controversial IPR requirements linked with financial incentives" (Prud'homme, 2012, 8) appears still to be active. These requirements are covered by remaining policies for "indigenous IPRs"[8] (IP owned by a domestic organisation, defined as one without majority foreign ownership), and still include having indigenous IP as a prerequisite for receiving subsidies from multi-billion dollar foreign trade funds, plus renewed 2011 sub-central rules subsidising firms meeting indigenous IP requirements through sci-tech funds.

Meanwhile, procurement rules appeared to have been scrapped after foreign pressure, but documentation and interview data suggests the picture is complex, not only for foreign but also domestic private firms. "The indigenous IP issue fizzled out rather a lot in 2011, but people didn't realise that although de-linking was taking place, the concept had already been around the state system for some time. So it had become rather entrenched in many people's minds" (anonymous interviewee, October, 2012). Although a State Council directive in November 2011 ordered all provinces to scrap their procurement catalogues, other commentators suggest their intent "likely remains latent" (Atkinson, 2012). Since the 2011 directive, reports have appeared that some coastal provinces are still giving procurement preference to local manufactures, while demanding other firms source raw materials and/or equipment locally[9]. Instead of putting these "encouragements" in writing, reports state they are made through personal state contacts (Global Trade Alert, 2012; anonymous interview data, 2012).

Indeed, the value of central state procurement does not appear to have been high in real terms: RMB 20.5bn in 2012 (Government Procurement Information, 2012), which is low compared to both

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[8] Zizhǔ zhīshi chǎnquan (自主知识产权)

[9] Unlike the USSR, in which the centre sent economic plans directly to enterprises, China's system even pre-reform allowed localities some decentralised administrative power.

provincial and much city procurement (in 2012 Nanjing procured RMB 30.922bn, similar to Wuxi, Suzhou, and Wenzhou). However, the rescission did not apply to purchases made by SOEs, *or* to the "major projects" covered by the MLP (Atkinson, 2012), preserving benefits for the solar firms dubbed "indigenous innovators" (Atkinson, 2012).

Technical standard setting is another recent development. Regulators often employ SOEs, with considerable resources at their disposal, to draft national technical standards (interview data, 2012), creating clear conflicts of interest; however this is not yet believed to have happened in solar PV, where the industry remains considerably export-focused. In the round, although scope for large, central SOE preference appeared through the "large companies" measures above, this remained limited because of local state dominance in procurement. Despite official measures for discriminatory domestic procurement no longer being in place, having some connection to the state, especially at local levels, still appears to help firms secure domestic supply contracts (especially given exceptions to the rescission of procurement rules, implying firms will still benefit from having particular state connections).

3.2 Impact of Reform and the Medium- to Long-Term Plan

The reform of China's NIS began shortly after the dawn of economic reforms in agriculture during the late 1970s (Xue, 1997), although the early reforms were on a trial-and-error, local basis. Centre-led, systematic reform began with the Central Committee document, *Structural Reform of the Science and Technology System*, in 1985 (CCCPC, 1985). This document and its principles formed the core of reforms to the national innovation system in the decade that followed, to around 1997; the reforms centred on the proposal that "economic development must rely on science and technology, while S&T research must render services to economic construction" (CCCPC, 1985, in Xue, 1997, 73).

Before these reforms, public research institutions (PRIs) conducted most basic and applied research: among them, the Chinese Academy of Sciences (CAS) and its local branches carried out most basic and some applied research, with the PRIs under various ministries in charge of applied research and development, in their own areas (Xue, 1997). The main role of universities was to train scientists, although they also carried out some research. SOEs' own R&D departments carried out "downstream" work. The majority of reforms in this period were to the PRIs, which were encouraged by government to broaden their funding sources, in preparation for a reduction in their funding by the government (at least directly). PRIs were also increasingly expected to compete with each other for grants.

The concept that arose in the 1980s around this development effort was the "three-tier" science and technology development strategy (Xue, 1997). The first tier, or "main battlefield" saw the investment of around two thirds of China's sci-tech resources through the decade, and involved the establishment of a number of nationwide programmes from the late 1980s, in particular the *Key Technology R&D Programme*; the *Spark Programme*; and the *National S&T Achievement Spreading Programme*.

The second tier aimed to develop high tech capacity in China in conscious competition with product developments being monitored on the global market. This involved two other programmes, the *High-Tech Research and Development Programme* (or "863 Programme"), and *Torch Programme*. The third tier involves the most advanced research areas, which began in the 1992 creation of the *National Basic Research Priorities Programme* (a.k.a. the "Climbing Programme").

Cohen and Levinthal (1990) found that in-house R&D improves firms' *absorptive capacity* via learning; however in catching-up economies, in-house R&D needs to be accompanied by spending on technology assimilation for this absorptive capacity to be really effective. This has been shown by the experience of Korea and Japan. While in-house R&D expenditures among medium- to large-sized Chinese firms rose considerably through the 1990s, spending on technology assimilation fell behind, with its ratio to in-house R&D decreasing after 1995. Crucially, this was not the case for Korea and Japan in the early stages of their technological catch-up (Cohen and Levinthal, 1990).

Compounding this, the percentage of medium and large firms carrying out "sci-tech activities" also fell, from 56.9% to 30.7%, from 1995 to 2003, their "R&D intensities" (R&D/sales ratio) stayed below 0.8% until 2005, retarding the development of "endogenous technology capabilities" (Lan and Zheng, 2010). The implication is that China's much-vaunted trajectory of economic growth through the 1990s belied a worrying lack of comparable technological catch-up. The continuing lack of indigenous technological development formed part of the rationale for the tranche of policies that followed.

A historic distinction had existed between "generators of science" (broadly institutions) and "generators of technology" (generally firms), two groups that created distinct types of output, with universities producing scientific papers, firms producing technology in the form of new products and processes, frequently protected through patents (Fai, 2005). Yet research (e.g. Pavitt, 1991) demonstrated not only how "science" often drove "technology", but that new technologies could spur novel scientific research areas, with feedback loops occurring. In May 1995, the Chinese Communist Party Central Committee (CCPCC) and the State Council thus issued the *Decision on Accelerating Scientific and Technological Progress*, to "revitalise the nation through science, technology and education" (*kejiao xingguo*). The government ensured an increase in investment on basic and high-technology research, while such activities as applied R&D were pushed into the market more aggressively (Lan and Zheng, 2010, 89). To use scientific and technological education as a tool for economic development, this took the form of a three-pronged approach: first, to drive growth in scientific and technological capabilities "primarily on (their) own indigenous efforts", second, train a qualified "scientific and technological contingent" to achieve scientific and technological capacity in some disciplines at, or near, advanced global levels; and third, foster cooperation and exchange through international cooperative research, joint laboratories, and sending Chinese to work overseas in academe and high-tech enterprise (Fai, 2005, 58). This initiative would drive the R&D funding programmes that followed[10].

In 1997, CAS published a research report entitled *Welcoming the Era of a Knowledge-Based Economy with the Construction of a National Innovation System* (Sun and Liu, 2010). This was followed in 1999,

[10] In contrast to the previous decade, the driving idea of this initiative was to allow the "transformation and commercialisation of sci-tech achievements". The *Science and Technology Findings Conversion Law* passed in 1998 was in some ways similar to the American Bayh-Dole Act; researchers could use sci-tech findings as an investment of up to 35% of start-up capital, and if their findings were transferred to other organisations, at least 20% of net income from the technology transfer had to go to these "performers"; academics were also allowed to have part-time jobs in companies (Lan and Zheng, 2010).

as President Jiang Zemin officially stated that China's goal was the establishment of its own scientific and technological innovation system (Sun and Liu, 2010), a point some authors consider to herald the beginning of a true NIS in China. Promotion of science and technology has thus grown as a central state cause, especially since 2003, and we will discuss the resulting adjustment of the state apparatus, and the interplay of state/private dynamics; of particular importance are the Medium- to Long-Term Plan (MLP), plus the "Indigenous Innovation" goals, and Beijing's Strategic Emerging Industries (SEIs) initiative.

Hu and Wen's 2003 *Guiding Opinion on Promoting the Adjustment of State-Owned Capital and the Reconstruction of State-Owned Enterprises* described an aim of the revamped SASAC as being to help form "predominant enterprises with independent [IP]", beginning the controversial "indigenous innovation" (*zizhu chuangxin*) campaign. On coming to office, Hu and Wen agreed that the state of Chinese technological innovation was "bleak", putting "scientific development" at the top of government's agenda. Wen also stated that China had "missed four opportunities for technological modernisation [since] the Age of Enlightenment" (McGregor, J., 2012a, 36), and used his position heading the Party Leading Group on Science, Technology, and Education to coordinate a Soviet-style "big push" campaign" (Atkinson, 2012).

Other authors date the strategic decision to "establish an innovative society" to between 2003 and the beginning of 2006, when the State Council and Central Committee heard Hu Jintao's *Speech in the National Scientific and Technological Meeting*[11] (Hu, 2006). The "big push" nationally was launched in a document entitled *The National Medium and Long-Term Plan for the Development of Science and Technology, 2006-2020* (MLP) (with the subheading, "the grand blueprint of science and technology development [for] the great renaissance of the Chinese nation"). The MLP stated: "despite the size of our economy, our country is not an economic power, primarily because of our weak innovative capacity". The MLP outlined general goals, specific targets and methods to upgrade Chinese innovation. It also stated that the NIS of China included four "subsystems": the technological innovation system, the knowledge innovation system, the national defence innovation system, and the regional innovation system (Sun and Liu, 2010, 1313).

The plan's explicit goal was to transform China into a technological powerhouse by 2020 and a "global leader" by 2050, through "innovation with Chinese characteristics". The document stated that a central method of generating IP would be "enhancing original innovation through co-innovation and re-innovation based on assimilation of imported technologies", and stated explicitly that a central "tool for China to create its own intellectual property and proprietary product lines will be through tweaking foreign technology", and that Beijing seeks to "enhance the absorption, assimilation, and re-innovation of imported technologies" (McGregor, J., 2012b, 4). A blueprint for this contemporary Chinese stance can be found in the protectionist policies of the Japanese Ministry of International Trade and Industry (MITI), in particular from a 1992 official Party translation of *MITI and the Japanese*

[11] An apparently unconnected policy that followed this slogan was the amendment of the Partnership Law to introduce Limited Partnerships. However, as the law states (in Article 61 of the Revised Partnership Enterprise Law) that "a limited partnership enterprise shall be established by not less than two but not more than fifty partners, unless it is otherwise provided by law. A limited partnership enterprise shall have at least one general partner", this appears to have hindered fundraising capacities other than from the state (McGregor, J., 2012a, 32).

Miracle: the Growth of Industrial Policy, 1925-1975 (by Johnson, 1982). China's *Outline for Industrial Policy* of 1994 was crafted from this document, mimicking directly Japan's choice in the 1960s of electronics, machinery, construction, petrochemicals, and automobiles as pillar industries.

In this vein, Mahmood and Rufin (2005, 339) argued that in states that remain a long way from the technological cutting edge, centralised political and economic control by government can drive economic development: government, they suggest, "can promote industrialisation by actively directing the flow of resources to firms and encouraging firms to invest such resources in technology upgrading". However as a country gets closer to the frontier of technology, the government should allow "political and economic freedom". Yet in China, "strategic" industries, as the focus of indigenous innovation assistance, were still intended to remain "state dominated" through sole state ownership or direct state control. This broad area includes armaments, power generation and distribution, oil and petrochemicals, telecoms, coal, aerospace, and air freight. The slightly more peripheral "pillar" sectors would remain largely in state hands, implying majority ownership, and including equipment manufacturing, automobiles, electronic communications, architecture, steel, nonferrous metals, chemicals, surveying and design, and "science and technology".

In 2009, Wen began a series of meetings involving the NDRC, Ministry of Industry and Information Technology (MIIT), Ministry of Science and Technology (MOST), and the Ministry of Finance (MOF), aimed at combining the government's various "megaprojects", "strategic industries", "pillar industries", and "emerging industries", to focus on economically vital and technologically novel areas that still lacked obvious global leaders, allowing China to take the lead. As MOST officially controls not only science and technology policy but also R&D budgets (Zhong and Yang, 2007), working with MOST and the Ministry of Finance appears a natural decision. The State Council's solution was the "Strategic Emerging Industries" (SEI) focus.

Meanwhile the State Council's overarching control of the major organs of the Chinese state is delineated as follows:

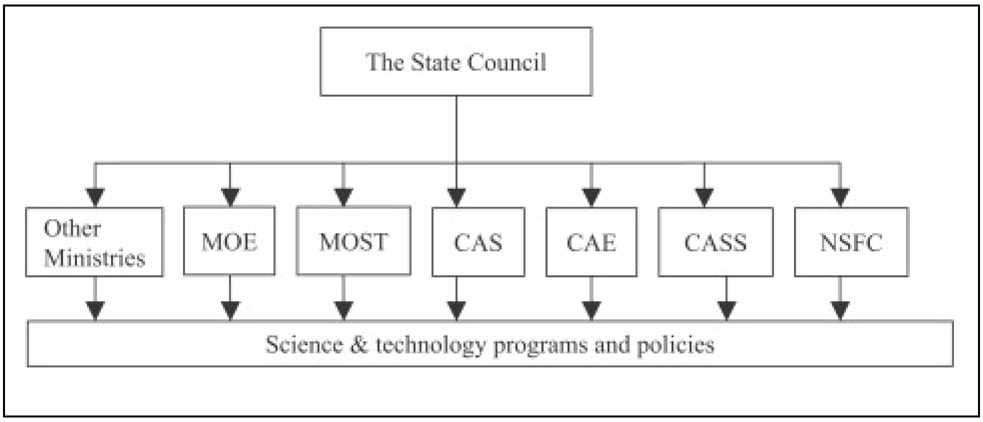


Figure 2: State Council control and Chinese institutions (source: Zhong and Yang, 2007)

This rationale is explained by Perez and Soete's (1988, 459) *Catching up in technology: entry barriers and windows of opportunity*: "improvements are achieved slowly at first, then accelerate and finally slow down again, according to Wolfe's law of diminishing returns to investment in incremental innovations". The phenomenon is illustrated thus:

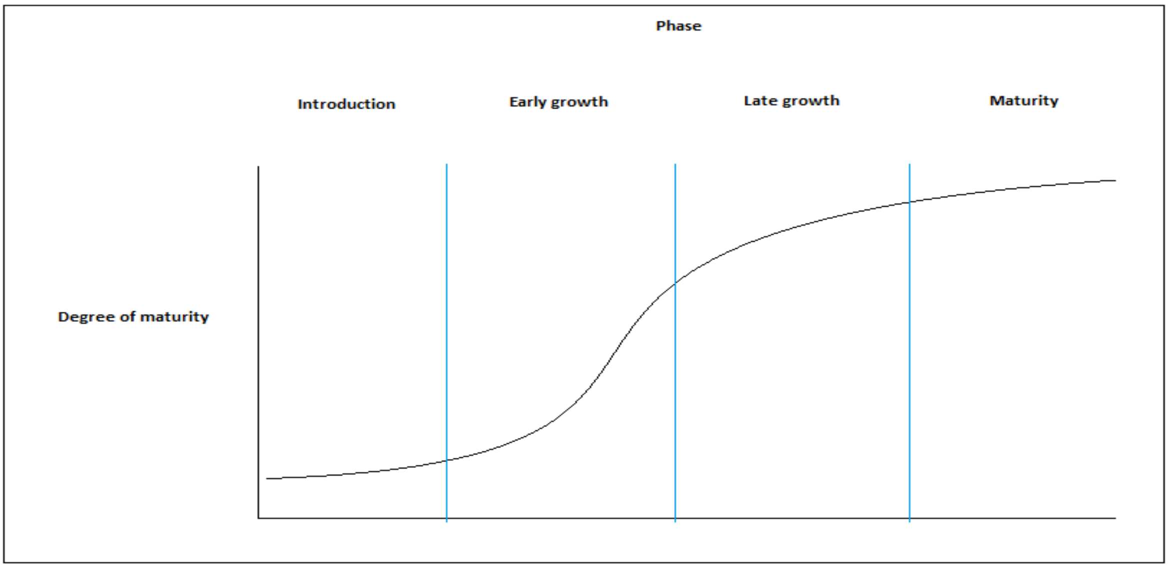


Figure 3: The technology improvement curve (source: Perez and Soete, 1988)

This group of industries would be funded to develop advanced "next-generation technologies and products", with estimates of up to $2.2 trillion of investment for seven industrial areas of clean energy, alternative energy, next generation IT, biotechnology, high-end equipment manufacturing, new materials, and clean energy vehicles (sub-divided into thirty-seven sub-industries). These seven are ranked in order of importance, with clean energy featuring highly because of environmental risks to China (and, states Atkinson (2012), to the Party's survival). Responsibility for SEIs is shared between the NDRC and MIIT, with the NDRC in charge of clean and alternative energy (more detail regarding the effects on solar PV is below). The SEI initiative however remains focused on maintaining the dominance of SOEs as *the right vehicles to lead innovation* (McGregor, J., 2012b, my italics), to whose innovation implications we shall return. The sectors and sub-industries relevant to us are:

1) Clean Energy Technology: high-efficiency and energy saving technologies, advanced environmental protection, recycling, reusing waste.
2) Alternative Energy: nuclear power, solar power, wind power, biomass power, smart grids.
3) Clean Energy Vehicles: electric-hybrid cars, pure electric cars, fuel cell cars.

Firms' percentage of state ownership broadly reflects their perceived strategic importance. The goals of "indigenous innovation" are thus "implicit and clear", being to capture market share for Chinese firms, with SOEs given a favoured position (McGregor, J., 2012b). Majority state ownership is common in industries deemed important, and in other industries' "core" firms. However, minority state ownership is more common in sectors which have been seen as not strategically vital, and/or not planned by the state. Although solar PV has come to be considered technologically vital, the sector (as we will discuss) was not planned by the (central) state.

3.2.1 The continuation of state ownership and R&D

Foreign and Chinese authors describe a re-inflation of SOEs' role in China's economy through these structures. Spending on buildings, plants, machinery and infrastructure now makes up 48% of Chinese GDP, ten percent above the peak in Japan and South Korea; most of this money flows through SOEs (McGregor, J., 2012a). More detailed evidence of SOEs' special position is from *The Nature, Performance and Reform of State-Owned Enterprise* (Unirule Institute of Economics, 2011). This found that the recorded performance of SOEs is not a reflection of real performance, but results from "numerous preferential policies and an unfair business environment", including fiscal subsidies from central government, different financing costs, and subsidised land and resource rents. If total subsidy and foregone costs (RMB 7.5 trillion) were taken off SOE profits between 2001 and 2009, average return on equity for SOEs is minus 6.29% (Unirule Institute of Economics, 2011).

The implication is that, while funding and other preferences for SOEs have given them a central role in innovation, despite their operating advantages over private firms, innovation may have been disincentivised through the creation of "soft budget constraints". This financial cushion that means should managers fail to carve out new market share for their firms and instead make losses, they are likely to be kept from bankruptcy by the state. (Although this may lower risk aversion, and this is a theme to which we shall return in which types of technology R&D is employed to pursue.)

As we will also describe, SOEs that register numerous patents (regardless of quality), receive still more subsidy (Atkinson, 2012); meanwhile, despite being barred from many sectors and having harder bank finance terms, private firms have been found to create 90% of new jobs, 65% of patents, and 80% percent of technological innovation (Atkinson, 2012). We describe the funding and legal mechanisms through which state preference is manifested, and how the state gives a superior resource environment to those firms whose managers (agents) know they will survive without successful innovation; we also describe how the system appears to be tilted against the firms whose survival may depend more on innovating competitively for superior product.

Furman, Porter and Stern (2002) looked at R&D publication rates to measure "emerging-technology" capabilities, meaning a nation's capabilities in technologies which could have an economic influence over the following fifteen years (these being computer hardware, optical communications, advanced computing materials, software, and biotechnology). Judging these capabilities on numbers of publications, China came between fourth and seventh in these technologies, among 33 countries. Fai (2005) states that this places them with the UK, France, and Germany as "research powerhouses", behind only Japan and the US as "superpowers", and that "this is also reflected by Chinese patent data". We will discuss below why the crude measures used here may be misleading, however. Furthermore, while high-tech exports in total Chinese exports rose from 5% early in the 1990s to over 30% in 2005, China was unique in that the majority of high-tech exports were accounted for by foreign-invested firms, usually using imports of components. (In 2005 foreign companies accounted for nearly 90% of high-tech exports, and had even lower R&D intensities (R&D/value added) in these fields than private firms or SOEs (Lan and Zheng, 2010).) Overall, this suggests difficulties in upgrading from "high-technology product assembling industry" (Lan and Zheng, 2010, 90).

Meanwhile, as we will discuss in our own quantitative study, a variety of patent-holders, including SOEs and high-tech companies, some of whom have relied on academic spin-offs, have been either insensitive to the market or lacking in commercialisation capabilities (Lan and Zheng, 2010). Rare non-state-owned companies like Huawei have advanced R&D capabilities, and can now employ these resources globally (Lan and Zheng, 2010). Yet even Huawei, for example, announced in an internal memo that over the past eighteen years it has made no "original inventions", with all its core technologies obtained via M&A or patent licensing (Lan and Zheng, 2010). Thus while the MLP agenda has accelerated funding for selected technological areas, whether it has succeeded in driving high-tech innovation to a significantly faster pace remains unclear.

3.3 R&D funding patterns and firm innovation outcomes

We thus describe how the political control mechanisms and programmes above may affect R&D and innovation in firms. In sum, a cluster of programmes have remained the main funding routes, being:

1) The Key Technologies Programme (since 1982), which deals with core science for development, involving over 1,000 institutes. Supervised by MOST, it funds 20% of Beijing's science and technology spend.
2) The National High Technology Research and Development Programme ("863" for its March 1986 founding), promotes IT, aeronautics, biology, energy, automation, and materials. Initiatives typically connect SOE-only R&D groups, state institutes and university departments.
3) The Torch Programme (1988), under MOST, has overseen the construction of over 50 national-level high-tech zones, providing infrastructural funding for indigenous innovation in materials, electronics, mechanical-electrical, and energy technology.
4) The National Key Laboratories Programme (1994) aims to raise technological capabilities through constructing R&D facilities with world-class equipment. RMB 1.3bn was spent in its first ten years on 153 labs, which collaborate with selected Chinese firms.
5) The National Basic Research Programme, since 1997 (the "973 programme"), carries out strategic research in energy, IT, healthcare, agriculture, and materials, receiving approximately 10% of Beijing's sci-tech funding.

The division of spending until 2010, including both main funding programmes and other smaller, more sector specific programmes, is as follows:

Research Programme	2001	2005	2006	2007	2008	2009	2010
National Natural Science Fund	1598.35	2701.28	3620.14	4330.96	5358.51	6426.97	10381.09
National Basic Research Programme of China (973 Plan)	589.30	982.97	1354.19	1645.81	1900	2600	4000
Key Techs R&D Programme	1053.40	1624.40	2887.90	5423.37	5065.56	5000	5000
National Science and Technology Infrastructure Programme	N/A	573.30	753.65	685.55	23.47	21.27	N/A
State Key Laboratory Construction Programme	130	133.60	216.40	1600	2167.74	2916.95	2759.22
National Engineering Research Centres	50	59.50	83.50	85.50	N/A	103	105
S&T Basic Work	199.68	N/A	102.74	178.43	150	150.48	155.15
Spark Programme	100	117	101.60	150	200	218.92	200
Torch Programme	70	70	108.25	138.75	151.76	227.65	220
National New Products Programme	140	140	139	140	150	200	200
Innovation Fund for Small Technology-based Firms (“Innofund”)	783.30	988.48	842.88	1256.20	1621.09	3483.57	4297.09
Agricultural S&T Transfer Fund	400	300	300	300	300	400	500
International S&T Cooperation	100	180	300	300	400	500	1301.77

Programme							
Special Technology Development (R&D Institutions)	158.30	186.04	200	250	250	250	250

Table 2: Spending by central government on main R&D programmes by million RMB (source: China Statistical Yearbook of Science and Technology, 2011; Gong, 2013)

Overall, these funds helped to push China's R&D expenditure to RMB 706.26bn for 2010, up by RMB 126bn from 2009. The following graph therefore shows China's overall R&D spend in the decade to 2010.

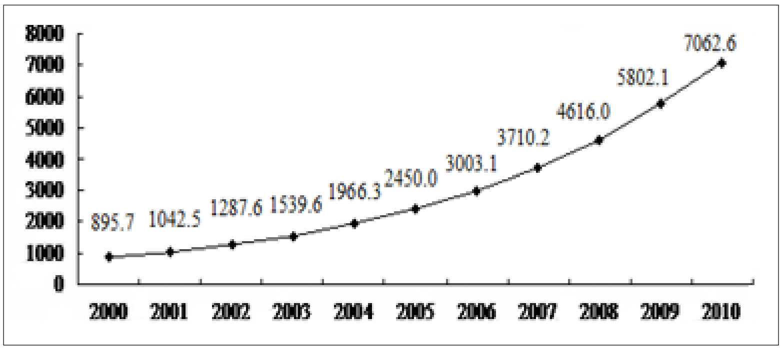


Figure 4: China's R&D Expenditure (2000-2010; RMB 100m) (source: MOST, 2012; Gong, 2013)

3.3.1 R&D funding through central and local governments

Having seen how R&D funding has been targeted primarily at SOEs (McGregor, J., 2012a), we should understand how science and technology spending can be divided between central and local government (by local we mean non-central government, i.e. provincial and below). This broadly shows that local spending, less than half central government spending in 1990, overtook central government in 2007 (excepting 2009), suggesting substantial local ability to direct funds. Indeed, some studies that suggest the state's retained shareholdings in listed firms have been responsible for their poor profitability, do not fully distinguish between different types of owners (Wang 2003, in Chen *et al*, 2009).

Year	Total govt budgetary expenditure	Appropriation for science & technology	Central govt	Local govt	Percent of total govt budget expenditure
1990	3038.6	139.1	97.6	41.6	4.51
1991	3386.6	160.7	115.4	45.3	4.74
1992	3742.2	189.3	133.6	55.7	5.06
1993	4642.3	225.6	167.6	58.0	4.86
1994	5792.6	268.3	199.0	69.3	4.63
1995	6823.7	302.4	215.6	86.8	4.43
1996	7937.6	348.6	242.8	105.8	4.39
1997	9233.6	408.9	273.9	134.0	4.43
1998	10798.2	438.6	289.7	148.9	4.06
1999	13187.7	543.9	355.6	188.3	4.12
2000	15886.5	575.6	349.6	226.0	3.62
2001	18902.6	703.3	444.3	258.9	3.72
2002	22053.2	816.2	511.2	305.0	3.70
2003	24650.0	944.6	609.9	335.6	3.83
2004	28486.9	1095.3	692.4	402.9	3.84
2005	33930.3	1344.9	807.8	527.1	3.93
2006	40422.7	1688.5	1099.7	678.8	4.18
2007	49781.4	2133.5	1043.0	1070.5	4.25
2008	62592.7	2581.8	1285.2	1296.6	4.12
2009	76299.9	3224.9	1648.6	1576.3	4.23
2010	89874.2	4114.4	2046.4	2068.0	4.58

Table 3: Government expenditure for science and technology by RMB100m (source: China Statistical Yearbook of Science and Technology, 2011; Gong, 2013)

The chart below illustrates that "enterprises" are the main sector in which R&D money is spent, making up 73.4% of R&D spending; following them are R&D institutions, with 16.8%, then higher education institutions at 8.5%. Of total R&D expenditure by 2010, government spent RMB 169.63bn, or 24%, while enterprises spent RMB 506.31bn, or 71.7% (MOST, 2012). This places China's total R&D expenditure at number three worldwide, spending 25% of the US, or 3/5 the spend of Japan (MOST, 2012). Meanwhile, as a proportion of GDP, China's R&D spend (at 1.76% in 2010) remains behind the US (at 2.9%), Germany (2.82%), Japan (3.36%), France (2.26%), the UK (1.85%), and the EU 25 average, at 1.95% for 2009.

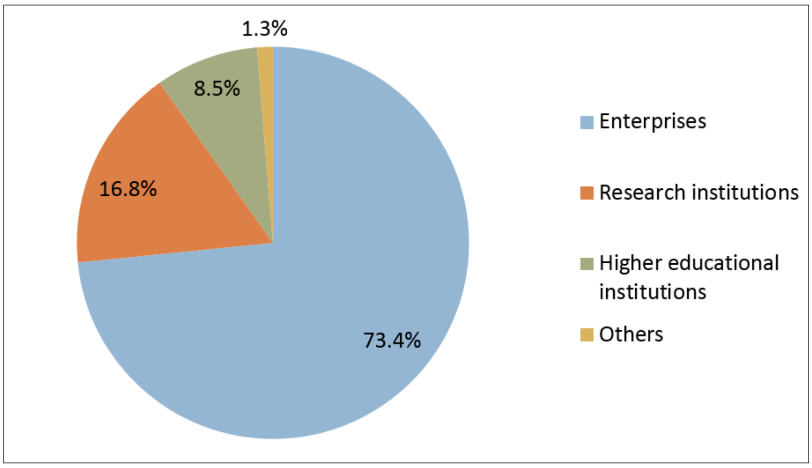


Figure 5: China's overall R&D expenditure by performer (2010) (source: MOST, 2012)

In the round, the changes that have taken place in the Chinese innovation system since the mid-1980s are clear. In terms of the volume of spending, the strongly centralised innovation system of 1985, built around institutes and some enterprises, had been replaced by 2006 by one structured around enterprises (Xue, 1997). Between 1987 and 2003 the employees of PRIs declined drastically, as enterprises' R&D staff numbers increased. Universities meanwhile have also become a base for significant R&D (Zhong and Yang, 2007).

There is a number of causes for the growth of R&D staff and spending among enterprises. The first (according to Zhong and Yang, 2007), is that among the 1149 reformed research institutes, 1003 became enterprises or departments thereof, increasing enterprises' R&D staff by 102,000; enterprises affiliated with universities and PRIs in high-tech fields have increased the R&D intensity of the enterprise category (Zhong and Yang, 2007). University-affiliated enterprises have expanded since the early 1990s, with 4593 such firms and a total income of RMB 97bn by 2004. The second factor is stimulation of R&D among enterprises by the increased competition caused by market reform in general since the 1980s; and the third factor, according to Zhong and Yang, is the reforms' creation of a more favourable environment in general for R&D (Zhong and Yang, 2007).

Table four demonstrates the decline in *direct* government R&D funding, from 79% of R&D funds in 1985 to 29.9% by 2003, as enterprises have become the dominant R&D investor.

R&D funding in China by source: selected years from 1985–2003 (%)

	Government	Enterprises	Others
1985	79.0	18.0	3.0
1987	60.9	39.1	—
1988	56.6	43.4	—
1990	54.9	23.4	21.7
1994	57.7	32.4	9.9
1995	50.0	35.0	15.0
2000	33.4	38.9	—
2003	29.9	60.2	9.9

Table 4: R&D funding in China by source: selected years from 1985–2003 (%) (source: Zhong and Yang, 2007)

However, because much of the volume for "enterprises" includes SOEs, a large proportion of this – and total – R&D funding originates with the state. Thus Zhong and Yang (2007) do not appear to demonstrate the disappearance of the fact of *state* dominance in China's R&D, or innovation system: simply that most state R&D funding is now channelled through SOEs. It is therefore imperative to understand the effects of this scenario on innovation outcomes.

While we describe in the theoretical literature review how agency-chains between these principals and agents may affect outcomes in our firms, we outline here what appear to be the different patterns of R&D and innovation, through funding, between broad firm types. The Chinese situation means funding appears to interact with ownership in various ways, creating different outcomes. Throughout, it is worth bearing in mind the potential for mismatch between the long-established expectations of western social science and this context: Hill and Snell's (1988) study of external control and firm strategy and performance in research-intensive industries employs the "long-established practice" of using R&D expenditure as a proxy for the importance of innovation. In China however, R&D expenditure can be caused by other, political, factors.

Many firms in China find access to state finance sources is vital to the funding of R&D, and this is in turn vital to patenting and innovation; both suffer without this support (Prud'homme, 2012). However, it appeared by 2008 that 80% of large SOEs still had no R&D team at all (Girma and Gong, 2008b), while SOEs' operations usually focus on short-term performance instead of the riskier investments needed in long-term R&D (Chan and Daim, 2011). Guan *et al* (2006) and OECD (2007) find that in general that SOEs which do carry out R&D are inefficient at using R&D expenditures to actually innovate. This is because, as with internal R&D, firms - and managers - may need incentives to apply this knowledge to real commercial ends.

Dong Mingzhu, CEO of social media firm Gree, also states numerous companies produce reports on their innovation efforts to suit the funding application process, but R&D stops after funds have been obtained (Gong, 2012). According to the *Audit on Central Budget Implementation and Other Financial Revenues and Expenditures* (National Audit Office, 2011) meanwhile, 93% of central sub-projects that should have had acceptance checks by the end of 2011 went unchecked; it thus appears that sub-central support may better monitor specific firms, compared to central programmes, caused by closer monitoring and greater reputational concern in smaller governmental areas. Overall, as discussed in section 3.1.5, the implication is that although central government is better able to provide large-scale R&D funding, local government allows the closer monitoring, relationships, and reputational incentives between principals and agents that are liable to see what R&D resource locally state-owned firms can acquire being used more efficiently for innovation.

3.3.2 State versus private ownership in R&D and innovation outcomes

Regarding more specific mechanisms for IPR funding, the revised administrative measures in the National Science and Technology Support Plans (September 2011) state that the "project carrier" needs to specify who will own the IPR that will be generated by the project. These projects normally have a short timeframe of 3-5 years. Projects regarded as being particularly important for China's economic development, that will considerably raise an industry's global competitiveness, or will lead to new technological standards for a strategic industry, are generally most likely to be given support: yet these are generally the fields dominated by SOEs, allowing them to perpetually dominate R&D funding access.

In general, despite government support, SOEs appear to perform sub-optimally in producing patented products and services. In 2009, of all medium and large domestic-funded Chinese entities, SOEs made up only 10% of all patent applications, and just 9% of all the higher quality invention patent filings we will describe below (Prud'homme, 2012). In 2009 (the last year with a study of this scale), 65% of patent applications by medium-to-large SOEs were for the lower quality utility and design patents, and only 35% for invention patents (Prud'homme, 2012), a higher percentage of utility and design patents than other types of enterprise. Despite their support, actual R&D spending also remained lower than enterprises with different legal registrations.

This may be caused in part by differences in management. The governance of SOEs appears very different to other types of firm, with top executives "appointed by the government and their experiences in these companies [continually] building part of their political careers" (Girma and Gong, 2008a, 581), the effects of which we will address in depth. Thus managers tend to focus on the short-term economic performance that provides a direct reward, rather than "risky long-term strategic investment in R&D". In various studies, most SOEs had spent a large proportion of innovation funds on acquiring technological equipment from foreign countries (Guan *et al*, 2006; Girma and Gong, 2008a), as SOEs prefer "material technology to immaterial elements". There then appears a lack of innovative fruit (China's 54 government-sponsored high-tech zones for example seeing unsatisfactory "general innovation performance") (Girma and Gong, 2008b). Thus SOEs "have more research capacity, but not as good incentives" (interviewee Minnan Wang, BNEF Beijing, November 2012).

China's financial system does not meet private firms' funding requirements, however, especially for SMEs (OECD, 2008, in Girma and Gong, 2008b), and with the capital market underdeveloped, these firms, which are mostly small or medium, are hard-pressed to obtain loans, as banks favour larger firms, especially SOEs. This means small private firms must often be self-funded. However, despite the resulting relative lack of resource, this means private firms do not have soft budget constraints, and often see the urgent need for innovation (they are simply relatively "starved" of the capital needed). Hutschenreiter and Zhang (2007) find that pro-SOE policies have withheld support for private firms with considerable potential. Chinese companies' innovation activities appear to be aimed mainly at quality improvement, and those SMEs which have government support generally perform better (Guan *et al*, 2006).

For a better innovation return on investment, Beijing has begun using a "patent indicator system" to reward patenting firms in general. However, combined with the "revolving-door" management problem, by which SOE managers are disincentivised by being transferred to other firms before R&D investments will bear fruit, incentives to register patents may lead to an incentive to register low quality patents quickly, particularly in the SOE case (or to infringe the IP of other firms). For China as an innovation system, "large amounts of money will be wasted" (Atkinson, 2012, 68), a hazard compounded by subsidised SOEs' dominance, plus governmental reluctance to allow the "creative destruction" of firms it owns, which may retard the growth of disruptive, innovating firms. One government cadre stated: "We want to identify large flagship enterprises to be the model for innovation, [but] the role played by [SMEs] is seriously undervalued and they are facing severe problems in market access" (Atkinson, 2012, 68). As SOEs receive funding relatively independently of their innovation success, oligopolies which should be made temporary by disruptive "Schumpeterian entries" in innovative product markets are protected from competition that would otherwise reward innovators (and the changes that should occur when firms that cannot keep up with the pace of technical progress see their markets shrinking rapidly (Dosi, 1981)).

China-listed firm data has been used to find a negative effect of state ownership on firms' innovation. Xie (2011) stated that state control overall has a "significantly negative effect" on the performance of R&D investment. Xie (2011, 235) speculates that this is because state control weakens governance, with owners absent in state-owned firms, "so managers lack sufficient incentive to manage R&D investment"[12].

To see the effects of the system more clearly, context via international comparison is useful. One study of over 200 South Korean firms showed how their more dynamic companies had several characteristics which differ from Chinese SOEs. First, they emphasize their own technological efforts in combination with foreign technological input; second, they monitor development of the "world technological frontier"; third, "they are committed to training workers, thereby developing human resources; fourth, entrepreneurs play a key role; and fifth, they use crises as an effective means to expedite technological learning" (Kim, 2007, 232). Other sources also find a lack of innovation in Chinese SOEs, particularly those owned by the central state (Feng, 2010). As the *Unirule* study suggested, SOEs' actual performance has often remained hidden, with these firms appearing successful in many analyses. Chen *et al* (2009) found that operating efficiency of Chinese listed firms varies by type of controlling shareholders. Their "SOECG controlled firms" *(SOEs affiliated to central government)* performed best, while SAMB *(State-owned Assets Management Bureau, the predecessor of the SASAC)* and privately-controlled firms performed worst, with "SOELG *(SOEs affiliated to local government)* controlled firms" in the middle. Although their classifications of SOEs are now considered outdated, the study established a connection between performance and level of SOE ownership. However, their definition of "operating efficiency" refers to labour productivity, and SOECGs' labour

[12] However we will also investigate the possibility that government may encourage firms to invest in projects with "longer payback cycles" (Gong, 2013, leading to speculative innovation (such as thin film technologies in solar PV which as yet lack commercial payoffs.)

productivity has been raised by their generous supplies of cheap capital, hence private enterprises scoring relatively low.

Meanwhile the conflicting findings of various authors suggest that the impact of corporate governance on innovation within enterprise performance, particularly among SOEs, is more controversial (part of the rationale for this thesis). Xie (2011, 234) uses Chinese listed firm data to demonstrate a negative effect state ownership imposes on firm innovation: state control “has a significantly negative effect on the performance of corporate R&D investment”. They suggest the possible reasons are that the state’s control “weakens the corporate governance, and owner is absent in state-owned firms [sic], so managers lack sufficient incentive to manage R&D investment” (Xie, 2011, 234).

Management problems however may also affect outcomes for purely private Chinese firms. Ownership and management are usually not separated, with financing coming from relatives or friends (Li and Xia, 2008).

Li and Xia suggest that such corporate governance arrangements are outmoded. This family management, despite helping speed development in the first stages of growth, comes to retard it later through its problems integrating human capital and external financial capital. They also refer to the effects imposed on family owners’ behaviour by the fear of bad treatment by the state, and in our case this likely includes a (relative) failure of *entirely* private firms to generate IP, due to the risk of its infringement by firms with the protection of the state (Atkinson, 2012). As a result, working relationships with state-owned firms become a vital project for many private firms, which also cultivate close relations with various government officials, levels, and departments, which are seen as helping them deal with pressures that may arise from the state/legal system. One of the legal challenges these firms face is the need to access unofficial sources of finance without prosecution; Ong (2004, 379) states that “it is well known in China that bank managers have a disincentive for lending to private enterprises because they could lose their jobs if a loan to a private company goes under, but not if it's a state-owned firm”. This makes securing financing for R&D, for example, more difficult. And while Aulakh and Gencturk (2000) suggest that in employing social controls that sanction instead of punish risk-taking, agents may be encouraged to attempt innovative ways of achieving performance objectives, many agents in our context will not have this luxury.

Ong (2004) also suggests private firms, lacking the need to carry out administrative work, have fewer agency problems than their state-owned counterparts, but more concern over legal system risk and lower provision of resource from the government, which he suggests makes it rational to pursue market goals. While private firms’ investments are generally less long-term focussed, the investments they make in innovation are more often market-oriented (this may also mean quicker revenue generation ahead of long-term research).

The majority of research however has investigated Chinese firms’ access to international knowledge sources and R&D connections, but much evidence shows Chinese companies benefit more easily from domestic than foreign knowledge sources (Li, 2010). Foreign companies are also often unwilling to give Chinese partners access to their advanced technology without an ownership stake. International R&D collaborations’ effects have thus been found to be insignificant, with firms protecting IP to minimize “outgoing spillovers” (however, these are commercial entities, and foreign universities have a different remit); yet the implication is that the most important determinants of innovation outcomes are domestic.

We should therefore summarise the likely positive and negative roles for innovation of state and private shareholding. The managers of SOEs appear likely to aim at “quick wins” in the form of buying in visible kit for technology manufacturing, especially because of the time pressure felt by “revolving-door” cadre-managers. The better innovation performance of SMEs (which tend to be private firms) provides some evidence for this phenomenon (Hutschenreiter and Zhang, 2007). But the state’s keeping poor innovators afloat (through SOEs’ soft budget constraints) is likely to harm the innovation system as a vital driver of economic growth: the soft budget constraint does damage because the firms it keeps alive use resources and occupy market space that would otherwise go to firms with more potential. This could even be called a pillar of the innovation system, with one cadre stating that “large flagship enterprises” are the “model for innovation” (Atkinson, 2012). In a relatively straightforward comparison of state-owned and private firms, Xie (2011) suggests that these innovation problems in SOEs are real. Yet Li and Xia (2008) and Ong (2004) demonstrate that those private firms are unable to secure the necessary resources; this means the Chinese national innovation system appears to be systematically depriving the more effective innovators of the resources they need. The overarching implication is that those firms which will currently be able to innovate most successfully in China’s national innovation system may be those which have the *incentivised management that comes from (majority) private shareholding*, but also have the *favour of the state, implying (minority) state ownership*. Meanwhile the level of state shareholding that may be preferable, non-central instead of central state, is described above).

Moral hazard is a profound risk in the Chinese innovation system. Agents, as we have seen, may lack incentives to deploy factor resources in the most efficient way. Li and Xia (2008) found that resources are unlikely to be used for market-oriented criteria, but in administrative tasks and for empire-building. SOEs are required to assist government in its goals to continue being granted state resources, instead of simply making profits. Zhang (1998) however provides some analysis of this phenomenon at different state levels, and having established the outline of the principal-agent chain, we should analyse how different government levels in the chain create varying moral hazard. Zhang moves from descriptive institutional work (e.g. of Qu) to an attempt to model the principal-agent relationship for such “monitoring-incentive problems of the public economy” (although Zhang did not apply this to technological innovation).

On SOE performance, Zhang describes the “naive argument” in China that Singapore’s state-owned enterprises (e.g. Singapore Airlines) are efficient, “so Chinese state-owned enterprises can also be efficient”, noting one cannot make simple analogies between public enterprises owned by small populations with those owned by large populations, as increases in degree of publicness and economy size increase layers of hierarchy, thus the distance between “original principals” and “ultimate agents”, making monitoring less effective. This means a public economy where agents “claim *de facto* the residual” instead of the principals (Zhang, 1998). If socialist economies become corrupt because “bureaucrats can afford to buy out”, this is likely to hinder wise re-investment of company revenues for innovation. Like their private counterparts, SOEs have decision-making, producing, and capital-owner members. Producing members are insiders, capital-owner members may be insiders or outsiders, but decision-making members may not be insiders, unlike in private companies. Zhang proposes four effects on the principal-agent relationship.

First, the original principal’s “optimal incentive to monitor” may increase or decrease with the size of the economy. We add that “incentive to monitor” may also depend on what kinds of “success” are needed and low quality patent filings - possibly via IP infringement - may provide the necessary success metrics). Second, for any given size of economy, a smaller “community of ownership” will increase the “principal’s monitoring incentive” and the “agent’s monitored work incentive”. For our purposes this can refer to smaller state owners (local rather than central), such as provinces. In other words, principals outside the central state create a greater incentive to monitor output, and greater work incentives for agents.

The third effect is that original principals being residual claimants are Pareto-dominated by lower actors. This means that because of skewed incentives up the chain, the lowest level of agents dominates decision-making (in a state context). This is connected to proposition four, which supposes that lower agents hold decision rights, and Pareto dominate the higher actors. The results of this situation are that the monitoring incentive of the original principals and work incentive of the ultimate agents decreases “with the degree of publicness and the size of the public economy”, and that splitting up a public economy of a given size increases “the monitoring incentive of the original principals and work incentive of the ultimate agents” (Zhang, 1998, 232). The implication is improvement of agent output in a mixed state-private shareholding context, and at lower levels of state; for example the “principal-agent chain” in township and village enterprises (TVEs) is much shorter than in SOEs, so the original principals (the “town government”) can better monitor the TVE’s management. As the size of TVEs expands, the “principal-agent chain becomes longer, and monitoring by the original principals and the central agent [town government] less and less effective” (Zhang also believes that “for TVEs to remain efficient, the privatization of TVEs is inevitable”; however in terms of principal-agent relations TVEs appear more “private” already, with their close principal-agent monitoring being similar to private firms (Zhang, 1998, 233)). Local government as a major shareholder has an interest in maximising profitability and dividends, and is represented on the board. A pure SOE manager may conceal profit, “or absorb it in operation costs” (Nee, 2005, 57), but the cadre-entrepreneur benefits from a profitable firm.

3.3.3 Levels of state ownership and firm performance

An account of incentivisation and constraint in firms by ownership types comes from Da’s (2010) study of the relationship between state ownership and corporate objectives (although this does *not* apply ownership to innovation outcomes). Firm objectives are more economically oriented for local than central government-controlled firms: listed firms’ chain of control is traced to owners; those whose largest shareholder is central government (or its agencies such as SASAC or ministries) are “central government controlled companies”, firms whose largest shareholder is a provincial government (or one of the four provincial-level cities) are “provincial government controlled”, followed by “municipal government controlled companies”.

Yet although Beijing controls local officials via promotion or demotion, local governments have considerable autonomy in economic decisions (Chung, 2000), due partly to the hazy division of duties we have described between central and local government (Qian, 2002). Here, it is possible that the combination of local government autonomy with the central government’s demands that they provide improvements in local GDP would lead to even less effective treatment of firms, with demands from local government that they invest resource not in longer-term innovation, but in unsustainable immediate increases in output and employment. Increases in construction and infrastructure, and in the output of firms providing for these local projects (Chang, Wong and Scott, 1999), appears to give some evidence for this, especially in the localities where state economic dominance is most marked (however we will discuss the peculiarities of the most "agglomerated" areas for solar PV).

Yet the reform period gave sub-central government economic incentives to become entrepreneurial, especially in the reforms that let them retain tax revenue (Davis and Vogel, 1990, in Da, 2010). Da perceives that moving down the political hierarchy from central to municipal government is equivalent to reducing government control and transferring state shareholdings from social-political orientated to market-orientated organisation (Da, 2010).

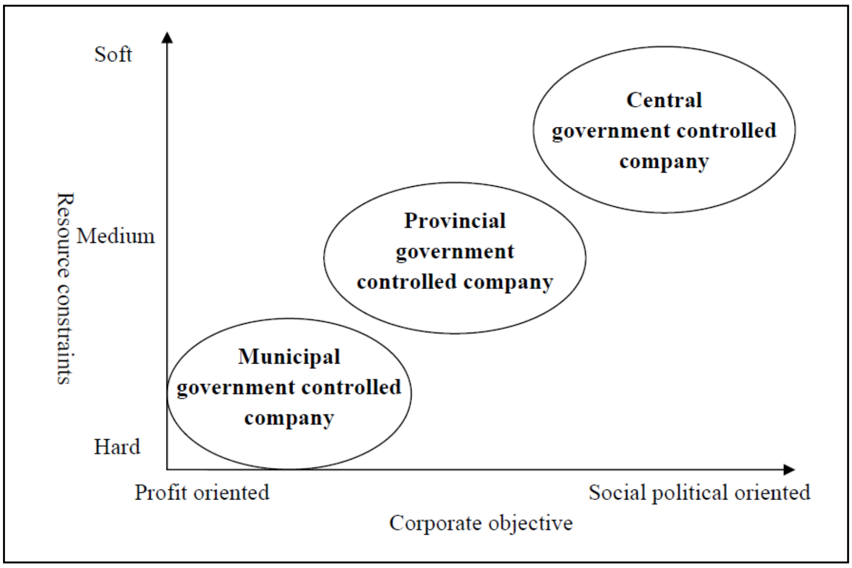


Figure 6: Level of government ownership and market orientation (source: Da, 2010)

Predominant provincial government ownership has thus become seen as "best practice" in company-state relations (although these firms seem to be maintaining competitive superiority, the continuation of solely centrally-owned firms in strategic areas suggests this ownership forms will be maintained for Party security reasons, including employment). In provincial government-owned firms, management often resists government, fearing firms may return to unprofitability (conversely, provincial government-run firms receive less political and financial support) (Da, 2010).

As we have seen, municipal governments have provided a superior "stable institutional infrastructure" (for their firms and their hybrid firms), a framework of which managers under municipal government control have taken advantage (Qian, 2002). One head of a municipal city SASAC stated: "One hundred percent state ownership cannot produce desirable [results]. Private and foreign investors can be fresh blood for our city and companies. There are no political or any kinds of constraints for them... in contrast, we can provide a stable institutional infrastructure for their development, because we can benefit from their development as shareholders. [A] good investment principal does not necessarily have to operate the business; rather, we can receive fruitful results through effective governance and active guidance" (Qian, 2002, 4). By implication, different principals (local and central government) create different outcomes, as do mixed state and private shareholdings.

Kumar *et al*'s (1992) study of models of organisational effectiveness identifies two control effects, which have clear ramifications for government effects on agency relationships. The first deals with "agent compliance", which is regarded as being the reception an agent gives the policies which emanate from the principal. This is regarded as being a core objective for agent-control: Kumar *et al* study marketing programmes, where agents can sabotage a programme by refusing to market products as required. Innovation however can also be sabotaged. The second area, "relationship flexibility", is the degree to which principal and agent are prepared to adjust to fluid, changeable circumstances. We suggest that this will be easier with the closer, more intimate principal-agent relations brought about by local government scenarios. As Kumar *et al* suggest, agents should not only better appreciate the way principals come to their decisions regarding rewards, but greater similarity in agents' self-perception of their effort or performance may exist to a principal's own evaluation. Ideally, monitoring should take place via personal and social interaction, which implies local relations will be superior. Repeated interaction and the shared decisions it allows lead to more "systematised" organisational values (and this is a better description of local government than central government interaction with firms in China). Securing principal-agent relationships for long periods allows principals to invest in agent "socialisation". Bello and Gilliland (2002) argue that those directives that influence an independent agent's market behaviour can then come from a principal's experiences.

Helping us understand the phenomena at work here, Feng (2010, 255) describes the management of technological learning for product commercialisation, comparing "Group-A" firms (mainly centrally-owned SOEs) with "Group-B" firms (every other sort, whose emergence surprised central planners, not being state-supported, at least early on). Group-A firms had not made in-house technological learning for "systemic product and complex technology development" part of collective learning, and remain dominated by managers from marketing, manufacturing, finance, and "political work divisions" (Feng, 2010, 268). Top committees had few product engineers, hindering innovation for systemic product development, an organisational style poor at "rapid and large throughput knowledge creation" (Feng, 2010, 268), making many of these firms simply MNCs' manufacturing bases.

Group-B firms insisted on building in-house innovative capacity, investing in complex product technology development despite resource constraints. Managers generally had backgrounds in product technology, and these firms have organised investments around such projects. Unable to bring political benefits to JVs, early on these firms were not generally MNC partners, as policies protected Group-A companies' advantages. Thus unable to become technological "dependents" (Freeman, 1982), Group-B firms had to become "self-dependent" (Feng, 2010), pursuing in-house development instead of JVs, the root of their product-oriented competitive tradition. The connection between state ownership and firm performance, according to Zhang (1998), means the state as "ultimate shareholder of most Chinese listed companies" creates ineffective corporate governance and unsatisfactory performance. Thus despite apparently having a superior environment for IP protection, the performance of SOEs has fallen below government expectations, with SOEs' facilities – and technology – out of date (Wei and Geng, 2008, 936).

Through our principal-agent theoretical template, we shall return to likely outcomes of the R&D funding and management scenarios for state, private, and hybrid state-private firms. At this stage, for a fuller picture of the innovation system in which actors in these firms operate, we will go on to describe the patenting and legal environment in which different types of firm exist, attempt to innovate, and to register patent IP.

3.4 China's intellectual property system

3.4.1 The development of China's intellectual property system

We shall return to state/private dynamics in describing the theoretical template, but we should now outline the legal system in which each type of ownership will operate. An IPR system is now usually seen as one of the most important innovation-facilitating regulative institutions for competitiveness (Acemoğlu *et al*, 2003). Lan and Zheng (2010) describe the accepted understanding of IPR as being that strong IPR protection creates incentives for investment in R&D, thus allowing technological progress for economies more broadly (Arrow, 1962; Nordhaus, 1967).

Before the twentieth century the Chinese state legislated for commercial and industrial practice in a more detailed manner than often realised, but "comprehensive, centrally promulgated, formal legal protection for either proprietary symbols or inventions" was lacking (Alford, 1998, 15). During the Mao era meanwhile, the *Socialist Education Campaign* of 1962 created an intensive totalitarian period, aimed at the very "eradication [of] material incentives" and other "reactionary" tendencies, in politics, ideology, organisation and the economy (thus the Campaign's alternative title, "the four cleanups"). During the Cultural Revolution that followed (1966-76), IP specifically was described as a "hopelessly reactionary" concept. As the Cultural Revolution got underway in 1966, even the compensation for inventors that had been permitted by the *Regulation on Invention Reward* (1963) was abolished. Thus any incentive for technological achievement as eradicated, and innovation now gave virtually no financial reward. From 1966 to 1978, only 7,700 "items of scientific and technological achievement" were registered by the government (Lan and Zheng, 2010).

It was only with Mao's death in 1976, then the reform period under Deng Xiaoping (from 1978), that embryonic patent law began, as Deng decreed that China should have patent laws to give inventors rights to their innovations, but "without undercutting their responsibilities to the state" (Alford, 1998, 69). This formed a core part (if a relatively little discussed one) of the economic reforms that Deng placed at the top of the national agenda during the Third Plenum of the Communist Party's Eleventh Central Committee (December, 1978). In particular, Deng's reforms would allow the construction of IP laws by making them a constituent part of the "Open Door" policies (*kaifang zhengce*) which allowed access to both foreign capital and advanced technology.

China's first Patent Law was thus established in March 1984 (China's State Intellectual Property Office (SIPO) was founded shortly before the drafting of this law). Yet during the period of the first patent law, SOEs could not handle their patents autonomously, and had to gain the permission of the authorities to license them out (Lan and Zheng, 2010), regulations which limited SOEs' engagement with, and enthusiasm for, IP (this extended to their R&D staff). Furthermore, by design the first patent law did not cover chemical, pharmaceutical, alimentary, or process inventions, to keep foreign investors out of sectors intended to be the preserve of domestic industries. According to Lan and

Zheng (2010), in the latter half of the 1980s, although Chinese firms (mainly SOEs) imported large numbers of production lines, their in-house R&D capabilities (and product development in particular) did not improve, even deteriorating in some regards, while large profits were made by accessing "updated" technologies and assembling imported components.

As such, before 1992 there occurred a rapid increase in total applications (with domestic applications leading, peaking in 1992). However the ratio of invention applications to others fell from the beginning (in 1985) to a low of 21.46 percent in 1992 (more recent figures are described below).

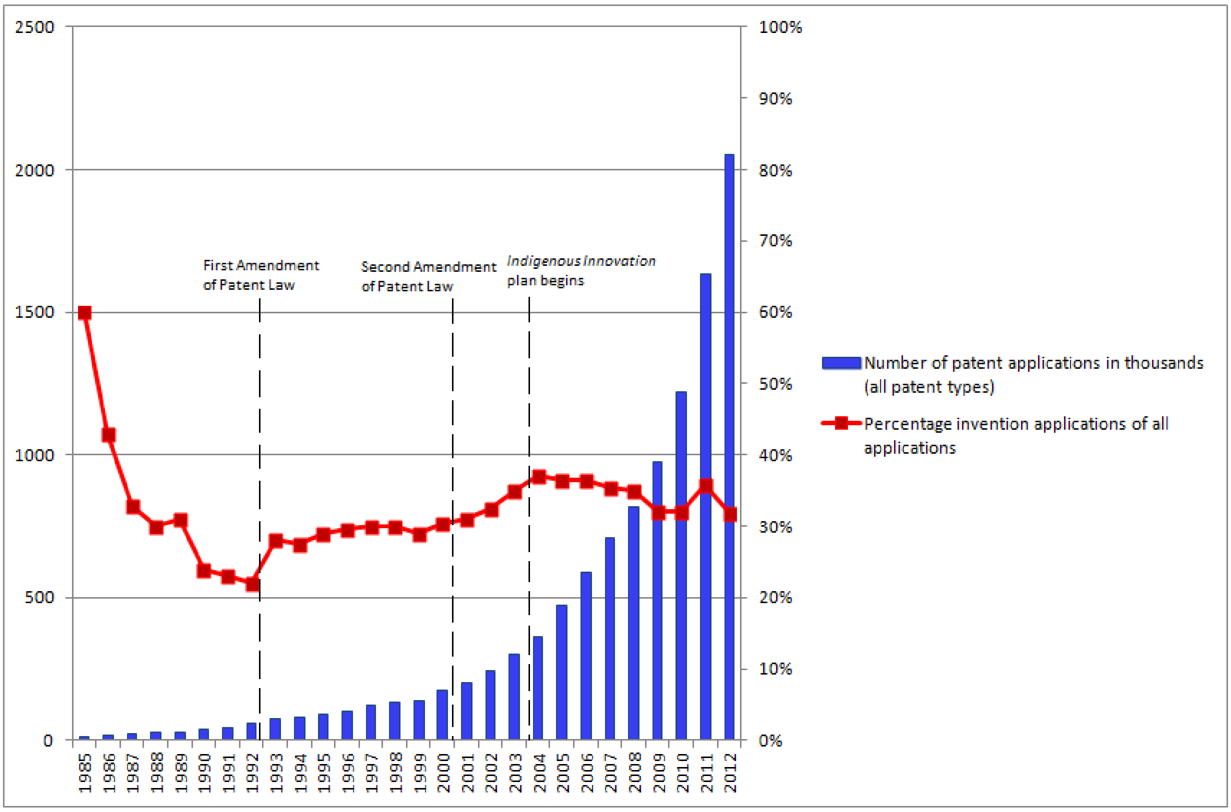


Figure 7: Stages of the development of the Chinese patent system (adapted from Lan and Zheng, 2010; and SIPO, 2010); note the trend of inventive patent applications as a proportion of all patents, in particular since the Indigenous Innovation plan.

The evolution of China's IPR protection model has occurred in part through pressures exerted by other states, in particular via the mechanisms of the World Trade Organisation (WTO). During the Uruguay Round of multilateral trade negotiations (1986–94) for the General Agreement on Tariffs and Trade (GATT, now the WTO), members negotiated the Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS), setting out minimum standards of IP protection for most economies.

Changes to the patent law were made in 1992, when the need for strengthened market reform and critical foreign commentary on the IP system saw the lifetime of invention patents lengthened from fifteen to twenty years, with utility models and designs extended from five to ten years. Providing agreements were made with their employers, individual employees also became permitted to own patents; a rapid rise in overall applications followed (although foreign applications exceeded domestic at the time). The changes in 1992 made food, pharmaceuticals, and chemicals patent-eligible. SIPO allows three forms of patent to be filed: invention patents, utility models, and designs, and there are marked differences between the types. These changes were consolidated in 1993, when inventors were given improved financial incentives. The types of patent differ as follows.

Invention patents are granted for both products (goods and services) and processes, and must meet a *novelty* standard (and be unknown to the public in China or elsewhere before filing). They must also show a standard of both *inventiveness* and *practical use*. Their award requires a detailed substantive examination. If maintained, they give maximum 20 years' protection.

Utility models can be awarded for a product's shape and/or structure. They do not require substantive examination, and although they need to be novel they require a lower "inventiveness" threshold, being required to show "practical use" or "functionality". This means they may simply improve product functions without offering a truly new solution. With less inventiveness, they also have shorter lifecycles. They generally take 8 to 12 months to be granted, receiving only 10 years' maximum protection if maintained, and give broadly the same legal rights as invention patents (before the 1992 amendments mentioned above, "invention" patent rights had 15 years' protection, while utility models had 5 years').

Finally, registered designs are granted for the aspects of a product's appearance that make it recognisable. They need no substantive examination, nor need to meet technical or functional standards, and must only be distinct from previous designs while not conflicting with others' rights. These receive maximum 10 years' protection if maintained.

Unlike China, most countries only consider the "invention" type worthy of being called a patent. Only forty countries use utility models, and fewer still have designs (Kardam, 2007). The rationale for this is that China's IP system, unlike that of the United States for example, was established with the intention of facilitating the *diffusion* of new technologies (Lan and Zheng, 2010), hence the use of design and utility models, their relatively short protection periods, and the use of the "first-to-file" (instead of "first-to-invent") principle of protection. The period 1992 to 2000 saw the strong growth of invention applications, more than tripling from 14,409 to 51,747. Utility model applications grew more slowly, from 44,369 to 68,815, while designs grew most rapidly, from 8,357 to 50,120. However, while utility applications fell from 66.99% to 40.32% of the total, invention applications have remained a minority, increasing from 12.45% to 29.36% of total patents (Lan and Zheng, 2010).

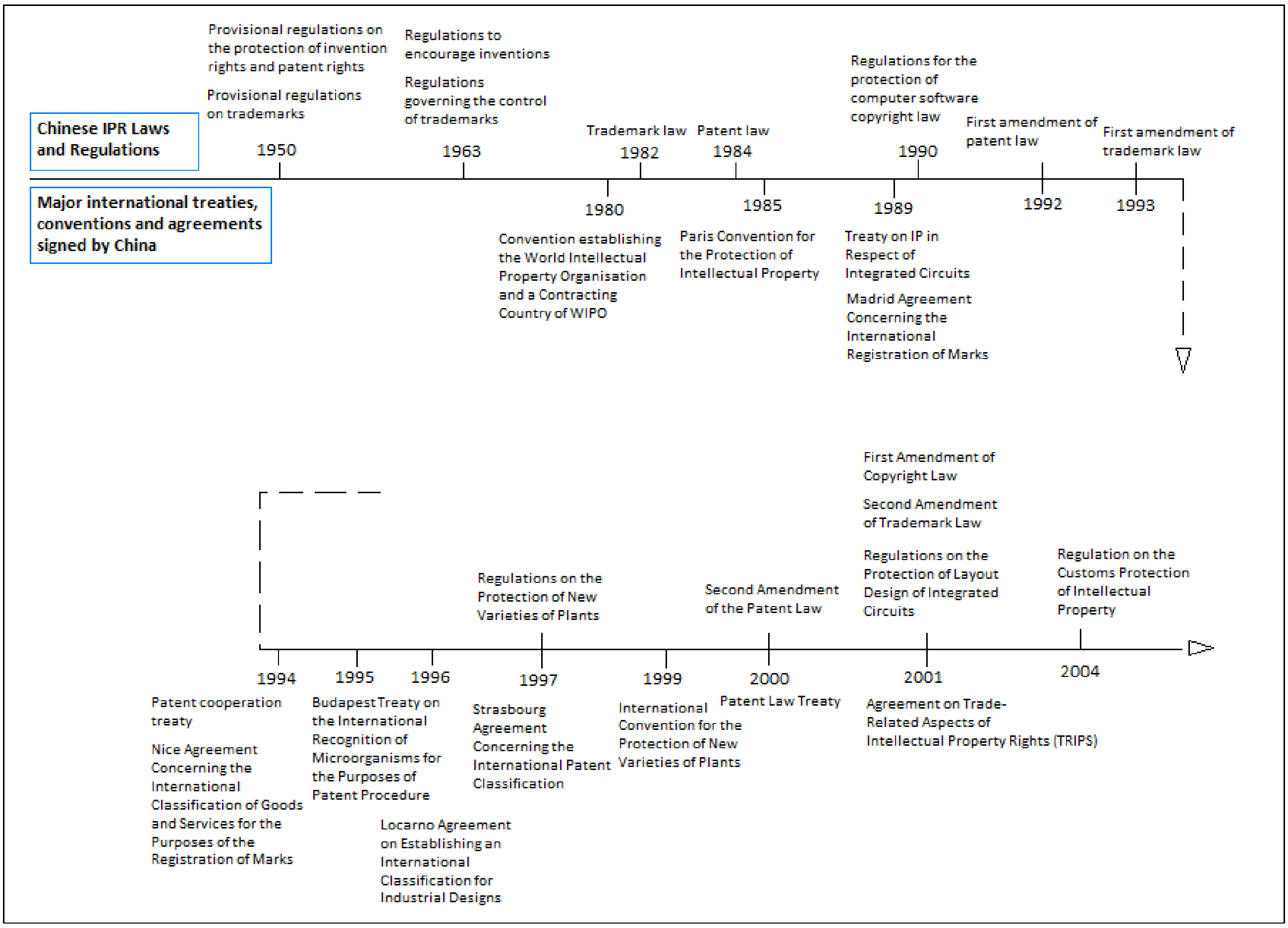


Figure 8: Timeline of China's major intellectual property rights (IPR) laws and regulations (to 2005) (adapted from Lan and Zheng, 2010; Dimitrov, 2009)

With SIPO and MOST both responsible for IPR, the area is dealt with at a very high strategic level (Kong, 2005). Patent law renewal was included in the State Council's first *National IP Strategy* (2008), which led to the *National Patent Development Strategy (2011-2020)* by SIPO in 2010, then the *Promotion Plan for the Implementation of the National Intellectual Property Strategy,* 2012. These have been referred to collectively as the "*2012 National IP Strategy*". SIPO and the State Council stated the revisions would promote "indigenous innovation", part of a broader initiative to develop domestic IP by accelerating China's own innovative capacity.

Patent granting and a relatively new enforcement system have seen various problems arise however. A developed system should have enforcement that is "consistent, transparent, and procedurally fair" (Dimitrov, 2009, 6). Yet instead of seeing the state as enforcing laws directly, it is useful to understand that it creates and maintains institutions to enforce when necessary (Dimitrov, 2009). Three enforcement channels exist: civil law courts, administrative agencies, and the criminal justice system (although the Customs Administration also provides some border enforcement, making IP a rare form of property protected through all four channels, giving a particularly comprehensive insight into state activities).

Considering the relative youth of the Chinese system, development has been rapid, with the quality, cost and timeliness of (invention) patents comparing well globally, while enforcement is "cheaper and faster" than in most developed countries (UK Intellectual Property Institute, 2010). Courts, including the highest, the IP Tribunal of the Supreme (Appeal) Court, hand down "some very sophisticated judgements", although ability to enforce "varies in different localities in China" (UK Intellectual Property Institute, 2010). However the quality of first level courts varies: 60% of their 1000 judges have no IP training (as such Beijing has encouraged foreign firms to use the IP Tribunal of the Supreme (Appeal) Court). Domestic firms invariably have to use local courts, however, and corruption remains problematic, especially in less developed provinces, as is the political independence of the judicial system. Appeals meanwhile are costly and courts do not yet award the damages that would justify them. Interviewees have raised cases where powerful local firms, usually SOEs, hold sway over local courts (on which more detail below).

However, as domestic firms' IP registration has increased, these firms appear to be pushing government to strengthen the IP regime. According to the Chinese Supreme Court, in 2005 over 16,000 civil cases and 3,500 criminal cases related to IPR violations were handled by Chinese courts, with over 2,900 people jailed (Kshetri, 2009). Cases involving IPR protection rose 21% that year, with 95% of China's IPR cases brought by Chinese firms.

Yet firms using the enforcement system have raised particular concerns about three of its aspects: insufficient compensation, high requirements for obtaining injunctions (to stop production of infringing goods), and difficulty enforcing awards. Firms claim it is hard to obtain damages sufficient to provide deterrents: a ceiling of around RMB 1m exists in practice (Atkinson, 2012). Without evidence discovery, evidence preservation orders are the method whereby firms prosecuting IP infringers may gain evidence. However, if a defendant does not co-operate with a court imposing an evidence preservation order, there seems little IP owners can do (Atkinson, 2012). According to the OECD, "failure to follow a court order is not regarded as a crime, and few penalties exist for non-enforcement… It is not worthwhile to pursue every [IPR] case, as the amount of compensation relative to the damage incurred and the costs involved may not justify pursuing juridical enforcement... In addition, there is a chance that even when the case is successfully pursued, the pirates may close down a "busted firm" and open a new "firm" and continue in the same vein." (OECD, 2008, in Lan and Zheng, 2010, 90).

Meanwhile, a number of patent litigation cases have been brought by domestic against foreign companies, with some apparently involving patents *filed with the intent of use for litigation*. Sources suggest over 50% of patents filed at SIPO are of foreign innovations, "with the sole intention of suing the same for patent infringement" (Atkinson, 2012, 37). Reports describe the role of the utility model in this emerging problem. For our purposes, this may also create domestic-to-domestic conflicts, exacerbating any politico-economic-related patenting problems. Indeed, interviewees state that in provinces with more SOE-dominated economies, judicial independence is more commonly compromised. This is hard to avoid, as "the reality is that you have to pursue your counterparty in the local court of its home jurisdiction" (Townsend, M., interview, 2011). Although the "traditional problem" of provincial court corruption is becoming less severe "the further up you go in the court system", higher up cases become political, often being bracketed as a "social stability" question, by which actors can use a place in the broader state system to avoid prosecution for infringement (Duke, interview, 2012). This "institutional location" may also influence whether the managers of the firm feel they should register their IP with SIPO in the first place, which depends on whether they feel able to protect it from infringement by firms which are more favoured by the state.

The specifics of the patenting and enforcement system have led to varying patterns of use by patent-registering firms, and the system appears to have marked interplays with, and impacts on, firm innovation behaviour. China is simultaneously "one of the largest IPR pirates in the world", while "no country in the world devotes as many resources to IPR enforcement as China" (Dimitrov, 2009, 17) (who adds that as IP in China represents an especially complex case, it, "allows us to get a deeper grasp of state capacity" in general)[13]. An alteration to Article 9 of *Implementing Rules of the Patent Law* (January 2010) stated that if a patent application "may relate to the security or vital interest of the State and is required to be kept secret" (Prud'homme, 2012, 15), it may not be published even if approved by SIPO, or filed abroad. This ambiguity means a wide range of patents might be blocked (Prud'homme, 2012), with the information they contain remaining in state hands. This helps highlight the nature of China's simultaneous promotion of the concept of IP to and by domestic firms, the IP-related pathologies that we suggest the Chinese state creates, and the environment in which private firms and shareholders must compete.

3.4.2 Patent Quality Trends

According to the World Intellectual Property Office (WIPO), China became the world's leading patent filer in 2011, overtaking US and Japanese domestic filings. Yet sources have questioned how much this represents a comparable increase in what would be seen as patent-quality material in developed countries, and whether a largely quantitative increase is being spurred by rewards for patenting. In particular, there appears to be a role for utility and design models in the increase.

Socioeconomic factors such as a growing educated workforce may have driven some patenting. Yet China has constructed a range of "quantitative patent targets" which despite their ambition may not encourage quality - or spur innovation - as intended (Prud'homme, 2012). Indeed these may actually discourage highest-quality patenting, and at worst actually encourage development and filing of low-quality patents (Prud'homme, 2012). Some scholars have stated utility models have become less popular than others (Huang, 2013), but in 2010 and 2011, domestic filings of utility models exceeded invention patents, *against* the previous decade when invention patents had steadily overtaken utility models (Prud'homme, 2012). This happened despite the invention patent examination period having been reduced from 53 months to less than half in 2010. Thus a disproportionate growth of low quality patenting seems to be underway. By 2009, Chinese nationals filed 877,611, nearly 90%, of the 976,686 patent applications to SIPO; of these, 230,000 were invention patents, with utility patents numbering 308,861 and design patents 339,654 (SIPO, 2010). Thus almost three quarters of patent filings fell in the "junk" class. One Beijing-based IP lawyer stated: "the government targets deprive firms of an incentive to really innovate", and another claimed: "the utility aspect is making the junk patent problem worse. If you subsidise people they will register rubbish" (interview data, September, 2012).

Chinese patents also show relatively low patent citation scores (one of the quantitative indicators of quality we will analyse), compared to developed world filings, as filing targets that seem to be driving filings may be overshadowing the "nuances underlying creativity", seen as the foundation of the innovation that creates quality patents (and ultimately innovation-led growth), as most scholars agree

[13] Dimitrov (2009) also adds that studies "typically examine only one subtype of intellectual property rights", instead, for instance, of the implications of the IP system on the innovative development of firms.

that the innovation that leads to the highest-quality patents is usually achieved after the right inputs "in the mid- to long-term" (Prud'homme, 2012). However domestic filers' invention patents appear to be falling proportionally, and utility models rising, with utility filings set to further exceed inventions.

Scepticism is growing about how much innovation underlies broad patenting growth. Chinese patent examiners are paid more if they approve more patents, and generosity of incentives for patent-filing may make it "worthwhile for companies and individuals to patent even worthless ideas" (*The Economist*, October 2010). Meanwhile, the reward system for firms to patent appears developed and precise. Subsidy programmes reward patenting predominantly by paying lawyer and patent filing fees; the main reward schemes being the *Patent Gold Award* (varying slightly between provinces), the *Patent Excellence Award*, the *China Patent Leader Award*, and the *China Technology Patent Award*. Reforms are underway (such as requiring firms to have patents granted before receiving rewards, instead of needing only to apply), although few qualifying requirements for these subsidies have existed until now. Theoretically, any firm can benefit from the patent subsidy system, but although rewards are not open exclusively to state-owned enterprises (and a specific SME Technical Development Fund for IP exists in most provinces), it is "probably easier for SOEs to win these awards" (Prud'homme, interview, 2012). Thus SOEs, whose managers may be under pressure to apply for patents, may also be more strongly incentivised to register them with less regard to actual quality. It should also be taken into account that growing technological competence often denotes improvements in the Chinese context alone (Fai, 2005), while a much stronger test of rising Chinese technological competence would be whether companies have been able to register patents in foreign jurisdictions, especially the USPTO, regarded as having the most stringent technical standards (and we will return to this question in our quantitative analysis).

The ways in which managers who are also cadres in state employ are assessed, and the differences this creates between their choices and the choices of private managers, may be responsible for a good deal of the patent-quality patterns we have described. In other words, the dynamics created by government control of cadres may actually hinder their innovation success, which is one of their main tasks. As discussed in the theoretical literature review, this would mean a monitoring method imposed by principals is hindering the performance of agents due to its creation of inferior incentives to agents in a private principal-agent structure (despite the latter's relative lack of R&D resource).

Meanwhile, the Cathay Industrial Biotech case illustrates the institutional risks for innovation in entirely private firms, demonstrating how China's innovation policy gives investment and legal security to firms with (at least some) ownership by the state. Although, like many scholars, Lan and Zheng (2010, 91) suggest that the "IPR system in China [has faced] the double challenges of meeting the demand of multinational companies which required strong IPR protection while at the same time satisfying domestic companies which favoured an IPR regime conducive to technology transfer and knowledge diffusion", this does not mention the private firms whose interests may lie in a differently administered IPR system.

Bureaucracy may avoid investigating "difficult" IP cases, such as "when counterfeiters are in cahoots with the local government" (Dimitrov, 2009, 21), which means any increase in enforcement may simply result from better enforcement for well-connected firms. This example demonstrates how studies that portray the Chinese state as "weak" or "strong" miss its simultaneous weakness and strength (Dimitrov, 2009), affecting the simultaneous weakness and strength of the innovation system. Associates at a Chinese private equity firm (interview, May 2012) advised: “investors should choose a large market company, not a new market entrant- the latter will be ripped off by the big guys because they have the power… Private companies lack the capacity to protect IP”. These interviewees believed minority state-owned enterprises (MISOEs) may thus be well positioned for innovation, granting both incentivised private management and some state protection.

We have traced how the Chinese state, through its basic political structure and policy framework, has created a legal system and reward system that financially support and reward the IP generation of state firms. This IP generation is “re-incentivised” through apparently advantageous IP protection in the courts, yet greater budgetary cushions and supports are provided that deny these firms as great a commercial incentive as their counterparts with more private shareholding.

3.5 Summary

Understanding the link between ownership structure and firm objective/s can also reveal the logic behind their activities. Comparing firm types reveals how SOE management must live under multiple pressures on their firms’ objectives (Kornai *et al*, 2003). While growing competition at home and abroad demands rapid product improvement capacity, state-owned firms are frequently expected to generate profits, help industrialise the country, develop technology, create jobs, and cut regional inequality. Therefore, although Shleifer and Vishny (1997) argue that the effectiveness of large shareholders’ control is tied to their ability to exercise their control rights, should they control enterprises but give them conflicting tasks, outcomes may be harmed in a given single field, such as innovation.

We will now apply the principal-agent theory we have discussed to the Chinese innovation system, to understand how this system shapes principal-agent relationships, and how these are likely to affect innovation in different types of Chinese firms.

4. Application of theory to the Chinese innovation system

4.1 Applying Principal-Agent Theory in High-Tech Innovating Firms in China

The following subsection will apply the principal-agent theory described above to the Chinese innovation system, analysing what the theory has to say about the working, and outcomes, of the innovation system. Fundamentally, the principal-agent problem we address is one whereby the workings of the principal-agent chain mean what the top principals want to achieve may not happen, because of the desires of other principals, and agents, further down the political chain.

4.1.1 Outline of principals and agents

In different types of emerging economies, the institutional context imposes numerous costs and problems on the enforcement of agency contracts (Young *et al*, 2008). As such we should understand who in the system we have described are the *principals* and who are the *agents*. Rhetorically, the Politburo are the agents of the principal, the "people of China", but in reality this organisation (or its seven-man Standing Committee) is the system's highest *principal* level. These principals sit at the head of a chain (or chains), including the ministries, the State-Owned Assets Supervision and Administration Commission (or SASAC, the official owner of most SOEs under the State Council), and the Organisation Department (essentially the human resource monitoring organisation of state)[14]. The managers of Chinese firms are the *agents*, which in the case of SOEs means managers who are also party member cadres, and answerable to the various principals of the state. In the case of central ownership, they answer to central state principals, and in local they answer to local state principals, who in turn are accountable to principals of the central state. For the agents (managers) of entirely private firms, they are accountable to different private owners (but usually in China the managers of POEs are themselves sole or part-owners); the agent managers of firms of mixed shareholding have a combination of principals to which to be accountable (and again in China they are nominally part of this combination).

The government wants to achieve more successful innovation by the firms it owns, and it does this (as we have seen in Chapter 3) by such actions as providing innovation targets and measures with which to assess firms' achievements, by providing selected firms with investment, and by procuring innovative products from certain preferred firms. In other words, the principals attempt to induce pro-innovation management decisions among agents through a combination of funding, monitoring, assessment, and incentivisation.

The relevant policies of the state (especially the Medium- to Long-Term Plan (MLP)) are thus an expression of concern by the top principals about agent performance, and an attempt to create a more successful innovation environment by bringing about the necessary changes in agent managerial behaviour. However, they do this while maintaining the preferences for state firms that the Party's

[14] These chains are generally several in parallel, for centrally-owned SOEs – ministries, SASAC and the Organisational Department.

top principals deem necessary to maintain their power and economic primacy, in particular in strategic technological industries. We will understand the functioning of this system more clearly by breaking down the system along principal-agent lines, including agent incentivisation, assessment, principal and agent goals, inter-principal conflict, and the effects of the length of the control chain between original principals and agents.

4.1.2 Incentivisation and assessment

The major problems we observe with salaried managers are in shirking, risk avoidance and short-termism; as we have seen, risk avoidance and short-termism are serious problems in relation to innovation. In the previous chapter, the discussion of cadre assessment demonstrated how in some ownership contexts, these salaried managers are largely assessed, and may be rewarded, on the basis of metrics such as financial performance, which can deal with shirking; but largely does not deal with risk avoidance or short-termism.

In the round, the state wants its managers to innovate successfully, but also appears to embed them in a system that cannot provide the necessary long-term incentives for them to make the decisions required. Indeed, we have seen in the way they are assessed they are in some ways actually rewarded for *not* doing so.

The conflicts between longer-term and shorter-term career issues can create mixed and confusing incentives for agents. Scholars have considered that long-term contracts dependent on provision of "additional information on current activities", are more important for managerial contracting than for short-term work, for which "current observations" are sufficient for performance evaluation (Fudenberg, Holmström and Milgrom, 1990), although conclusions drawn from single-period scenarios cannot always be applied to multi-period relationships (Lambert, 1983). The actual forms of assessment in our case (and the monitoring required for them) create various conflicts that hinder state principals' innovation aims. Although the grand innovation aims of the top principals are encapsulated in specific innovation policies, different principals in the chain assess agents for different things, giving agents a variety of goals to meet. In essence, using the example of the western venture capital case we have mentioned, it appears to be more difficult for state-appointed and state-monitored managers to safely invest in research typified by severe informational asymmetry and uncertain outcomes (compared to venture capitalists who are better able to devise mechanisms to reduce risk).

As a shareholder SASAC's role as investor meanwhile is broadly nominal, which gives managers more opportunity for wasteful projects in their own interests (often at investors' expense). Furthermore, although innovation itself is assessed by patenting output, the Organisation Department also assesses agents on a range of other issues, such as "loyalty", and other markers of firm productivity. Meanwhile, using patenting output as a measure for agent assessment is liable to lead to the registration of low quality patents. As such, assessment (a form of monitoring), appears to hinder top principal aims in many respects, with agents given conflicting assessment by different principals in the state principal-agent chain.

Although Schumpeter (1942), described consumer "wants" as guiding choices by "the people who direct business firms", in our context what is prescribed for these managers is not simply by the "wants" of consumers, but by the principals of the Chinese state, including the considerations the party deems useful, which is liable to lead to adverse selection regarding innovation. While standard economic theory also stresses managers responding rationally to "wants", this is limited by the assumption of straightforward "rational" frameworks of action. On this point, it is less likely an agent will apply any "improvement he might discover" for innovation, rather than "any other course" (Babbage, 1835), because of disincentivisation via these assessments. Fama's (1980, 301) discipline by competition "from other firms", creating "devices for efficiently monitoring the performance of the entire team and its individual members" is also lacking in the state model, as agents' activities become skewed towards meeting other the assessments of these other monitoring "devices".

While listing SOEs was one device designed to secure investment, certain unforeseen consequences have arisen in the action of incentives on innovation outcomes. One was the introduction in the Company Law of 2006 of manager stock options. Some had doubted before whether this security would function in the desired manner, and options have not had the predicted significant positive effect on investment in R&D (Li, 2004) (we may speculate that state firms' soft budgets giving continued income have limited their impact). Furthermore, while Chinese Company Law in 2006 allowed the use of stock options, in 2008 SASAC suspended stock option schemes in listed state firms (Caijing Online, 2009), to "strengthen its control" (as we discussed above, stock option schemes were not permitted in wholly- and majority- state-owned firms).[15] This appears now to apply regardless of the level of state with a shareholding (e.g. central, provincial, etc.) (Caijing Online, 2009).

Although a politico-economic environment will ideally allow the assessments and incentives that facilitate innovation, given not only the resource disadvantages that private firms appear to have in China but also the soft budget constraints that allow many SOEs that fail to innovate to continue, combined with the mixed incentives and assessments state ownership creates, technological change in China is likely to be hindered.

4.1.3 Principal-agent conflict

First, to the problems of the principal-agent chain we should add the conflict that is liable to exist between the principals themselves in this multi-principal scenario. As we will see for solar PV, within the state the top principals set innovation targets, but also allow principals lower down, such as in the Organisation Department, to assess agents in ways that are not conducive to their being met (such as the other care assessment metrics we have seen). Furthermore, local vs. central government conflict can occur. Local governments have been told by central government both to raise their own GDP and their tax take, which can make long-term innovation spending burdensome, on the assumption that local government time horizons are shorter than the time to pay-off. Some local governments however will help their innovating firms get access to resources, so the effect for agents of local

[15] This arose because some of these firms began using stock options without asking SASAC's approval; assuming its control had been threatened, SASAC suspended all stock option schemes for listed firms with state ownership (Caijing Online, 2009).

principals in the chain may vary. Innovation can be a good medium-term way of raising GDP, but this is unlikely to mean "blue sky research", which has particularly risky and distant payoffs.

Meanwhile, the principals themselves also exhibit political behaviour problems, which appear as a bureaucracy tries to manage an innovation process that would otherwise be more reliant on the private sphere. This involves Organisation Department principals not allowing agent-managers to remain too long in any single company to stop them "going native", but which also stops them developing a deep technical knowledge of company processes (Da, 2010) – or having the necessary long time horizons. "Though some argue that the nature of those principal–agent problems may differ little depending on whether ownership is public (state) or private'' (Stiglitz, 1994, 30, in Qu, 2003), Qu (2003, 776) thus states that "property rights theory generally suggests that state ownership is inefficient".

Qu (2003, 776) finds the "top priority of government" to be "preserving and increasing the value of state properties", despite it being difficult to verify "which management decisions are actually value-increasing or not". There also exist the short-termist assessments determining the next career posting of an official, and in applying these to technology investment, officials may lack incentives to invest long-term in R&D: "especially in the state-dominated PLCs, most board members and managers are still having a corresponding status of civil service, their remuneration promotions are still relying on the assessments of their superiors in the political and administrative hierarchy". Managers need not worry that bad management will lead to their firm being taken over, as holders of public shares cannot "vote with their feet" (Qu, 2003, 778); this also implies that managers have little incentive for the long-term investments required to stimulate emergence of unexpected types of new knowledge (Edquist and Johnson, 1997), as this is liable to go unnoticed. In other words, the government wants R&D but the long chain may prevent it, through actions such as cadre assessment (and the demands of mixed principals). The relationships in this hierarchy also lead to the particular problems of information asymmetry.

4.1.4 Information asymmetry and moral hazard in the Chinese innovation system

Unlike private venture capitalists at the other extreme, the monitoring principals lack the needed technical expertise discussed. State principals are also likely to have low engagement, given their other responsibilities. These factors create massive potential information asymmetry and resulting moral hazard. Thus in place of expertise and real monitoring ability they use the superficial targets we have described for agents to meet. In reality (suggest scholars including Da, 2010) this may mean spending enough of their (plentiful) state investment on R&D to quickly acquire low quality patents, while also spending on IP licenses, and bundled technology, plus turnkey equipment, for rapid new products and processes. For agent-cadres, a bonus leading to the innovative output principals desire would have to involve a long-term payoff, but it may be more "rational" for cadres as individuals to focus on the short-term benefits to their state career. Chinese cadres also face a problem of diluted responsibility, knowing that a single business unit will have little impact on overall state innovation goals.

If incentives remain unaligned, delegation itself remains problematic, because of the existence of different objectives (as we described in Arrow, 1963a). The problem here is not simply the concern about what the agent's incentive may be, but how an agent's incentive to drive innovation can be aligned with their other incentives (e.g. to maintain employment) in SOEs, compared to the incentives for managers who only have to answer to private, commercially-focused principals. This implies that adding principals (creating a multi-principal situation) through private shareholding (or foreign private shareholding) may actually simplify incentives if the private/foreign shareholder, and reduces the impact of the superfluous goals set by the state.

The very existence of moral hazard may imply that giving agents incentives gives only limited correction for information asymmetry problems. Studies have thus replaced incentives with coercive systems of rules and supervision (again in insurance, Spence and Zeckhauser (1971) showed how incentives only *reduce* moral hazard). By implication, without constant agent monitoring ability, strong incentives will be needed. Essentially the Chinese state tries, via the Organisation Department's cadre promotion mechanisms, to do both, but does so via monitoring performance for a range of conflicting achievements: demanding R&D but assessing short-term outputs (like new production facilities), and seeking creative destruction technologically but demanding a mindset which is loyal to the party.

We saw (in section 2.4.4) that what incentives managers have to carry out R&D do not necessarily take into account that these investments are often long-term. The particular version of this phenomenon in China is that the grading of managers by the state along numerous other metrics is likely to create disincentives to carry out R&D. Furthermore, in China the state creates innovation incentives such as patent metrics that may distract from proper long-term R&D horizons, such that the very act of trying to close the informational asymmetry gap creates a problem for the direction of R&D investment.

As we have seen, private ownership does not generally attempt to operate the same way: for example, the "directors of a firm clearly specify to the CEO that they expect profits—but they do not constrain the CEO by specifying a particular procedure" (Miller, 2005, 215), which would constrain the CEO's profit-oriented work, and require "constant monitoring". It is the market that is expected to discipline managers (which also, ideally, applies to rewarding R&D spending in new product markets). The Chinese state however urges tech firms to innovate, then constrains agents' actions by ranking them on such markers as indigenous IP registrations, including utility patents. These incentives are an attempt to overcome informational asymmetry by directing agent actions, but may skew the direction of effort towards low quality innovation. It has been stated that this "procedural-control" argument "represents a discontinuity with [principal-agency theory], rather than a simple extension of it" (Miller, 2005, 215), but it can be seen as an attempt to deal with the principal-agent problem itself.

4.1.5 The divergence of our case from classical theory

At this point it is worth referring back to Miller (2005), to see how our case differs from the classical theoretical norms he has described. Regarding information asymmetry, state principals may not be able to observe outcomes (or agent actions), which involve long-term innovation output, so they cannot reward agents accordingly. As for *initiative being with a unified principal*, we have another problem. The principal's preferences may not allow them to act rationally for innovation- the state is not unified, but consists of different groups with different aims, the aims of the Organisation Department, being different to those of SASAC. *Backward induction based on common knowledge* is also very doubtful, with the state simply having too many agents to monitor (however, as we will discuss, smaller numbers of agents may be found at lower, local levels of government, allowing better knowledge of firms' innovation). But if the state lacks this knowledge of agent response function, the state principal must also lack a swathe of *bargaining power*. Regarding "results", it is precisely the first result that demonstrates that attempting to impose *outcome-based incentives* for firms' innovation may not overcome moral hazard problems. Demanding innovation from (short-termist) cadres may lead them to simply buy the latest equipment, not make long-term investment from which they personally will not benefit. Thus the agents resist risk being transferred to them. Outcome-based bonuses to control the *efficiency tradeoff* are thus hard to secure, and judging firms by patent output to achieve this may lead to lower grade patenting.

Here we should also refer back to Smith, in asking whether principals – the masters he described – actually have most of the bargaining power in our case. Just as performance-related pay has been discussed in classical contexts, principals try to promote agents according to achievement, but this creates problems in their behaviour that differ to those found in previous contexts.

While our context differs, it also suggests that principals have difficulty directing agent behaviour. We saw that Holmström's (1979) "informativeness" solution required contracts covering "relative performance evaluation", measured against other similar agents, but in our context the "noise" effects in cadre evaluation, in the other performance areas demanded of them, are liable to be severe. Many assume "classical forms of economic behaviour on the part of agents within the firm" (Fama, 1980, 301), but we deal with agents in a more complex career situation.

Principal-agent theory allows powerful insights into how a particular economic system actually functions, and offers a correction to neoclassical economic models for our case. Scholars have hypothesised that the market will help innovation through companies orienting themselves to consumer choice: we discussed Schumpeter (1911, 41), who foresaw a "decentralisation of power to consumers", whereby "people who direct business firms [execute] what is prescribed for them by wants", because "individuals have influence [as] consumers". Yet we have seen that the efficient market system that enforces competition between agents is often severely hindered by the apparatus of state. These ownership structures will dictate just how much any given principal gains from the success of agents below him, or how much an agent gains from his firm's success under his management. As we discussed (in section 2.4.4), In the nexus of state management, Fama's (1980, 301) insight, that "in the team… each manager is concerned with the performance of managers above and below him since his marginal product is likely to be a positive function of theirs", is dependent on how strongly particular aspects of "success" *can be* rewarded, and how much one firm affects the success that a "shareholder" seeks.

4.1.6 Ownership, governance and innovation in different Chinese enterprise types

At this stage we should consider how the range of different forms of ownership affect corporate governance, and in doing so impact R&D in Chinese firms. We will consider the main principal-agent phenomena that we have described, and suggest their application to the broad Chinese ownerships types.

Comparable enquiries have been pursued in other non-Chinese contexts, with authors connecting R&D and patenting to corporate governance, and ultimately to principal-agent questions. We have referred to Driver and Coelho Guedes (2012, 1575), who investigated corporate governance and ownership effects on R&D. Their evidence suggested that greater governance reduces R&D activity, although a CEO ownership stake (giving CEOs "skin in the game") supported it, to which we shall return. Their evidence for the negative effect of high governance on R&D contradicts the "good governance" view, but supports "the importance of managerial security and autonomy" in sustaining potentially hazardous investments: firms with strong governance may ration R&D expenditure to increase dividends, or divert spending to projects with faster payback, while large institutional holdings also appear to hinder R&D. The phenomena that may be at work in this context – the impact of risk aversion and particularly short-termism – were considered by scholars we have also discussed.

As well as beginning the formal study of labour relations in general, Smith for example noted that managers may neglect attending to the requirements of principals, "because in the one case they get the whole profits for themselves" (Smith, 1776, 277). Managers are liable to invest with an eye to their own advancement, and therefore to the *appearance* of actions beneficial to the principals; "being the managers rather of other people's money than of their own, it cannot be well expected, that they should watch over it with the same anxious vigilance" (Smith, 1776, 124), in other words they are likely to consider their own gains first. His suggestion of "performance measurement", is a reaction that governance can increase. However this may simply skew performance towards risk-averse and short-termist choices by managers that appear useful to principals.

According to the theory, risk-aversion and short-termism are two of the major factors affecting investment decisions. For any manager to invest in R&D requires a risk, in that this money will take a considerable time to create any noticeable result, if any, which means this investment could be made elsewhere to more immediate gain for a manager – either in financial return, or success that is immediately visible to a principal. Thus risk-aversion and short-termism are closely connected. Firms in China, but also elsewhere, thus follow short-term horizons, which can harm long-run R&D projects. Although studies of the determinants of R&D expenditure are still relatively rare, questions this has raised about the effects of corporate governance and finance on innovation have led authors to use principal-agent theory to test what channels of influence exist from corporate governance to R&D spending.

It therefore follows that, in China, investments in R&D will be more successful in the corporate governance situations where managers, first, have an incentive to make them at all, and to invest in innovation over the long-term (rather than for apparent short-term "display") such as benefitting by reimbursement or reputation. Further, investments will be more successful when principals will benefit from the innovative success of a single firm, requiring both some level of technological expertise (for successful, qualitative monitoring), and presumably being able to focus on the monitoring of a smaller number of firms, instead of a huge spread. These factors for agents and managers can express themselves in different forms.

Managers need to see that the legal environment will make such investments worthwhile, by allowing them to protect any patents that arise (Driver and Coelho Guedes (2012) described a theory of investment under uncertainty where signals for profitable investment are given when the marginal addition to “firm values accruing from the investment” is above incremental cost: in other words managers need to know they can reap gains from investments).

Managers as we have seen also need the prospect not just of protection for innovation, but of reward: otherwise they are liable to spend money on projects that give more immediate personal gain. While managers may wish to use resources productively, agency problems see them often lacking the incentives for these resources’ efficient deployment. Li and Xia (2008) found that resources are frequently used instead for “empire building”.

Meanwhile, the problem of principals with a lack of technological expertise leads to adverse selection in innovation. China experiences clear cases of this problem (as distinct from moral hazard), and it is one that is best revealed through understanding the actions of venture capitalists (VCs). If funders are ignorant of the technology or at least the more advanced technologies in an industry, high information asymmetry with respect to “technology-intensive” firms exists. Should they choose to invest in firms planning to make money out of advanced technologies in the industry, they may be unable to tell good from bad (we assume that the agents – prospective managers – can). Here we should start to consider how different types of ownership among Chinese firms affects information asymmetry, risk-aversion and short-termism in particular.

In the information asymmetry above, in some cases *state* investors may not be concerned, because with soft budgets the main question is to fund well-connected state-owned or state-backed firms (which they know will have better survival prospects). In this case they may fund mainly poorer technology-intensive firms, while the better ones are acquired by foreign VCs, which are more concerned with recognising their quality and will thus offer a better deal. (Sometimes state-owned VCs may “piggy back” on the foreign VCs, leading to MISOE ownership as opposed to pure private.)

In other cases they may need to make income more urgently, leading to the choice of “technology-light” firms: “trying to be first to market with a certain business model or service new to China or at least slightly differentiated from what was already on the market… [or] start-ups trying to survive by taking advantage of connections to the state to feed at the trough of state procurement” (Fuller, 2008, 21). Either option leaves relatively little innovation, or patenting, even if in the first case there may be a lot of R&D. Fuller (2008, 22) has carried out research in IT-related start-ups, which found that among foreign VCs’ investments, a higher proportion were technology-intensive investments than among domestic VCs. In fact, almost all the tech-intensive investments done by the latter (16 out of 18) were done through “piggy backing” on the foreign VCs. This is to say that lacking the means to reduce informational asymmetry themselves, state investors rely on combining with domestic private and/or foreign investors.

In the western context, various scholars’ work suggests no firm conclusion about whether more principal involvement is beneficial for R&D (Lhuillery (2011) finds that principals involved in governance had a positive impact on R&D intensity; Kor (2006) found that outsider investors had no effect on either R&D intensity, and Baysinger *et al* (1991) found negative relationships). In China however, the most important difference appears to be the short-termism that *some* types of principal involvement, and oversight, can create.

As we have seen, with state ownership, a principal being composed in theory of the entire Chinese people means a principal with extremely poor monitoring ability. We have seen that their more immediate monitoring principal, SASAC, has a very limited, if not entirely nominal, place as investor, and instead managers must keep in mind the assessments of the Organisation Department. Instead of allowing the longer-term investments required for successful R&D, the Organisation Department often cycles managers between SOEs over short periods of time, meaning they are more incentivised to buy in equipment that is immediately visible to the principals who assess them (creating Freeman's "technology dependency" described above), or pursue quantitative patenting strategies, which may mean applying for numerous lower-value utility patents. Accordingly, Zhang (1998, 232) finds that as "ultimate shareholder of most Chinese listed companies", the state creates ineffective corporate governance and "unsatisfactory corporate performance". According to Wei and Geng (2008), SOEs' performance falls below government expectations, with their facilities and technology "out-of-date" even by 2008, suggesting their R&D spending and/or its direction has been sub-optimal. (Although Li and Xia (2008) do not have an R&D or patent focus, they state that since reforms began, SOE managers have gained autonomy through decentralised control, but to continue obtaining state resources, they pursue government-mandated goals, as SOE managers are also government officials.)

Thus state ownership, as we have seen, may provide superior resources in some cases, but hinders successful R&D by creating short-termist goals among its agent-managers. Meanwhile private firms often have managers with strong personal incentives for successful R&D investment, but lacking other investment they must often rely on resources, especially finance, from a network of family and friends (Li and Xia, 2008), while they also lack the legal protections for innovations that are enjoyed by state-owned firms. This leads us to suggest that hybrid ownership, combining some state and private shareholding, will allow management to benefit from private incentives, without the state control over agent assessment that creates short-termist investment choices around R&D (particularly if state shareholding is in the minority), but with both the legal protections and resource provision of state ownership. The remaining question is around the impacts of shareholding by different levels of the state, being central or sub-central government.

Wang (2005, 149) finds that some research suggests "that the state's retained shareholdings in listed firms have been responsible for their poor profitability. However, these studies have shortcomings as they fail to properly identify and distinguish among the *different types of owners*" (my italics). Another study, by Chen *et al* (2009), also analyses the efficiency of state and private holdings of listed firms by subdividing ownership by the state into its various agencies. This shows how "operating efficiency [varies by] type of controlling shareholders. SOECG [central government-affiliated] controlled firms perform best and SAMB [the State-owned Assets Management Bureau, i.e. SASAC's predecessor] and private controlled firms perform worst. SOELG [local government-affiliated] controlled firms are in the middle" (Chen *et al*, 2009, 171). This admittedly outdated subdivision of state-owned enterprises demonstrated that different ownership levels within the state generate (or help to generate) divergent levels of "performance". We should note however that this study and others deal with "operating efficiency" (referring to labour productivity), and as the "SOECGs" are provided with large supplies of cheap capital, unlike private firms, they will more easily register high labour productivity. In terms of the success of R&D investment in creating innovation meanwhile, more local state ownership is likely to allow better oversight, with principals responsible for fewer firms, meaning they will be more concerned by any given firm's ability to sell innovative product, and better able to monitor agents' R&D investments, plus increasing agents' concern for their reputation in a smaller locality.

We have brought together examples of how the standard principal-agent theory is lacking for our context, and how China's state structure creates very particular principal-agent and moral hazard problems. Conversely, and as we saw in our discussion of the levels of government above, the further away from central state majority ownership one goes, the smaller the investment sums available appear to be, but with reduced moral hazard, and less muddled aims among agents. The implication is that the incentives of management can be better aligned with pro-innovation decisions.

In summary, we have seen how state ownership seems likely to grant more resource to firms for innovation, but concurrently the monitoring and incentive system for example may also harm incentives for them to innovate; private ownership however is liable to do the reverse, while also presenting privately owned firms with a risk of having their IP infringed, given that they lack the same protection as state firms. We have also covered the difference in the principal-agent relations between central and local levels of the state. Meanwhile it appears that some combination of state and private management may be to the advantage of innovation.

Having begun by outlining the accepted premises of principal-agent theory, we applied the theory first to high-tech innovation in general, then having described China's innovation system, applied theory to high-tech innovating firms in China, demonstrating the areas of better and worse fit for our context. This subsection has explained how we are adapting standard principal-agent theory to a non-western, state-led, multi-principal innovation environment. As we are employing patenting as a metric with which to assess Chinese firms, we now discuss the use of patenting and R&D data in such studies.

4.2 Discussion of patent studies

4.2.1 Rationale for the study of patents

In the following section we will explain the aims behind the study of patents and firms' patenting in general, how patents and collections of patents can be valued, the connections between both R&D and patenting and litigation and patenting, and what patent studies can tells us about the relative technological abilities of firms. For despite what Nesta and Saviotti (2004) call a general awareness of the increasingly important position of knowledge in development (following Schumpeter, 1911), economics has a comparatively limited range of "analytical tools" for the systematic analysis of the dynamics of knowledge creation and utilisation (Nesta and Saviotti, 2004).

Patents have thus come into common use in judging specific instances of innovation, but also as indicators of innovative ability within organisations. Thus patent data provides a resource for analysing technological change, and can be used to study more long-run, between-firm differences in inventive activity. This can be in tandem with, or should it be lacking, as a substitute for, R&D information (Griliches *et al*, 1986). One may, for example, use firms' patenting distribution (by technological field) to establish their position in a "technological space". As we will discuss, various lines of inquiry have also asked how to assess the value of patents, then what they may tell us about the capabilities of patent-registering firms.

The study of patents is driven by the broad desire to find indicators of innovative activity, and Griliches (1986) describes a patent as a "minimal quantum of invention", as approved by a patent office, which indicates "a non-negligible expectation" about the marketability of an invention; the limitation of course is that not all inventions can be patented, because some may not be made public, while there are huge quality variations within patenting. This has led to much debate about how to value patents themselves (as we will discuss below).

Schmookler (1952) used patents as an index of inventive "activity", being an index of input, rather than inventive output. Like Solow, Schmookler saw the study of patenting as part of the study of drivers of economic growth (Griliches, 1990), but adopted a narrow interpretation of inventive activity, excluding research, which he considered to be the search for new *knowledge* generally. He also excluded development, which he saw as the refinement of existing inventions. In other words, the study of patenting as an R&D indicator has since broadened considerably from Schmookler's input definition, or "work specifically directed towards the formulation of the essential properties of a novel product or process" (Schmookler, 1966, 8) (yet we should recall that R&D and technical workforce statistics as alternative input indicators were very limited before the 1950s).

Broadly, patents have steadily become used as measures of general technological change in an economy, and of innovative capacity within specific firms (and of the connection between the two). Studies have for example used patents as technical change indicators and related them to sales in firms (e.g. Comanor and Scherer, 1969). This study related pharmaceutical patents both to number of new chemical entities and to all new products introduced by different firms in the following years, finding a closer relationship between patent applications (instead of grants) with all new products (instead of just number of chemical entities). Other early examples include Scherer (1965a), who demonstrated a relationship between patenting rates and profitability in a cross-section of companies. Although patents cannot represent all inventions (von Graevenitz, Wagner and Harhoff, 2011), patents have been found to be a useful proxy of innovative output at multiple levels over time, with citations also found to correlate to a useful degree with actual knowledge flow (Hall, Jaffe, and Trajtenberg, 2000). They also suggested that studies now need to go deeper, but also wider, for example analysing past practice using such sources as USPTO data (for depth), then linking to other sources (for width), which our study does.

Broadly, there are now two main quantitative data sources in innovation studies, R&D expenditure and patents, with R&D usually seen as a proxy indicator for input, with patents used as a proxy of technological output, although their merits as proxies have been debated. The use of patents has been criticised on the grounds that changing motives for patent applications over time may affect rates of patent applications (Fai, 2005), because of varying patenting propensity between firms and across industries, and variation between jurisdictions in the quality requirements for patent registration. That Schumpeter regarded invention simply as an idea or knowledge preceding product development has also caused some critics to suggest that patents only capture the former (Fai, 2005). We follow Fai's view, that as long as the "pattern of knowledge requirements" reflects a real underlying pattern of technological capabilities, patents can be used as a proxy for underlying realities of technological change, not simply as a crude measure of "inventions", meaning motivations for patent application become irrelevant. Also, if just one national system is employed for comparison between patent-registering firms or other entities, the potential problem of differences in patent standards between jurisdictions is very much reduced.

Patent data is also increasingly commonly used to study national competitiveness, constructing technology advantage indexes and analysing the global locations of inventive activity for various industries (e.g. Dosi, Pavitt and Soete, 1990); patents have also been used by economic historians to analyse regional economic growth patterns (Griliches, 1990). In particular, a significant independent effect by patents on firms' market value has been established (e.g. Griliches, 1981). It is to valuing these patents specifically that we now turn.

4.2.2 Approaches to patent valuation

It is important to understand the background to valuing patents in order to build our own method. Studies in the 1950s continued to try to establish patent values for companies, or as Griliches (1981) put it, the average value of the inventions represented by patents. One of the early sources of data on this area was through surveying patent owners, in particular the 1957 survey by Barkev, Sanders and associates at the Patent and Trademarks Foundation (US). The authors conducted a 1957 postal survey of the owners and assignees of a 2% sample of all the patents issued in 1938, 1948, and 1952, with two major findings: first, the majority of all sampled patents had been "used" commercially (at the time or in the past), at over 55% of respondents (the percentage in use was higher for small firms, although so too was rate of non-response). This contradicted the idea that most patents were not used, or not connected to notable innovation.

Discussion of how to establish the value of patents for firms was continued by Nordhaus (1967), in analysing observable and latent patent value. The use of patent renewal information to establish patent value was pioneered by Pakes (1986), and Lanjouw, Pakes and Putnam (1998), and backward citations have been used since Carpenter *et al* (1980): the former refers to patents being renewed as an indication of their usefulness to the owner, and the latter to other patents cited in the application, demonstrating that it draws on other innovations. Backward citations are also seen as a way of assessing patents' technical novelty: Carpenter *et al* (1980) for example found that references to scientific literature correlate to patent value. Questions of patent breadth, and their impact on patent value were introduced by Klemperer (1990) and Gilbert and Shapiro (1990). Breadth of a patent has been used by Lerner (1994) and others, who showed how the value of American biotechnology firms rises with patent scope (measured by number of IPCs, or International Patent Classifications, the technological fields a patent covers). The next stage was the discussion of patents' inventiveness in the form of "technical non-obviousness", by Greene and Scotchmer (1995), followed by Gallini (1992), who found that a good deal of patent value could be determined by the difficulty of "inventing around" the patent.

A range of other valuation methods have been introduced, such as forward citations, by which later applications cite the patent, suggesting that it is genuinely useful innovation (since Trajtenberg, 1990), patent scope (or the technological area it claims to cover, since Lerner, 1994), and family size (Putnam, 1996 and Lanjouw and Schankerman, 2004), while number of claims (i.e. the technical extent of the protection sought by the application (Tong and Frame, 1992)), are also employed in patent value studies. Less commonly the legal arguments used in a patent application have also been used (by Lanjouw and Schankerman, 2004, and Harhoff *et al,* 1999). Although related to non-obviousness, Greene and Scotchmer (1995) first used the term "novelty" in an economic context, taking the degree of novelty needed to meet the requirements to receive a patent as determining patents' value for holders (Reitzig, 2003).

It now also seems clear that the "difficulty to invent around" also affects patent value, given that patents are intended to block competitors' research (i.e. minor improvements to a previous patent imply a patent is easier to invent around). In discussing "disclosure", Greene and Scotchmer (1995) introduced another value parameter. They assume that disclosing technical information gives competitors information, which may mean inventors choose secrecy instead of patenting. However, it may be that the confidence needed to disclose demonstrates a genuine innovative lead. In the round, there is no official measure of patent value, although these general parameters are seen as being useful, and inform our own choice of parameters.

For firms themselves, Pakes's (1986) paper also suggests that firms will apply for patents early in the process of invention, a point at which uncertainty around returns is severe: thus patenting firms later gain more information on patents' real value. Most end up being of little value, although the occasional winners still justify the investments needed to launch them. Indeed, Griliches (1998) also finds that the majority of individual patents have little value, and that most "inventiveness" comes from a small proportion of the most valuable patents. This means the ability to find (and to generate) genuine inventiveness is what counts among the mass of patents. Although Griliches (1981) finds this leads to relatively pessimistic implications for using overall patent counts as indicators of *short-run* changes in the output that comes from R&D input, the implication for this thesis is that inventive patenting provides a good *general* indicator for a firm, if not of year-on-year changes.

Firms' competitive use of patent data also suggests the usefulness of patent valuation. Firms now use patent data in intelligence gathering: Rivette and Klein (2000) show that firms had started using USPTO patent registration information to understand acquisition targets' technological capability, and to help set prices for intangible assets (e.g. IP) which did not normally enter accounts. So patents provide "the best means of measuring the concepts of accumulated technological capabilities and competences" (Fai, 2005, an insight which has also been used to update the competence- and resource-based approach to the firm). Griliches (1990) states that no other method rivals the data volume available, or its technological and industrial detail. Indeed, as some investment into China by foreign multinationals is moving from being market-seeking to competence-seeking, scholars have asked what Chinese patent data can tell us about the location of the domestic firms in which these competences are located (Fai, 2005).

Comanor and Scherer (1969) asked how well an invention patent count could act as a surrogate for two other measures of technological change: R&D staff (an input measure), and new product sales (an output measure). Their conclusion was that patents were more closely correlated with the number of R&D staff than with the number of professional staff in general. It therefore appears that the companies which have more R&D staff and more new product launches also apply for and are granted more patents. A combined "research productivity" measure is therefore generally created by the patents-to-R&D ratio, and simply counting overall patents can lead to a misleading impression of real research output, which Lanjouw and Schankerman (2004) state may be used alongside a model of patent quality which, they suggest, uses four separate indicators: number of claims, forward citations, backward citations, and family size.

4.2.3 The connection of patents to R&D

Any study employing both metrics should understand the relationship, if any, between the two. Research into the connection between R&D and patenting has been growing since the 1960s, Scherer (1965a) and Schmookler (1966) being early examples. Although it remains concentrated in certain technological sectors, especially pharmaceuticals, and is mainly focused on the Anglo-American shareholder context, research falls into various streams, especially: analysing possible links between R&D and productivity growth (e.g. Griliches, 1986a and Bronwyn Hall, 1993); using patents as indicators of the effort that goes into R&D to understand patterns in knowledge-production (Griliches *et al*, 1990; Kortum, 1993); and analysing movements in patents, R&D, and market value (Pakes, 1985, and Cuneo and Mairesse, 1983).

In the first area, Griliches *et al* (1986) find that when a firm alters its R&D expenditures, parallel changes occur in patenting levels. This varies however: industries with higher than average patents-to-R&D ratios were chemicals, drugs, petroleum, engines, construction/farm machinery, aircraft and electrical equipment, but other industries patented less than average for firms doing equal amounts of R&D. For larger firms in the sample, patenting was broadly proportional to R&D (although smaller firms showed somewhat more patenting per unit of R&D, these were a smaller group). Cockburn and Griliches (1987) observe that industries with a lower tendency to patent per unit of R&D include large R&D-spending industries with considerable support from government for research, including motor vehicles and aircraft. However this may be less applicable in China, with patenting encouraged by government.

So although patents represent by no means all R&D output, with only some appearing as patents, a rather strong relationship exists between R&D and number of patents granted, across industries and firms (Pakes and Griliches, 1984), with patents a good indicator of "unobserved inventive output". Bound *et al* (1982) demonstrate that this relationship is not just due to size differences, plotting patents and R&D per unit of firm assets. Within-firms time-series show a median R-square around 0.3, yet the evidence remains that a change to R&D expenditures results in a change to patent numbers (Griliches, 1998).

In western contexts overall however, the relationship appears a close one. While differences between industries in terms of patenting propensity exist, with electronic firms using patents to protect innovations more often (while mechanical industries favoured secrecy), Mansfield (1986) found that firms apply to patent 66-87% of all patentable inventions, and Archibugi (1992) found 40-60% of all patented inventions will become (commercial) innovations.

Patents are usually applied for relatively early in research projects (hence the use of studying patent applications), and as most of the R&D spend goes on development itself, most time-series variance in the variable comes from differential success in developing existing projects, not starting new ones. King (2004) also notes it is important to recognise input-output time-lags in R&D. Leydesdorff and Wagner (2009) find that a two-year time lag between input and output is appropriate for highly aggregated data, while Prodan (2005) showed that a 1-3 year time-lag between input and output gives solid "explained variance in technology output" (as we will discuss later).

Studies of firms' size, R&D and patenting have found that both very small and very large companies are generally more R&D-intensive than average sized companies. Bound *et al* (1982) found that a strong relationship between R&D and patenting exists, particularly among small firms, where those which carry out R&D patent more on average per unit of R&D spend than larger firms (in their US-focused sample, these authors found that firms with R&D programmes over $1-2m have an almost constant patenting to R&D ratio, save for firms at the top end of R&D programme size; the study differs from Scherer (1965), who focused only on the largest corporates). Both Scherer and Bound *et al* find slight diminishing returns at the highest intensity of R&D inputs. Bound *et al* also point out that much work (notably Pakes and Griliches (1980)) has generally shown a marked contemporaneous relationship between R&D and patent applications, although there also appears to be total elasticity nearer one if lagged R&D is included. Some surveys have also found that patent-to-R&D ratios seem dominated by what could be mainly irrelevant fluctuations in R&D numbers (such as the Yale Survey, in Levin *et al*, 1987, which found little relevant cross-industry variability).

Authors have asked how R&D as a "competence" can benefit firms. For "organisational competences" to be sources of competitive advantage they must meet three conditions: be heterogeneously distributed within an industry, impossible to buy or sell in the available factor markets at less than true marginal value, and be difficult to replicate (Henderson and Cockburn, 1994). There are many possible causes of heterogeneity, but authors (e.g. Dierickx and Cool, 1989), suggest that having unique R&D capacities fits this model. Numerous studies have now demonstrated that there are severe differences between firms in ability to conduct R&D into new product lines (e.g. Henderson, 1993).

Organisations' "architectural competence" meanwhile allows them to use "component competencies", integrating them in new ways. For our purposes this is clearly connected to firms' locations in the Chinese state structure. This architectural competence has various aspects. Research performance seems to be associated with an ability to "span the boundaries of the firm" (Henderson, and Cockburn, 1994, after Allen, 1977): hence firms that develop "gatekeepers", or individuals who bridge the gap between firm and environment (so stimulating information transfer between them) are likely to outperform others. However, it may be difficult for Chinese private firms to do this safely. Yet the ability to cross these boundaries appears increasingly important, with the technological paradigm changing from a closed to open innovation system (Chesbrough, 2003). Although firms gained an advantage in closed systems by funding R&D units to launch new technologies, in an open innovation system, firms may buy others' technologies, and apply their IP in other markets (Lee and Lee, 2008). China's need for firms with the architectural competence to both integrate and *protect* new knowledge is clear[16].

4.2.4 Firm protection and infringement

Scholars have noted that patents' effectiveness as an appropriability mechanism affects firms' incentives to carry out R&D (Levin *et al*, 1987). By implication, an environment that hinders the ability

[16] Notably there are also constraints on R&D data in the Chinese case: Boeing *et al* (2013) find comprehensive data on R&D expenditures to be unavailable for listed Chinese firms, meaning even listed firms (as well as unlisted) present data obstacles in this regard.

of some firms to protect patents will harm this incentive. Overall, patents' effectiveness as an appropriation mechanism for R&D returns is not constant, and firms' returns on patent protection will differ depending on industry and firm conditions even in western contexts (Cockburn and Griliches, 1987). However, as Cockburn and Griliches point out, environment, through level of appropriability, does determine the returns patenting can produce: thus the politico-legal environment will influence firms' decision to innovate in the first place, by carrying out R&D.

As we have seen, a firm's ability to protect its patents appears strongly to influence its decision to carry out R&D, and to apply to patent. Lanjouw and Schankerman (2004) find that risk of litigation is higher if patents are owned by firms with smaller patent portfolios, and small patentees have a notable disadvantage in protecting patent rights, because their greater risk of being litigated is not balanced by faster resolution of suits (it is also less costly to protect a given patent if it is in a larger portfolio). Thus risk appears to be increased by the ability of larger state entities to use the legal system.

This portfolio effect also seems stronger for smaller firms (measured by staff). For them, having a patent portfolio is likely to be a central method of avoiding litigation, while bigger companies are better able to depend on repeated interaction with other firms - in both IP and product markets - to discipline behavior (Lanjouw and Schankerman, 2004). Although these authors have found that in more concentrated technology areas, where patenting is dominated by fewer firms, companies are also less likely to become involved in infringement suits (and will more likely encounter the same disputants over time, predicting higher inclination to settle). Large Chinese state conglomerates' power to circumvent infringement rules may limit other firms' willingness to patent however, which may hinder in particular the innovation output of private competitors.

Indeed, small firms seem to actively avoid R&D in areas where litigation threats from bigger firms are more severe (Lanjouw and Lerner, 2004). Even when firms can settle patent disputes without suits, the threat of being able to litigate will influence settlement terms – thus affecting incentives to do R&D. Levin *et al* (1984) also find that the ability to appropriate the returns from R&D is essential if firms are to have the incentive to invest in it. Cockburn and Griliches (1987) used the *Yale survey* measures of the appropriability environment in which firms find themselves to gather evidence of interaction between industry level measures of patents' effectiveness, and market valuation of firms' R&D and patenting level (as R&D capital is around 14% of total value of other assets, by implication such a change in appropriability environment would nearly double valuation). Given that companies with bigger portfolios are more likely to patent innovations, they could have more patents that are not worth litigating. Despite this, it seems there is no evidence that average patent quality falls with larger portfolios (Lanjouw and Schankerman, 2004). However, poor appropriability or ability to protect can lead to underinvestment in developing technology. With technical change the leading cause of economic growth, this means firms' access to reliable protection if they are to apply for patents has serious ramifications for China.

Patents for products have been considered more effective than for processes, but in protecting products generally, lead times, learning curves, and service or sales efforts have been seen as more effective still than patenting (Lanjouw and Schankerman, 2004). In these authors' sample, only 20% thought product patents were as commercially effective as sales or service efforts; indeed, the perceived ineffectiveness of patents in numerous industries leads us to ask why firms apply for them.

Here, executives describe two motives for patenting: one is measuring R&D employees' performance, and the second is for gaining access to foreign markets, including to permit licensing. Investment in these R&D staff however is affected by the extent that rivals can learn about innovators' technology, knowledge of which may assist rivals' R&D effort by enhancing productivity. Nelson and Winter, and Spence, are among those who have created models to establish the different offsetting effects: Spence (1974) called these the "incentive and efficiency effects of interfirm spillovers". Although in various categories of innovation, some industries reported that patents actually reduce costs and/or time needed for duplication, Chinese firms still need to be able to patent to enable them to compete at the domestic and foreign level, which as we have seen provides a major patenting incentive.

Despite the correlation between patent effectiveness and costs of imitating patented products, in several industries patents were relatively ineffective, but duplication costs remained high. In this case products' complexity may make reverse engineering more costly even with weak patent protection (although given its wide technological scope, the effect for solar PV will vary. Studies by Mansfield, Schwarz and Wagner (1981) and Lanjouw and Schankerman (2004) have all found that patents generally raise imitation costs, and that the costs and time required for duplication are related to patent effectiveness. Meanwhile, many firms believe that only a few competitors are capable of actually duplicating new processes and products (Lanjouw and Schankerman, 2004): this may also be the case in China, but if these competitors have state backing their existence may still be very problematic for other innovators. Small private start-ups in particular need protection, for whom patents may be even more important, providing a tangible asset to sell later on.

Investigations of the link between firm size and R&D intensity (the "Schumpeterian hypothesis" that size helps R&D) have found that the effect of firm size on R&D intensity is in fact statistically insignificant (and that industry effects in types of business in fact explain half of the variance in R&D intensity). This implies that China's creation of giant SOEs may not ultimately be worthwhile in driving innovation; indeed, large firms can suffer a general loss of managerial control in their resource allocation (Driver and Coelho Guedes, 2012), which leads us to consider how principal-agent theory questions influence our approach to these measures.

We will now outline the development of China's solar PV sector to date, the purpose at this stage being to illustrate how this follows the national innovation system in funding, and how the sector and its R&D must compete in the changing international market. This will ultimately inform the hypotheses for solar PV firms in China's national innovation system.

5. The Chinese solar PV industry

5.1 Introduction to solar PV technologies

5.1.1 Solar PV: production process and technology types

Solar PV production falls into the two broad categories of *crystalline silicon* and *thin film*. The vast majority of global commercial production (80-90%) is based on crystalline silicon (Solarbuzz, 2012). In crystalline silicon PV, production involves four main steps (de la Tour *et al*, 2011):

1) **Purification of silicon** from silica (Si02) found in quartz sand. The very high purity required for the PV industry (over 99.999%) is obtained via energy-consuming processes with high technical requirements.
2) **Ingot and wafer manufacturing**. An ingot is a cylinder of this pure silicon. If this is a single crystal, it is called monocrystalline silicon, or if it consists of multiple smaller crystals it is polycrystalline silicon (monocrystalline leads to more efficient power conversion in PV cells, but its production is more energy-intensive, thus more expensive). "Doping" is then carried out, whereby impurities in the form of atoms such as boron or phosphorus are added, to create n-type (negative) or p-type (positive) silicon (see Functioning below). Using a saw, ingots are then sliced into thin layers called wafers, and polished.
3) **Cell manufacturing**. To create the cell, one n-type and one p-type wafer are layered together to create the p-n junction which converts light energy to electricity. The top and rear conductive metal contacts are also applied. Various design modifications can increase efficiency.
4) **Module assembly**. With electrical junctions created, cells are encapsulated together in glass sheets to form larger modules which will be cooked in laminating machines. PV systems are structured around the modules, which are assembled into an Array, and with the addition of ancillary equipment to the module (mounting systems, inverters, wiring, junction boxes, batteries and charge controllers) a complete system is created.

Thin films meanwhile are potentially cheaper than c-Si because of their lower materials costs, but remain less efficient than silicon (thin films hold a niche position in low power and consumer electronics applications).

Thin film manufacturing primarily uses amorphous silicon (a-Si), cadmium telluride (CdTe), and copper indium gallium selenide (CIGS). One possible route is the development of amorphous silicon using microcrystalline silicon, which seeks to combine the high efficiencies of c-Si technology with the simpler and cheaper manufacturing of amorphous silicon. This is not yet widely produced however. Broadly, thin films are manufactured through thin film layer materials being deposited onto substrates of glass or plastic; a transparent conductive oxide layer forming the front electrical contact, and a metal layer forming the rear contact.

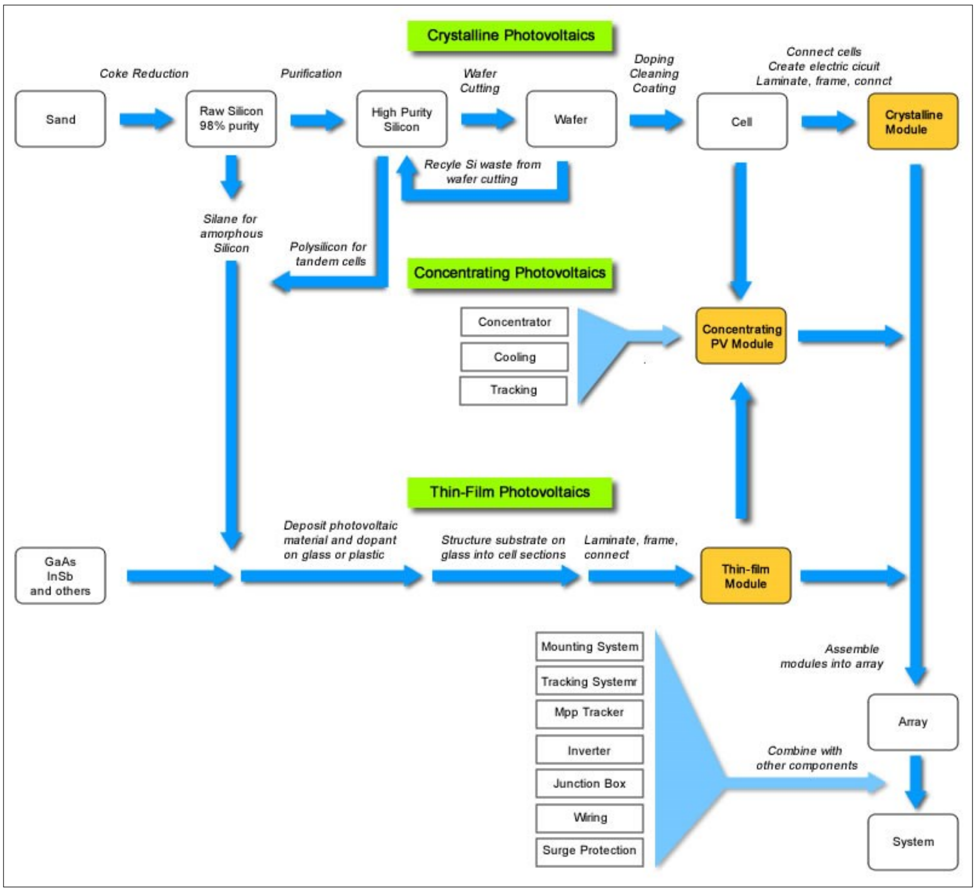


Figure 9: The solar photovoltaic value chain (source: Green Rhino Energy, 2012)

5.1.2 Functioning of a solar PV cell

Solar photovoltaic cells are in essence semiconductors that function through illumination. They consist of two (or occasionally more) layers of semiconductor material (usually silicon) called "wafers". One layer is positively charged (p-type), the other is negatively charged (n-type). Sunlight, generally accepted as consisting of energy particles called photons, is absorbed by the cell (some photons will be reflected or pass through cells, which are textured to increase absorption).

Once sufficient photons are absorbed by the n-type layer, this increases the energy of the electrons in the layer (which is negatively-charged because of its high electron concentration), freeing them from the material, thus leaving a "hole", into which flow the electrons of neighbouring atoms. Electrons move to the p-type layer (positively-charged because of its low electron concentration), creating charge flow. Metal contacts placed on both the p-type and n-type sides transfer energy into the circuit. Electrons then re-enter the n-type layer to re-join the previously created holes.

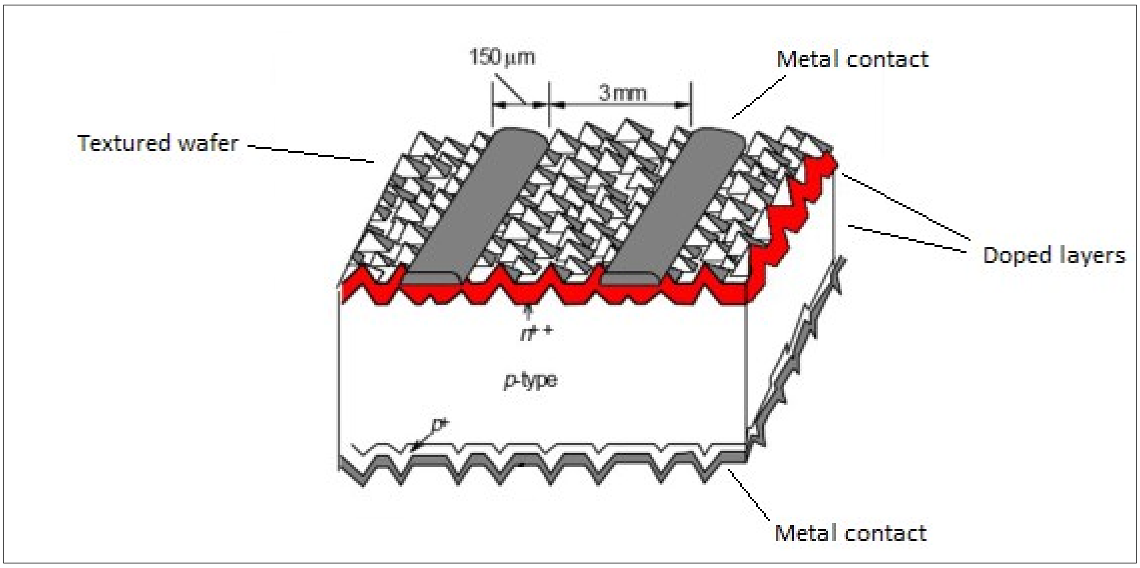


Figure 10: Functioning of a solar photovoltaic cell (source: Joaqium Nassar, Paris Tech, 2011)

As a *group four* element (in the fourth column of the periodic table), silicon has four external electrons which it likes to share with neighbouring atoms to build covalent bonds. This forms a tetrahedrally-bonded crystalline structure. Quantum mechanics demonstrates that this crystalline structure has special electronic properties; briefly, this means electrons can only be released within specific "band gaps" (of energy). These determine whether a material is a metal, insulator, or semiconductor: while semiconductors have insulator-like bands, the gaps between these bands allow the controlled release of electrons, such as in a particular range of wavelengths of light.

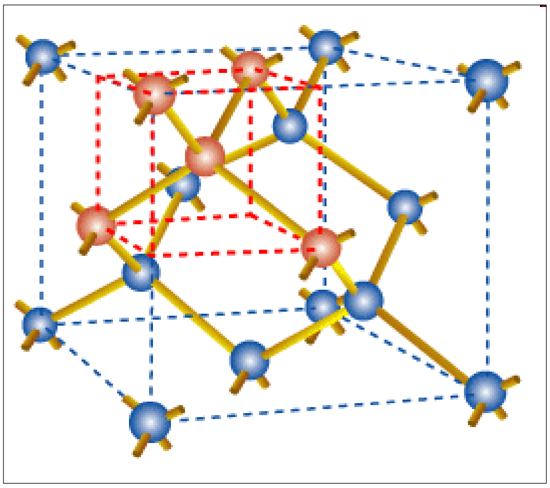


Figure 11: Tetrahedrally bonded crystalline silicon (source: Joaquim Nassar, Paris Tech, 2011)

Small amounts of selected impurities are added to the silicon ("doping"). N-type doping usually uses phosphorous, from column five of the periodic table, meaning it has five outer electrons. Four electrons take part in bonding with neighbouring silicon atoms, leaving one spare electron: this creates a negative charge, hence n-type. Boron is used for p-type doping, being from the third column of the periodic table, with three outer electrons. This means one electron is "borrowed" from a Si-Si bond, which bonds the boron atom to four neighbouring silicon atoms. The borrowed electron leaves a "hole", creating a positive charge.

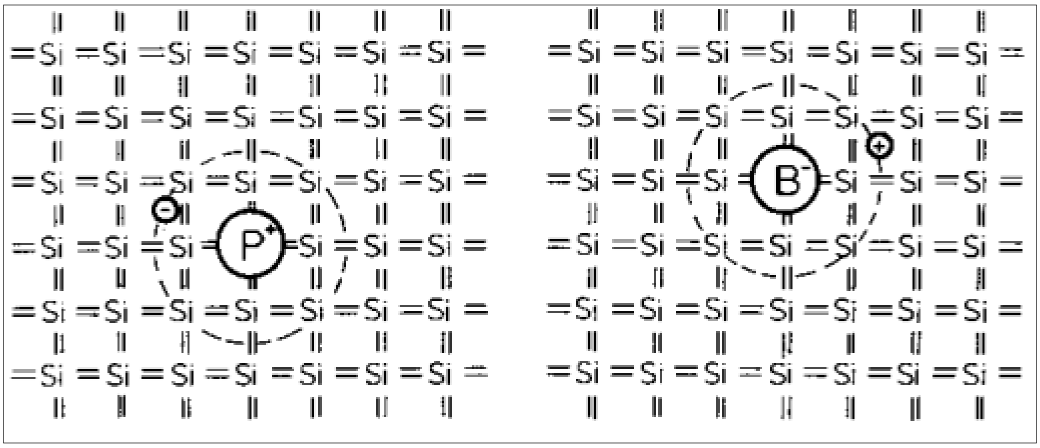


Figure 12: Silicon doping with phosphorous and boron (source: Joaquim Nassar, Paris Tech, 2011)

A particular wavelength of light can be understood as a flow of photons of a given energy-intensity. The band gap that allows the release of electrons corresponds to a particular energy-intensity. For silicon, this band gap is a wavelength of around 1107 nanometres (nm): this is infrared light.

Most commonly, efficiency is determined by using materials that adjust the band gaps through which electrons can be released by photons (photons at energies above or below the band gap cannot do this: they generate only heat when absorbed, which decreases efficiency). Different materials and processes allow the capture and conversion of more photons within a band gap, and from more band gaps.

Solar cell efficiencies now range from 6% for amorphous silicon to over 40% for multiple-junction research lab cells. However, higher efficiency cells have generally been less economical: a 30% efficient gallium arsenide cell currently carries one hundred times the price of an amorphous silicon cell (in commercial production). Meanwhile, concentration systems (CPV) boost light intensity and have been effective on larger installations ("solar farms"), requiring larger up-front investments. As well as the efficiency of the solar cell itself, the technical specifications of other components such as wiring, inverters, charge regulators and batteries also have an effect on the PV system as a whole.

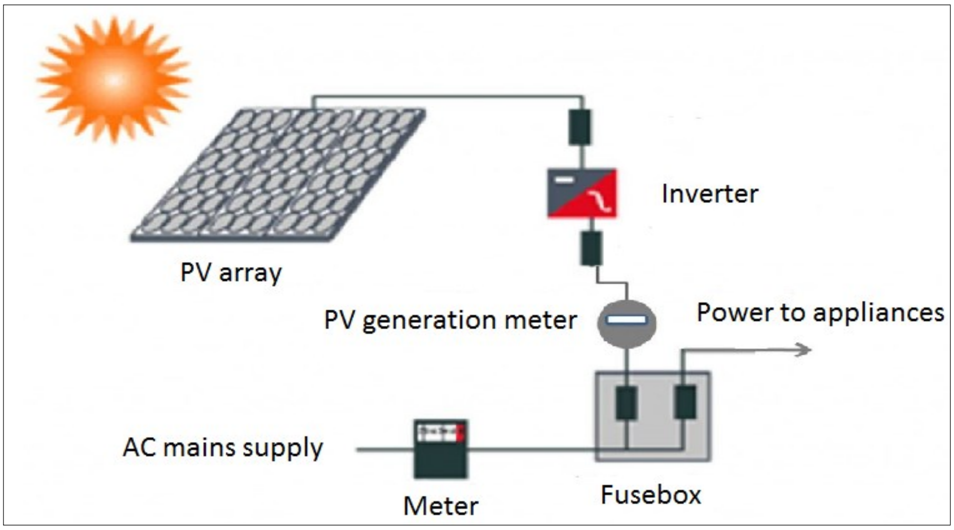


Figure 13: A solar photovoltaic system (source: Paris Tech, 2011)

5.2 Chinese solar production and innovation

The first Chinese PV research appeared in 1958, with small pilot projects beginning in the early 1970s (Yang *et al*, 2003). By late in the decade, three state semiconductor factories, in Yunnan (Yunnan Semiconductor), Ningbo (the Ningbo Solar Cell Factory), plus Kaifeng (Kaifeng Solar) underwent conversion to monocrystalline solar cell factories (Dai *et al*, 1999). Late in the 1980s, these manufacturers updated their production facilities, with four new firms founded (Marigo, 2006). These were: Non-Ferrous Academy, a Beijing-based SOE connected to the Beijing General Institute for Non-Ferrous Metals, which closed by 1999; Qinhuangdao Huamei, which shut down in 2003; Yunnan's Yu Kang Solar, a joint venture of the provincial government with a Korean and one other foreign investor which closed in 1997 (due apparently to marketing problems); and Harbin-Chronar, a Sino-US joint venture which closed in 2003 (Dai *et al*, 1999).

While two firms, Harbin-Chronar and Yu Kang Solar, were foreign/state joint ventures, the others were SOEs. All these firms' production facilities were funded via either state R&D programmes or via international, mainly western, aid (Li, 2004b). American suppliers provided much of the production equipment, sometimes the entire production line (which included ingot pulling and squaring gear, wafer slicing, cell and module manufacture (Yang *et al*, 2003)). Only in 2000 did China begin to manufacture capital equipment for solar PV (Yang *et al*, 2003).

Company	Starting Date	Equipment	Technology	Production Capacity 1995	Production 1995
Harbin Chronar	1991	All imported	a-Si	1 MW	200 kW
Non-Ferrous Academy	1987	All imported	mc-Si	100 kW	20 kW
Qinhuangdao Huamei PV	1990	Key imported	sc-Si	1 MW	200 kW
Kaifeng Solar	1975 (new line 1998)	Key imported	sc-Si	300 kW	180 kW
Ningbo Solar Cell Factory	1976 (new line 1998)	Key imported	sc-Si	300 kW	300 kW
Yunnan Semiconductor	1983 (new line 1987)	All imported	sc-Si	500 kW	300 kW
			Total:	3.2 MW	1.2 MW

Table 5: Early Chinese solar photovoltaic cell manufacturers: equipment sources, technology and production (1995) (source: Dai *et al*, 1999)

China-made PV cells averaged 10-12% efficiency in 1999, with a maximum of 13.5%, while foreign manufacturers' cells averaged 14-15% efficiency (Dai *et al*, 1999). Their cells' lower efficiency generally saw Chinese firms unable to generate profits, or to invest in expansion as a result. Production capacity rose from 4MW in 1998 to 5MW in 1999 (Dai *et al*, 1999; Zhao, 2001), while Zhao *et al* (2006a) called the 1990s a decade of importing, digesting, absorbing, and innovating for the Chinese solar PV industry, which led to capability and capacity improvement.

The period immediately after 2000 saw a cluster of new cell and module manufacturers, in particular Shanghai Topsol (2000), Suntech, Trony, and Yingli (2001), Topray and Tianjin Jinneng (2002-3), and CEEG Solar in 2004 (a joint venture between the Chinese Electrical Equipment Group of Jiangsu and the University of New South Wales). From its founding, Shanghai Topsol also established a technical collaboration with Shanghai Jiaotong University's Institute of Solar Energy, which helped build a crystalline silicon cell production line (some production machinery was built to in-house designs (Yang *et al*, 2003)). The firm became an early example of how to achieve (some) technological take-off in the Chinese industry, building collaborations with other research institutes and firms nationally.

Yingli (a conglomerate known formally as Baoding Tianwei Yingli) was established in 2001, and began making cells two years later, becoming China's first cell and module firm also to manufacture multicrystalline ingots in-house (Schmela, 2005). Yingli bought Swiss wire saws for ingot cutting, plus Italian module production equipment, while virtually all its materials were bought from the United States or Europe. Yet only in 2006 did production reach 77 MWp (one large solar farm being around 50 MWp), the firm taking considerable time to make its production line function efficiently to scale. Meanwhile CEEG Solar, with University of New South Wales academic Dr Zhao Jianhua as General Manager, saw capacity reach about 300 MWp by the end of 2005, with production at approximately 150MWp (Schmela, 2005) (we shall return to R&D in the PV industry later in this section).

China is now the world leader in cell production and module assembly. Over 50% of PV panel production by 2011 was in China, with seven of the global top ten cell manufacturers and eight of the top ten module manufacturers (China Greentech Initiative, 2011). China's market share in upstream segments is lower, although Chinese firms have carried out capacity increases, producing 15% of global silicon in 2010. The pattern is similar for ingots and wafers, with China representing a minor but growing part of world production (we shall explain below how ownership patterns may affect the direction of Chinese PV firms' innovation).

Downstream cell and module segments have lower technological barriers to entry, and Chinese firms have also used manufacturing cost advantages: by contrast, silicon purification requires more advanced technologies and specific know-how. Cell production technology is relatively accessible because, unlike in more complex upstream segments, turn-key production lines can be bought and run with little experience. However, Chinese production increases have seen their cell/module manufacturers' profits slump, compared to the upstream segments in which China does not (yet) dominate. Beijing now sees solar PV manufacturing as a vital industry, falling under the aegis of an SEI, and excess capacity is partly caused by considerable central, but also local, government subsidy.

Numerous reports now point to a change in political direction for the industry. Competition for market share between numerous companies has resulted in production of cheaper, but less efficient products (Wang X., interview, 2013). Higher-efficiency products have had relatively little uptake, but analysts believe that as Beijing tries to drive mergers by reducing subsidies, this will change. Consolidation appears likely "from the second half of 2013, but especially in 2014" (Wang X., interview, 2013).

However central and local government attitudes differ: Beijing seeks industry consolidation while provincial governments try to support local firms to help them win out in the same process. Yet it appears that with local governments in budgetary trouble since 2010, this cannot last: "there simply isn't enough money". Indeed, Beijing is aiming to provide more money for "bigger firms which can show they have a tech advantage", and will keep providing credit lines only to some firms (Wang X., interview, 2013). Thus an ability to produce and register IP is now seen as crucial to survival.

Although studies of innovation in China's solar industry are at a relatively early stage, these can be outlined briefly. The only substantial review of Chinese solar patent data thus far is de la Tour *et al* (2011, 767) (although this did not analyse state ownership by firm and across technology types, dealing instead with international comparisons and tech transfer). The authors compare international patent data, finding that Chinese producers have acquired "technologies and skills to produce PV systems" mainly via buying manufacturing equipment and recruiting from the Chinese diaspora.

Meanwhile, Marigo (2006) has described the growth of Chinese state R&D funding for PV technologies, with the period since 2006 seeing China become one of the top five national spenders on PV R&D. In her study of clean technology in general in China, Sims Gallagher (2014) suggests that the strength of barriers to technology transfer has been exaggerated. Sims Gallagher also suggests that technology acquisition in China's solar PV field is a "success", and states that Chinese firms generally face few barriers to finance (Sims Gallagher, 2014). Tyfield *et al* (2015) focus on low carbon innovation around Chinese urban transport in particular, especially electric vehicles (EVs). Tyfield *et al* demonstrate that while government (and corporate) innovation efforts have focused on electric cars, the simpler electric moped (or electric two-wheeler, E2W), has seen much quicker uptake, with global production now dominated by Chinese firms. Altenburg, Bhasin and Fischer (2012) have also described the balance policy-makers must achieve between climate change mitigation, industrial competitiveness and technological development. Fischer (2012) also focuses on China's solar PV specifically, in particular the area of domestic installations, and their slow growth compared to domestic manufacturing.

In silicon, ingot and wafer manufacturing, de la Tour *et al* (2011, 767) found China's patenting to be higher than its contribution to world production, yet the reverse is true in downstream segments, where China is the leading manufacturer but generates only 15% of worldwide patents (de la Tour *et al* do not mention the patent quality differences however, below). Patenting in silicon production shows an effort to break a "technological lock"; Beijing wants China's industry to move into higher value innovation-based manufacturing, explaining why solar PV cell and module innovation has also been chosen as an indigenous innovation target, with support for firms with "innovative capability". The NDRC has stated: "By 2015, average total power consumption shall be lower than 120 kWh/kg [in silicon production], conversion efficiency for monocrystal [cells] will reach 21%, polysilicon [cells] 19% and amorphous silicon thin-film cells 12%". Also, "new types of thin-film will be industrialized", "technological advancement and industrialisation of silicon-based thin-film cells and copper indium gallium (di)selenide (CIGS) thin-film cells" promoted, with "improving conversion efficiency of thin-film cells" (NDRC, 2012, in Wiley Rein, 2012, 4).

The precise sectors Beijing is targeting are: high purity polysilicon, through "solar-level polysilicon production technology involving low energy consumption and low cost" (an interviewee, Eric Peters, also emphasised China's desire to "build up" polysilicon); silicon ingots and silicon wafers, by supporting "high-efficiency, low-cost, large-size ingot technology, focusing on the development of [quasi-mono] crystal ingot technology; achieve breakthroughs in key technologies for new-type slicing below 150-160 micron, such as cutting technology for silicon carbide and steel wires, in order to improve the quality of silicon wafers, the number of wafers per unit of silicon materials, and to reduce silicon material losses during slicing". In crystalline silicon cells: "aggressively develop and industrialize crystalline silicon cells with a high conversion rate and a long service life. Provide key support for the research and application of low-reflectivity texturing technology, selective emitter technology, electrode alignment technology, plasma passivation technology, low-temperature electrode technology, and full back junction technology. Pay attention to key technologies of thin-film silicon, crystalline silicon heterojunction solar cells, as well as other new types of solar cells"; finally, thin-film cells, by focusing on "development of laminated and multi-junction [cells], which combine amorphous and microcrystalline [silicon]. Reduce light-induced degradation of thin-film cells. Encourage enterprises to research and [develop] high-efficiency and large-area silicon thin-film cells. Develop roll-to-roll production techniques for flexible silicon-based thin-film solar cells" (NDRC, 2012, in Wiley Rein, 2012, 3).

In sum, China's solar PV sector has grown enormously from being an entirely state-run set of research institutes, to being a substantially private commercial industry. However, both state ownership and state R&D demands still have a heavy influence of the sector.

5.3 China's institutional governance of the solar PV sector

We have seen alternative energy's priority place in the Strategic Emerging Industries (SEI) programme under the ongoing Medium- to Long-Term Plan (MLP). One interviewee (Eric Peeters, Dow Corning, 2012) stated: "Solar [PV] is strategic as an industry for China… it is about energy independence, especially to a country with fast rising energy consumption". However solar also represents an area in which China aims to outpace the rest of the world in innovation, and dominate its home and global manufacturing markets. To this end China has passed laws for installation, and used stimulus money for R&D. We will discuss how these may affect innovation by different types of firm.

The *Solar 12th Five Year Plan* of September 2012 implemented new standards and increased government control over the industry's technological direction, including in advanced thin films, where Chinese production costs (as of 2012) remain above the leading US producer (First Solar) (it is unclear whether Chinese thin-film cells have seen efficiency rise sufficiently to make them cheaper than silicon cells on a cost-per-kilowatt produced basis (Dewey and LeBoeuff LLP, 2012)). It also aims, by 2020, for PV power generation to become economically competitive in China, with the cost of PV modules to fall to RMB 5,000/kW, of PV systems to RMB 10,000/kW, and of power generation to RMB 0.6/kW[17]. The plan specifies products, technologies and processes to be supported.

The plan also directed the industry to "support R&D and industrialisation of key production equipment used for polysilicon, silicon ingots/wafers, cells and modules, thin-film cells, and power generation applications" (Wiley Rein LLP, 2012, 3). Meanwhile the "localisation rate of production equipment and auxiliary materials for PV cells will reach 80%, and Chinese enterprises will master key technologies involved in PV grid connection, manufacturing energy storage equipment, and system integration".

The institutional situation that has allowed the manufacturing industry its growth is due considerably to local government, and its relations with Beijing. Beijing wants consolidation, but as we have seen, provinces want to support their local firms, which "can't last, there simply isn't enough money, so there is a big consolidation coming soon. Central government is now providing more money for the bigger firms which have a tech advantage, so it still provides credit lines, but only to some firms" (Wang Xiaoting, interview, December 2012). This suggests that without subsidy, firm survival depends on competitive ability though innovative manufacturing.

Beside firms' actual shareholding, Metaal (interview, 2012) stated that although Chinese companies can get some government support "if they are private", other state or military connections via shareholding or state-connected CEOs are especially important: "JA Solar is partly owned by the army [and] Yingli's military connection is their CEO being former PLA [People's Liberation Army]". In sum, while the central government both originates funding and attempts to drive consolidation, and with it restore industry profitability, the importance it has placed on GDP growth for its provinces has created a conflict that may have prolonged this process. However solar PV firms understand that generating more patent IP will help secure their position in a solar value chain that the government

[17] This seems to indicate that Chinese producers are selling solar modules below cost: a stated goal is reducing the PV module cost to RMB 7,000 per kw ($1,100 per kw or $1.10 per watt) by 2015, however the current price of Chinese PV modules is already below this.

appears to be trying to "sinocise", while the primary source of R&D funding and support continues to be the state.

5.3.1 Resulting R&D patterns in the Chinese solar PV industry

We should note at this point another reason why our choice of sector is important. In industries featuring stable product and process technologies, innovation will usually grant little strategic advantage, so R&D expenditure will in consequence usually remain low. However in those industries in which product and process technologies change constantly, innovation has much higher strategic importance, with R&D expenditure being high. Thus R&D expenditure is a strategically relevant variable in a research-intensive environment (Hill and Snell, 1988).

As well as expenditure itself, having connections with research institutions, complemented by *in-house* R&D, are seen as the most useful technology sources. The Ministry of Science and Technology (MOST) remains in charge of most R&D programmes (including the "National R&D Project", and the 863 and 973 Projects (Marigo, 2006)). The 863 Project has been focussed on supporting research into Cadmium Telluride (CdTe) and Cadmium Indium Gallium Arsenide (CIGS) cells, and the 973 Project funds thin-film, polymer, and dye-sensitized cell research. Meanwhile R&D funding has supported solar PV since 1981 (ad hoc funding then being brought first into the *Key Technology R&D Programme* in the late 1980s), with funding going to projects including upgrading manufacturing lines (early on these were at Kaifeng and Ningbo), amorphous, mono- and polycrystalline silicon cells, and cell measuring equipment (Zhao *et al*, 2006b; furthermore, the government funds R&D in institutes and universities, in particular CAS and its branches).

Until 2005, the firm Suntech had received the largest single government commercialisation grant (RMB 4m, to commercialise crystalline silicon cells). However, since this time a consensus has emerged that too many state bodies have been providing support to the PV industry (Dai *et al*, 1999), meaning inefficient resource use, badly organised R&D programmes, firm projects that fail to achieve their potential, and under-commercialised research. Indeed, in 2005 over forty universities and institutes were involved in PV R&D, almost all aimed at cell efficiency and module structure improvement. More recently however, firms' in-house R&D has grown, but is supported by local and national levels of government[18]. According to Zhao *et al* (2006b), despite much improved commercialisation and industry-academic connections, R&D is still affected by relatively poor human capital, especially in training and technical education, in research institutes and firms.

Parts of the technological context in which R&D takes place are described by de la Tour *et al* (2011). In 2007, although China had already become a world leader in cell production and module assembling (then at 27%), its market share upstream, in global silicon production, was just 2.5%. As described, Chinese firms increased capacity, producing 15% of global silicon by 2010, and a similar trend is taking place in ingots and wafers. China is now especially strong in the downstream segments where technological entry barriers are lower (although so too is profitability). Here, production technology is relatively accessible, because unlike in upstream, "turn-key production lines can be bought and run

[18] In the 11th Five-Year Plan (2006-2010), the MOST PV R&D budget was approximately RMB 120m ($16.4m). In 2005, Germany spent $30.3m, Japan $60.5m, and the US $86m on R&D in the area (Marigo, 2006).

without much prior experience in manufacturing". Module assembly is (relatively) technologically straightforward and labour-intensive, giving competitive advantage to Chinese companies. Upstream, silicon purification demands advanced technology and know-how.

An anonymous interviewee (2012) stated that although he is not certain when "the innovation will really take off", Chinese customers now also have IP "on the sales side, meaning module manufacturers" (indicating that it is increasingly worth defending in China, and that firms are now aiming to compete with more advanced product internationally). This implies "IP is getting broader. More firms have IP on their designs, and Chinese firms also have design patents on cell designs now" (we will discuss this pattern below).

However one interviewee (Macdonald, Wall Street Journal Asia, May 2012), believes that entirely private firms may not feel it is worth innovating because their IP may be infringed by SOEs. He believes this demonstrates how China's politico-economic structure "must be starting to hinder innovation", and with it China's ability to "move up the value chain". Another interviewee (anonymous) highlights the DuPont titanium oxide case, where process technology was stolen by an SOE, which is now mass-producing the product, yet the Chinese government denies the firm infringed. This form of apparent infringement is "more hazardous than the process technologies developed and owned by [solar PV firms including] Manz. This is because in solar you can stay ahead by continuing to innovate, as solar manufactures are changing. But innovation won't save you if titanium oxide is the same thing in 10 years' time". Thus "the SOE issue exacerbates the risks here regarding simple technologies", i.e. infringement of their IP. So more straightforward materials, possibly including silicon, may be riskier" (the implication is that majority private firms may be more successful if they develop more complex technologies which majority state-backed firms may be unable to infringe): conversely, it is possible that state ownership may assist the long-term, slow pay-off investment that more complex technologies require.

Metaal (interview, 2012) states that Beijing "wants companies with at least some Chinese money gone in", then to see that "Chinese companies are innovating, even if they can't make much money because it is expensive to produce. They want Chinese companies to be getting into positions to lead on innovation, because the money in manufacturing itself is [terrible]. They must keep ahead on IP". However, "if western companies keep innovating" states Metaal (2012), "they will be OK. Chinese companies… may buy foreign innovators in their space then leave them alone. It's hard to integrate, just look at Jili and Volvo. It is in general very hard for Chinese companies to integrate foreign companies. So they may very well just buy them and leave them as their international arm".

The R&D scenario for the industry in China is thus one of very specific R&D demands and guidance from government, but with funding skewed towards firms with closer state relationships in various forms. Pressure to innovate and own patent-IP is intensifying with the pressure of industry consolidation in China; we will return in the hypotheses to how different firms' ownership will impact their ability to innovate in this dynamic environment.

5.3.2 The global context of Chinese solar PV R&D

Meanwhile the solar sector growth trajectory has shifted. The US Department of Energy expects the cost of solar power to fall by 75% between 2010 and 2020, and US grid parity with fossil fuels to be reached in that period, to be followed by “rapid, large-scale adoption of solar electricity across the US” (Dept. of Energy, 2012). Solar is now competitive without subsidy in Japan, South Korea, Israel, Australia, Italy, Greece, Spain, South Africa, and Chile, caused partly by a drop in panel price to $0.60-$0.70 per watt (Thailand, Mexico, Argentina, Turkey and India could reach parity in three years). Although a good deal of this drop has been caused by cheap Chinese solar panel production, numerous US government-connected laboratories are now at the forefront of research. Thus without successful innovation, Chinese manufacturing dominance today may not remain tomorrow. Chinese propensity to file abroad also appears relatively low, an indicator of potential innovation problems. Firms must compete for market share in an industry of rising technological standards (and for government favour, as government support via the NDRC is now *considerably influenced by patenting levels* in this as in other sectors) (Eberhardt *et al*, 2011). Although a limited amount of Chinese solar innovation is held in trade secrets (including in the manufacturing process-innovation that often comes from production line “tinkering” rather than R&D departments), such policies are encouraging the growth of some patenting (Metaal, interview, 2012), although patent ownership patterns in the different technology types across solar PV remain to be seen.

Globally, significant PV patenting began in the 1950s through space applications, regarded as the first PV diffusion phase. The second phase, since 1975, has seen at least 100 patent filings each year. The third diffusion phase, on-grid, is evident twice over, first in significant patent growth (always over 1,000 annually since 1997), and second through PV inverter patenting (always over 20 patents annually from 1990, then 50 from 1998). Meanwhile, PV patent filings and production have shown similar dynamics. On average, a 50% growth rate in PV sales has seen a 17% growth rate in PV and inverter patent filing (Breyer *et al*, 2012). The ratio of international to national patent families has risen from around 15% (in the mid-1980s) to 40% by the late 2000s. Breyer *et al* (2012) suggest that anticipated international markets are reflected in these filings. High R&D growth is also shown in the ratio of PV international patent families to international patent families generally: in the decade to 2009, international PV patent families increased from 0.2% to 0.8% of all international patent families, suggesting anticipation of a growing role for PV in global energy supply. In the first diffusion phase, most patent families were filed by firms in the US, Germany, the UK and France (the UK and France receding during the second and third diffusion phases), but in the last decade some firms from East Asia have gained international PV patent families[19]. China intends to become a player “in all important industries, especially [those with] high growth rates and potentially high profit margins” (Breyer *et al*, 2012), including PV.

PV is relatively diversified technologically, with the leading 25 firms making up only 12.7% and 15.5% of global national PV patent families for 2000-2008 and 2008 respectively. Some leading patent assignees have not yet begun selling products, or are only preparing to enter the PV market (including Samsung, LG, Sony, Fuji, Contrel Technology, Emcore, and GE). Around 50% of tech-specific patents are for crystalline silicon (c-Si), whose market share is 81%. Globally, public-listed firms invested on

[19] Firms in South Korean and Taiwan, having been successful in semiconductor technologies, have employed know-how to move into technologically similar growth markets including PV.

average around 3.5% of sales on R&D (2009), while the leading ten firms invested 4.6%. PV equipment suppliers invest significantly more than average in R&D, usually around 10% (Breyer *et al*, 2012). Breyer *et al* calculated a global average R&D spend per employee of about €110,000. Chinese firms were below that average, but not by over 50% (we will return to variations in R&D expenditure in the hypotheses).

However several PV firms with leading market shares have not invested in corresponding patent portfolios; these include the leading Chinese firms Suntech, Yingli, and JA Solar. Breyer *et al* (2012, 14) suggest that some firms believe a non-publication strategy is more advantageous: “valuable process IP is not as easy to protect as design IP”. Yet this also suggests patentable IP is not being developed by these firms to the same extent; if Chinese firms are focused on process IP, this may also suggest they are attempting continued domination of c-Si manufacturing, not more advanced designs such as thin film technologies. This implies that, should the market open up for thin film and other more advanced silicon technologies, Chinese firms may be at a technological disadvantage. By implication, the state’s funding through its indigenous innovation drive would then have helped direct firms to patent in (less advanced) c-Si areas, where patents, and the rewards from the state that follow them, are more straightforwardly obtained.

The innovation taking place in China should be seen against the backdrop of increasing innovation in solar PV worldwide. In seeking to understand which Chinese firms, by ownership, are most capable of innovating, we will next describe how the institutional knowledge we have built has informed the construction of our theoretical template, with which we will make hypotheses about innovation patterns in the Chinese solar PV industry.

6. Methodology

6.1 Introduction

As discussed, the overall goal of this thesis is to investigate the effect of different forms of shareholding (state, private, and foreign shareholding), then different levels of state shareholding (by levels of government locality), on the ability of mainland Chinese solar PV firms to generate innovative output, as measured by their patenting. More exactly, our analysis concerned the effect of the different principal-agent chains manifested in the different shareholding arrangements within the context of the Chinese innovation system; this is also an analysis carried out to better understand the relative successes and failures of innovation, and innovation-led economic growth, in the current Chinese politico-economic scenario.

From the outset of the research process it was clear that qualitative exploration and investigation of the context and technological field would be used to inform a quantitative analysis. The earlier qualitative stages involved first gaining a comprehensive understanding of the place of Chinese innovation policies in the country's political system; researching the role of the domestic and international IP legal framework in this system; and understanding both solar PV technologies and manufacturing techniques themselves, and the domestic solar PV industry as a major global player.

To outline these qualitative stages, I carried out an early research trip to the solar PV "winter school" at ParisTech, which involved a five day intensive course, taught by ParisTech physicists, on solar PV technologies, development, and manufacturing methods. This was followed by a research trip to Belgium and the Netherlands, to interview employees in significant solar PV manufacturing clusters, and in related venture capital firms. These interviews were focused on the trends of technological competition from China, and included discussion of the most valuable areas of IP.

For six months between April and October 2012, I carried out my China-based field research. Based in Beijing (with supervision at Tsinghua University), I interviewed employees in solar manufacturing, innovation finance, IP enforcement and IP law, as well as domestic and foreign journalists. My interviews were carried out in Beijing, Shanghai, Chengdu, and Jiangsu (as I drew up my list of interviewees before travelling to China, and carried out interviews in a wide range of sectors, I avoided the "snowballing" of contacts that could have brought in any bias). I also took tuition in the use of the Hexun online company search system (discussed below). Although my field research was vital in understanding the qualitative background of the innovation system and solar PV industry, it was throughout this exploratory phase that it became clearer that due to the unwillingness of solar PV executives and staff to disclose their firms' technological strategies during interviews, I would adapt by using quantitative data sources more heavily than originally envisaged (described in the next sub-section but one).

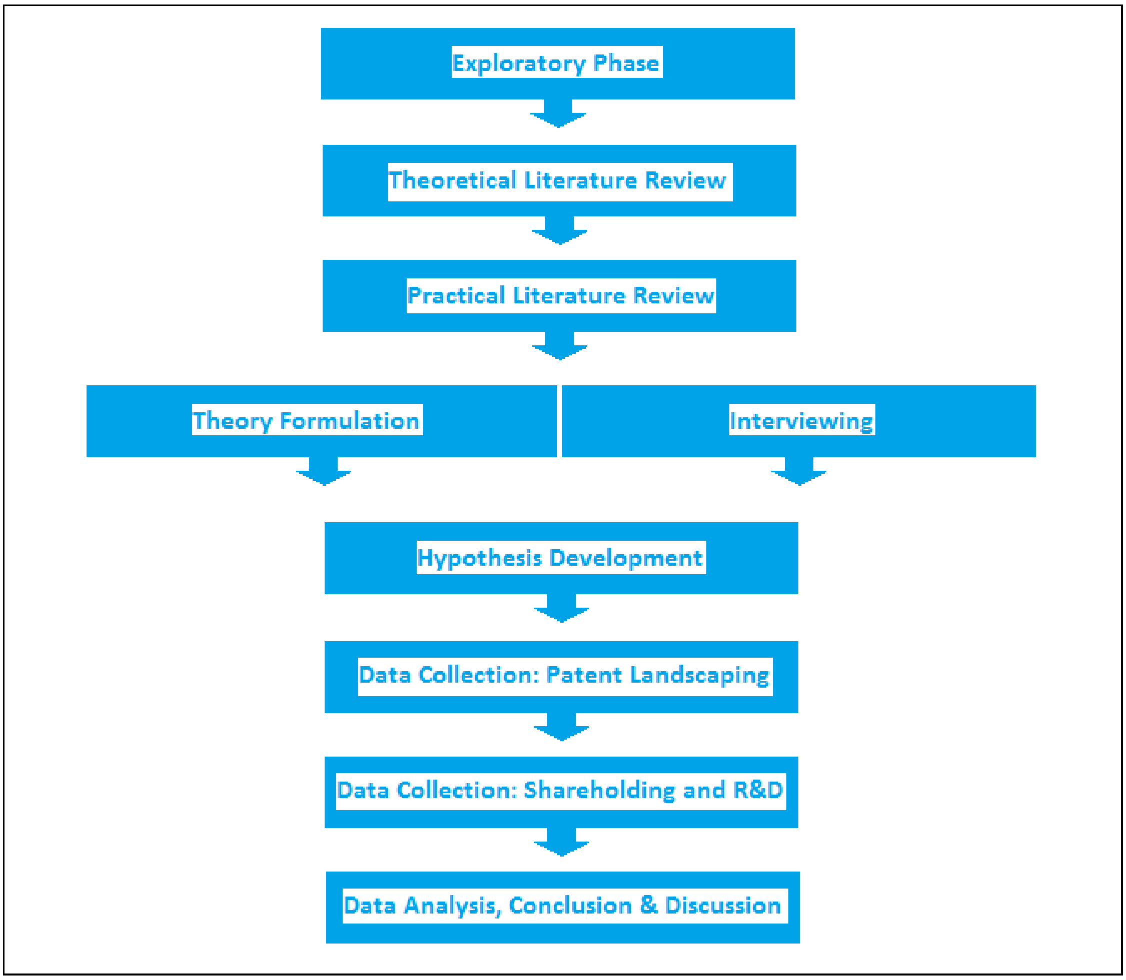


Figure 14: Overview of the research process (adapted from Kim and Miner, 2007)

6.2 Interviewing methods

I carried out fifty-eight interviews in total (not counting conference attendance in China and the UK, which has provided supplementary information). These interviews have all been semi-structured, and I divide them into the following themes: legal, technology, politico-economy, and investor. Interviews have been carried out in person in the UK, China, the Netherlands and Belgium, and by phone in Switzerland, Germany and the US.

My interviews began very early in the research process, to help select a specific technology area in China, to obtain general guidance on the Chinese innovation environment, and for advice on how to source quantitative data. These conversations, though also semi-structured, were generally less structured than later interviews. Later, and especially during my China-based research, interviews were more focused on specific areas, with more exact informational objectives.

Semi-structured interviewing is a tool with which to ask similar types of question to interviewees, while accounting for various unexpected tangents they may wish to pursue. Relevant associations between interviewees and lines of investigation can then be drawn out. Different methods and viewpoints can thus be integrated "to identify and represent, as accurately as possible, the phenomena under investigation" (Easterby-Smith *et al*, 2008). This is also necessary to my research, to increase confidence in the accuracy of the observations produced.

The broad reasons for using semi-structured interviews begin with Jones (1985), who states that research begins with some knowledge of the subject on the part of the researcher. This leads to particular lines of questioning which are seen as particularly central, which can naturally change during the interview process depending on new information coming to light. While (highly) structured interviewing begins with carefully selected question sets which have been refined through much prior analysis, this depends on both sufficient research time to hone these questions, and considerable prior knowledge of all question areas (structured interviews are also particularly useful for comparing results from large interview samples). None of these criteria apply in our case. Meanwhile, unstructured (or "non-directive") interviews are often believed to be the best means to gain a clear picture of the interviewee's perspective (Easterby-Smith *et al*, 2008). However this method may produce no clear understanding by the interviewee of what the researcher is looking for, especially in researching complex phenomena.

Semi-structured interviews are also suitable for other reasons. The semi-structured interview is a qualitative one, whose aim is to find not only the respondent's viewpoint but also why they have it (Jones, 1985). In our case, confidentiality is a potentially sensitive issue, and semi-structured interviews allow a higher degree, as replies can be more tailored (Easterby-Smith *et al*, 2008). Non-verbal cues (including facial expression) can also be recorded more freely. For this reason, face-to-face interviews are preferable to telephone interviews *per se*, however telephone interviews formed a significant proportion of my own, both by necessity of time constraints and to re-contact interviewees to follow up.

All interviewees were informed that any part of their responses could be anonymous if they wish, and that I could be contacted later should they wish to anonymise any response. I also used the term "discussion" rather than "interview" when contacting potential respondents, to reduce formality and increase the potential for genuine exchange. Some interviews were recorded, but where I judged that the very presence of a sound recorder would hinder interviewees' honest answering (despite assurances of confidentiality), hand-written notes were taken instead.

One technique used to obtain as much detail as possible from interviewees was "laddering" (Baker and Knox, 1995, in Easterby-Smith *et al*, 2008), which involves beginning from more straightforward questions of fact, then "posing upwards", or going into more depth to obtain more detail about their reasoning (done sensitively to avoid arousing suspicion). The other techniques I used (adapted from Easterby-Smith *et al*, 2008) are:

- Basic probes: repeating the initial question if an interviewee goes off the point
- Focussed probes: used to find specific information, and can often start "What sort of...?"
- Silent probes: when the interviewee is hesitant, a brief silence can help
- Giving suggestions: giving the interviewee an idea or theme to ponder

- Mirroring: expressing in my own words what the interviewee has just said, prompting the interviewee to expand on the answer. To avoid bias, probes should not lead (e.g. "Would you say you are happy with...?").

The settings for interviews are also influential. As well as telephone interviews, I used a number of settings for my face-to-face interviews, by necessity and choice. Bowey and Thorpe (1986, in Easterby-Smith *et al*, 2008) described how researchers find unguarded conversations are easier outside the formal confines of offices, and I used relatively neutral spaces such as cafés, although in some cases interviewees preferred to meet in their offices.

In sum, the four themes of interviews provided me with guidance as follows: legal interviewing was aimed at obtaining advice (and written sources) on the Chinese IP system, and comparing the place of Chinese private and state-owned firms within it. Technology-focused interviews began as a source of information on which area of China's cleantech economy would be the most appropriate for study; having chosen solar PV, these interviews were used to develop my knowledge on its technological areas, helping a qualitative understanding of the Chinese industry, and to structure the patent database along technological lines once it was obtained. They also provided detail on likely future industry development in China and worldwide. Politico-economic interviews were carried out with experts on China's innovation and IP system, including lawyers, academics, and journalists. This information was vital in building the theoretical framework, providing information on how the innovation system affects managerial decision-making around R&D investment. They also provided data on the development of China's IP system, trade and commercial laws, and state interactions with and development of China's solar industry. Finally, investor interviews provided actual investment experience and preferences (including, like technologist interviews, real IP-related problems encountered). They also provided comparative information on other sectors, and more contextual information on China's economy in general.

In interviewing style, I have divided my interviews into three broad methods, which I have called exploratory, focused, and pin-point. The first type was most common in the early stages of research, and involved a discussion using a set of points decided beforehand, but allowed to go in different directions. These were intended to help set the research direction, find the most appropriate research question, and gain as much general information as possible from the interviewee. Focused interviews were the most common method I employed in China in particular, by which time I needed more detail about specific questions, but where many interviewees' hesitance to discuss particular aspects of their work (due to political sensitivities) prevented a more direct approach. Pin-point interviews were most common both later in the research and with technologists and investors, whose expertise on specific business and solar technology areas I required. They were frequently used with China-based experts in legal and commercial fields, and technologists outside China (please refer to the appendix *Interview table* for full details).

These semi-structured interviews formed part of a "multi-method" research approach that covers quantitative and qualitative methods. Brewer and Hunter (1989, 182) described these multi-method approaches as "either single studies or more complex programmes of continuing research, which systematically employ various combinations of field, survey, experimental, and non-reactive methods to address their research questions". Combining quantitative and qualitative methods, multi-method approaches can help increase the robustness of our findings (Mingers, 2001), helping gather more information on the different aspects of a phenomenon, thus producing more comprehensive explanations. Quantitative analysis may obscure important questions, such as how state or private owners may address a firm's corporate governance, how this is related to firm objectives, and how this has shaped their technological innovation, as manifested in patenting. This is central to the importance of semi-structured interviews. Surveying the theoretical and technical literature also helped to focus these interviews, generating additional insights.

6.3 Methods for obtaining quantitative data

We shall now outline the assembly of the quantitative dataset, before describing the quantitative analysis in the following section. I first carried out a search for Chinese solar PV patents via Cambridge IP Ltd's patent landscape system, using the full range of search terms for solar PV (see appendix). This is described as follows.

6.3.1 Methods for patent search and compilation process

This stage involved the *patent landscaping* of Chinese solar PV patent ownership. The patent landscape study of China's solar PV patent holders aims to cover every solar PV patent held at SIPO, and enables us to establish which firms are innovating to more or less advanced levels in solar PV (this is followed by establishing their levels of ownership, explained below). This provides the empirical fit with the theoretical framework. The patent landscape process, including the stages of patent search and filtration, carried out at Cambridge IP Ltd, is described as follows (also see the Appendices for the full list of the information contained within a patent):

1) The process of accessing and compiling the appropriate patents began with the creation of a *Mindmap* (a diagram used to outline information visually), which is a diagrammatic "tree" illustrating the broader and more specific technologies of interest, and the relationships between them. The Mindmap allowed me to carry out the patent searches that followed in a coherent order.

2) The next stage involved using Cambridge IP's LexisNexis Patent Search account to obtain all the patent data. This involved using a list of search terms assembled using the Mindmap technique to obtain every solar photovoltaic patent registered at the State Intellectual Property Office (SIPO) in Beijing (this also included all three tiers of patent quality allowed by the Chinese system (inventive, utility, and design) and all patent families, including foreign-registered families, to be obtained).

   As such, the Mindmap diagram allowed the creation of a coherent list of search terms. For the patent search, please refer to the search terms in the appendices, used in the algorithms for Boolean searches for patent titles and abstracts.

To use a simple example, one broad search takes the form of the following syntax (see appendix for the list of search terms, and the list of the Boolean searches derived from them):

(silicon! W/3 process! AND solar AND photovoltaic) OR (silicon! W/3 process! AND solar AND PV)

Or

(silicon! W/3 ingot! AND solar AND photovoltaic) OR (silicon! W/3 ingot! AND solar AND PV) (ingot! PRE/3 silicon! AND solar AND PV) OR (ingot! PRE/3 silicon! AND solar AND photovoltaic)

3) All the patents were then uploaded onto Cambridge IP's processing system, *Delphion*, in separate lists of the type shown in the generic (non-solar PV) example below:

Figure 15: Patent uploading (source Cambridge IP Ltd., 2012)

The correct "data extract" that would include the data we deemed necessary was included, for every patent, as in the list in the following example:

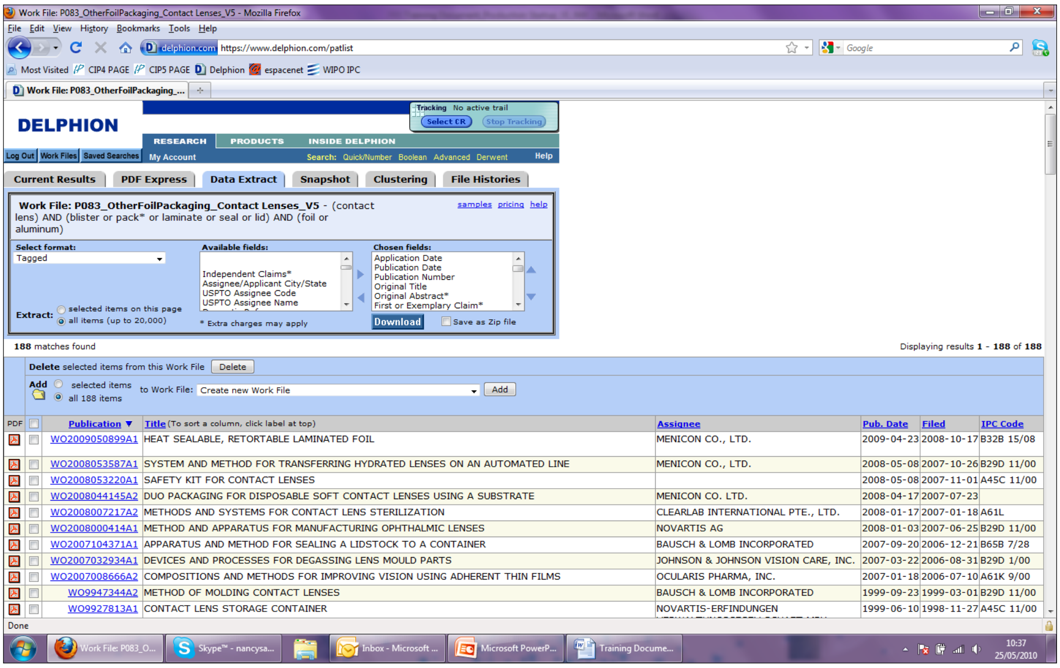


Figure 16: Data extracting (source Cambridge IP Ltd., 2012)

This search process was repeated, up to a maximum of 5000 patents at a time, for each Boolean search algorithm as needed.

As the search inevitably also produced numerous patents which referred to innovations other than solar PV, those which referred to solar PV patents were kept, and those with only non-solar PV codes were removed. Taking some weeks, this had to be done by a hand-trawl of the patents. The complete workfiles were uploaded.

4) We then ensured that the sample contained only patents *originally* registered at SIPO, by using a location filter.

5) The next stage, for the approximately 9,000 remaining patents, was namelist normalisation. Firms often file patents under different company names (for example the German conglomerate Bosch can appear as Bosch GmbH, Robert Bosch GmbH, R. Bosch, and so on), and occasional spelling errors can be found in assignee names. Holding companies meanwhile will sometimes use the overall holding company name, or that of a subsidiary for different technologies, even if the patents are filed under the same inventors' names. Furthermore, Chinese firms sometimes file using their name in Chinese characters, or Pinyin (Chinese transliterated into western script), or under a variety of possible English names. As a result, it was necessary to hand-check all the names of patent assignees, and normalise them into one name per assignee organisation. The exception was for cases where two or more separate subsidiaries of a conglomerate appeared, which were listed as separate firms if necessary. Following this, the entire list of normalised names was filtered down, from a sample of approximately 980 organisations globally, to include only Chinese (excluding Taiwanese) firms (and no non-profit institutes or universities, although firms established by these entities were

allowed). This produced a list of approximately 600 appropriate assignees (from which the sample of 150 would later be taken). Although it is possible to normalise the names of the inventors, this was not needed for our purposes.

Following the namelist normalisation, Redeye was used to filter the patents along the following general guidelines, which we will describe:

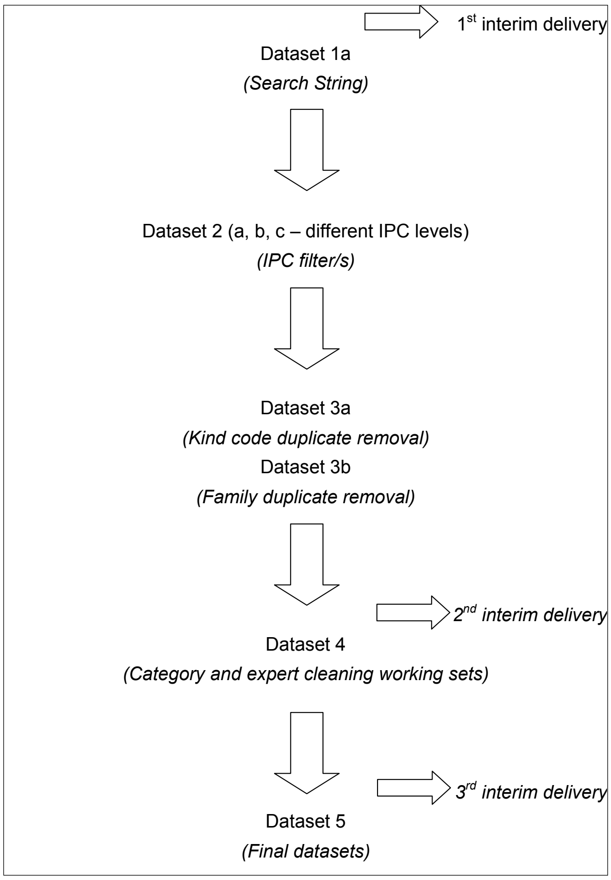


Figure 17: *Redeye* patent filtration (source: Cambridge IP Ltd., 2012)

6) The next Redeye processing stage was to filter the patents for the appropriate International Patent Classification codes (IPCs), which classify patents by the types of technology to which they refer, allowing us to divide these patents into technology types within the solar PV field (to be discussed further in the hypotheses). These categories were: silicon processing; wafers; cells; modules and arrays; components; concentrated solar; and thin film and next generation (see appendices for an example range of IPCs). For each of these filtering stages, the system was used as follows: in the Filters tab, a criteria was chosen from the drop down menu, e.g. IPC codes; then the specified filter keyword was entered (e.g. a specific IPC code); "Add" clicked; Repeated as necessary; "Render" was selected and the results could be viewed.

7) The next processing stage involved Kind Codes. A kind code usually uses a letter (sometimes a letter and a number), at the end of the individual patent registration number, which

determines the type of patent (in our case inventive, utility, or design) and the level of publication (whether the patent has only been applied for, or has been registered). The main kind codes used by SIPO in China are as follows (for the list of all other possible Chinese kind codes, please see appendices):

A: Unexamined application for a patent for invention
C: Granted patent for invention
U: Utility model application
Y: Granted patent for utility model (since 01/04/1985)

Filtering for kind codes involves removing any patents which have the same registration number but a different kind code suffix (in so doing we make sure, for example, that we do not double-count an application and the patent that resulted from it). So for example CN102055572A and CN102055572C would count only once. Please note also that we count only those applications that have been granted.

8) Finally, we filtered by Patent Family. A patent family is a set of different patents taken out in various jurisdictions to protect a single invention, or a set of several inventions sharing a common aspect that are published at different times in the same jurisdiction (WIPO, 2012). Once we have removed non-Chinese entities, filtering by patent family therefore allows us to see which Chinese firms are the most successful at patenting overseas, another indicator of patent quality.

The outcome of this filtering process gives us a patent data sample that covers the following data:

- Number of patents filed by each firm in the sample
- Number of inventive/non-inventive patents by each firm
- Number of patents filed by each firm in each category of solar PV technology
- Size of each patent's patent family, where one exists
- From the information on each patent, we also extract the number of forward citations, where applicable, for each patent. Forward citations, as described above, refer to a patent being cited as prior art for any subsequent patent by any applicant, and is usually taken as an indicator of relative quality.

This process allowed me to create a list of firms which had a minimum of one SIPO patent, of any kind, in solar PV (from which I then removed firms of which there was no other trace despite their appearance as patenting firms with SIPO). This is the whole population from which I drew my final sample, and my sampling procedure was simple "decimation": I went down the list taking every 10th firm until I reached my desired total. I then became concerned that this procedure might not have given me an adequate number of what could reasonably be defined as high-performing firms. After examining the population I decided that I would stratify my sample with a higher stratum of higher-performing firms (defined as those with at least five SIPO invention patents), and decided that 10 such firms would be a sufficient number. I then checked the sample and found that I already had five such firms in my sample. Needing five more, I repeated the process of decimation until I had found five more such firms (this also gave me all the listed firms available). I added these to the sample and took out the last five firms I had originally selected.

Thus I had combined two strata, both randomly selected:

1. Firms with at least one SIPO patent of any kind but less than five SIPO invention patents
2. Firms with at least five SIPO invention patents

Therefore I created a stratified random sample. Clearly I *oversampled* stratum 2, by doubling its size from the original five. Although the sample is thus not precisely representative of the population, it is theoretically representative.

6.3.2 Methods and process for establishing firm shareholding levels, R&D, and control data

Having explained the rationale behind the selection of each of these fields of data, we will describe the sources from which they were gathered. Please note that due to the variety of Chinese companies we analyse (for example listed, unlisted, and previously listed firms), for many firms we use a combination of the data sources below.

<u>Capital IQ:</u>

The *S&P Reuters Capital IQ* database contains the shareholding details of every listed company (on all stock markets), and allows analysis along a number of planes (this is appropriate because our sample includes every currently listed Chinese solar PV firm). First, Capital IQ allows analysis along both private and public investments, which can be broken down historically. For each firm, once specific shareholders and their shareholding volumes are gathered for each year, these are checked for their status as foreign, private, or Chinese state of any type (via Baidu, Google, or annual reports, as below).

Capital IQ also compiles all annual reports for each financial year that a firm is (or was) listed. These typically provide background data on the major shareholders, as well as in many cases all shareholders. In the minority of cases where shareholding information was not available in either the database or the corporate literature to which databases linked, the firms were called by phone to confirm their status. With the exception of many firms listed on the mainland Chinese stock markets (Shanghai and Shenzhen), the annual reports also provide some R&D data, in the form of either staff numbers or expenditure.

<u>Hexun:</u>

Hexun.com is an online Chinese business and finance information service which includes the shareholding data and annual reports of all the firms listed in mainland China and Hong Kong, as well as a considerable range of firms on other stock markets globally.

On Hexun, in the homepage search box, a given company's stock market "ticker" is entered (for example *JASO* for JA Solar). On the following company-specific page, the link "股权分析", or "equity analysis" is selected. From this, the following sub-categories are chosen: 股本结构, 十大股东; these are shareholding structure and top ten shareholders. As with Capital IQ, for each firm, once specific shareholders and their shareholding volumes have been gathered for each year, these are checked for their status as foreign, private, or Chinese state of any type, and whether the shareholders are other firms or investment funds.

Also as for Capital IQ, annual report access is also provided for the listed Chinese firms, and when this method also left gaps in the data, firms were called by telephone. The databases also provided access to the control data needed. Where possible, all information provided by the databases was checked against data provided on individual company websites. Where these were contradictory the data provided by the databases was given precedence.

6.4 Variables

6.4.1 Dependent variables

Our dependent variables are indicators of innovative success as measured by patenting information. We distinguish between measures of **patenting performance** and of **patenting productivity**. Measures of patenting performance are derived purely from patenting data. Measures of patenting productivity involve a second stage, and are derived from patenting performance divided by a measure of R&D. The patent metrics are collected from a sample (obtained from Cambridge IP, as described above) of patent information for 150 Chinese solar PV manufacturing companies, comprising all the patenting carried out by this sample of firms, up to and including 2012. Note that the years to which patents are allocated are years of application, but to be included in the dataset a patent must also have been granted.

We may note at this point that the standard treatment of patent performance in studies of western firms is to take patent count weighted by forward citations. There are two problems if one seeks to follow this procedure:

1. We have very different qualities of patent. A patent that has led to a foreign, especially USPTO, family registration, is considerably harder to achieve than a SIPO inventive patent, then (at the bottom) the SIPO non-inventive patent. From the point of view of this study the USPTO patent is the most interesting, but if we were to use only USPTO patent data for the dependent variable we would lose most of our information – because USPTO patents have been obtained by only a very small minority of the firms in the sample.
2. The other problem would relate to forward citations. The standard procedure is to take five years of forward citations – in other words, for a patent applied for in 2008, to look at citations up to 2013 (one could not then consider patents applied for after 2008, because the data would not yet be in). However the large majority of patents granted to my sample of firms appear to have been applied for after 2008.

The most systematic way of addressing this problem is to use factor analysis. Each of the factors generated in turn can be used as a dependent variable (Tolmie *et al*, 2011). So far we have been dealing with "patenting performance" (or "PatPer"). Clearly other things being equal, a firm which is spending, or has spent more on R&D, will have a stronger patent performance. This effect can be modelled by including a measure of R&D as an independent variable in the regression. Alternatively, we can define our dependent variable as patent performance per unit of R&D, or "patent productivity" (PatPro). An inventive firm would arguably be one which had high patent productivity (which made efficient use of its R&D) rather than high absolute patent performance. The dependent variable in these cases therefore becomes our measure of PatPer, divided by R&D spend (see below on our R&D data and R&D measures).

6.4.2 Independent variables

The core independent variables are a number of measures of ownership type. They relate to:

1) **Domestic private, central state, and sub-central state, shareholdings**. The relevant hypotheses do not assert any linear relationship between any of these, and the inventiveness or innovativeness of the firm. Instead they make assertions about the effects of different categories of ownership, e.g. "Central MASOEs" and "Municipal MISOEs", etc. The data here is therefore used to assign firms (in a specific year) into one of these categories (and thus to create dummy variables for four of them). They are defined as follows:

- POE (100% privately-owned enterprise)
- Central SOE (all SOEs regardless of government level refer to 100% state ownership), Central MASOE (above 50% state ownership), Central MISOE (state ownership of 50% or below)
- Provincial SOE, Provincial MASOE, Provincial MISOE
- Municipal SOE, Municipal MASOE, Municipal MISOE
- Super-municipal SOE (super-municipal refers to ownership by the governments of Beijing, Shanghai, Tianjin, or Chongqing, these being the provincial-level cities of China), Super-municipal MASOE, Super-municipal MISOE.

  The broad point of this distinction is that the state has direct control over a MASOE or SOE whenever and however it wishes to exercise it.

2) **Foreign shareholding**. Since the hypothesis is that the stronger the influence of foreign shareholders, the more innovative the firm, this is a continuous variable, i.e. percentage of foreign shareholding. (Note that for a large proportion of the sample this value is zero)

3) **R&D data.** As explained above, R&D plays an important role in the hypotheses and regressions. For PatPer it is an independent variable. For PatPro it is the denominator in the dependent variable(s), with PatPer for time t divided by R&D for time t-2 (because there is an assumed lag of 2 years between R&D input and patent output: see the R&D discussion below). R&D data is compiled as annual R&D expenditure.

6.4.3 Control variables

The first two control variables are commonly used in this type of work and also available here:

1) **Age of firm in years since foundation**

2) **Size of firm in number of staff**

3) **Location:** this control variable should also be used, since there is a substantial body of work which claims that (for example) inland firms behave differently from those in the coastal provinces, which are more advanced and where accordingly the government is likely to play a less interventionist role. That claim implies two simple categorical variables, which would reduce to one dummy: coastal (1) or not coastal (0). However there are less crude distinctions – coastal, central, western – and the fundamental proposition in most of this work is that the more advanced the area, the less interventionist is the state. Thus location is represented by provincial GDP per head, making it a third continuous control variable.

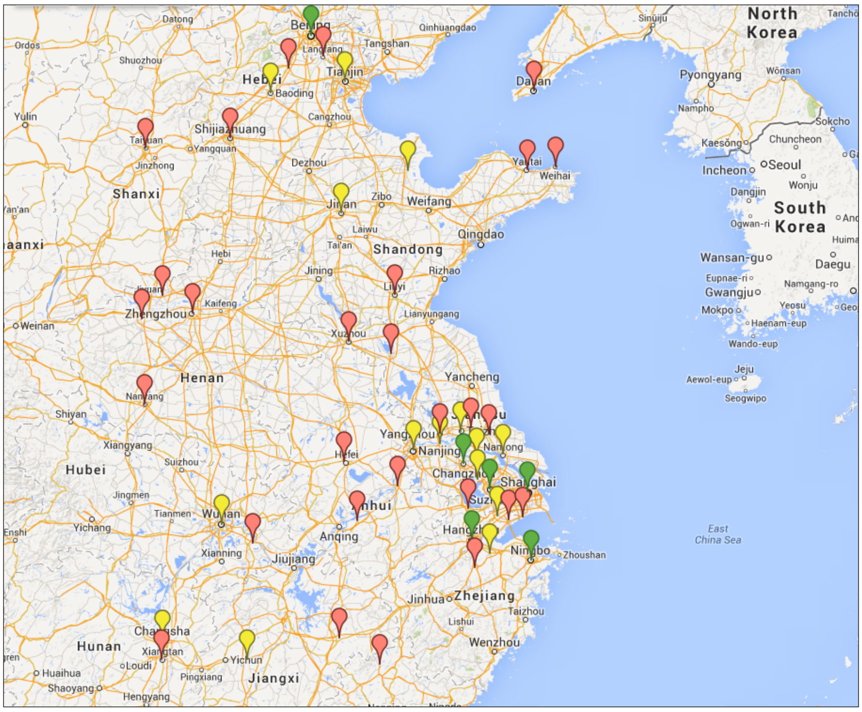
4) **Agglomeration**: the final control variable was assembled for agglomeration. Porter (1998) and Krugman (1991), among others, have built on the thesis originally pioneered by Marshall (1890), which established the benefits of firm clustering, using the case of metalworking firms in Sheffield during the industrial revolution. The concern in our case is that solar firms may benefit from proximity to other firms, through interchange of talent within the workforce, and the increased efficiency of suppliers and buyers nearby.

   In order to be able to introduce this control variable into the regressions, the following procedure was undertaken: for each firm in the sample, the location (by city) of its headquarters was recorded. A list was then made of all of these cities with HQs of firms in our sample, and the number of firms in the sample located within each city (which ranged from 15 to 1). Each of these cities were marked on a map of mainland China; next, each was assigned a number representing its "agglomeration rating", i.e. the number of firms in our sample within 100 miles (meaning how many other patenting firms in our sample would be within 100 miles for a single firm in this city, plus the firm itself). As with "location" above, this appears to be a superior method to using a cruder dummy.

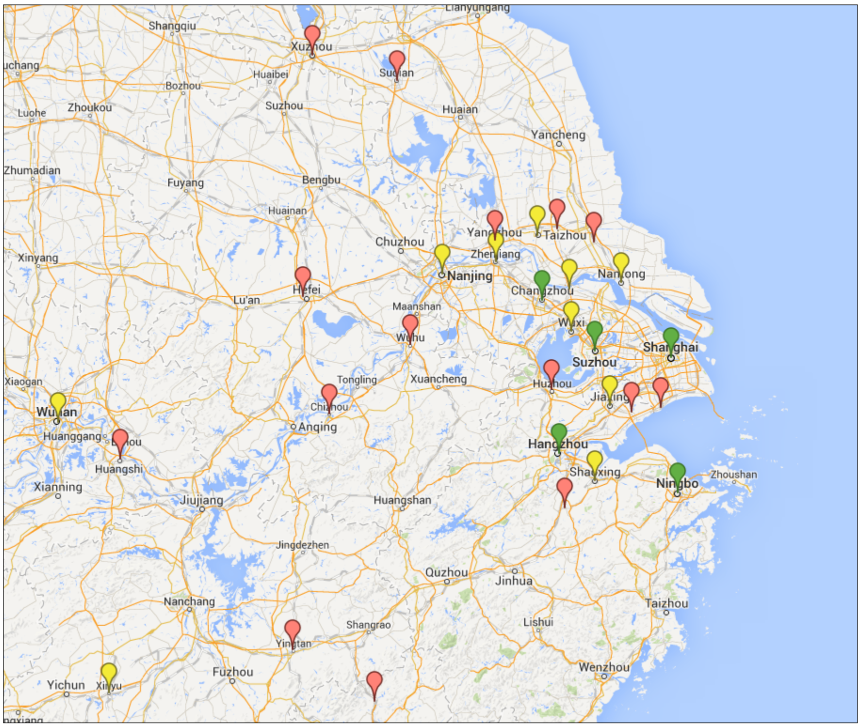
In the maps below, this rating was marked on each city using the following key: red is a city with 1 patenting firm; yellow means 2 to 5 patenting firms; and green means 6 or more patenting firms:

a) Agglomeration: all China

b) Agglomeration: China excluding the periphery



c) Agglomeration: coastal China



d) Agglomeration: the provinces of Jiangsu, Zhejiang and Shanghai

Figure 18-21: Maps of the agglomeration of patenting solar photovoltaic firms across China

6.5 Treatment of data for regressions

In approaching the relationship between the variables, first we lag the dependent variable by two years on R&D, and by a further year on ownership variables (there is no lag on the control variables except size, which has a three year lag). As argued in the discussion of patenting, patent output can be regarded as mainly an output of R&D, and not an instantaneous one: it is conventional to assume a 2-year lag between R&D and patent applications (Leydesdorff and Wagner (2009), Prodan (2005) Hall *et al* (1986)). Likewise, R&D (in quality and quantity) is regarded as determined by size and ownership characteristics, again not instantaneously: here we assume a modest one-year lag. The following issues arise with such a model:

1) Sample selection bias. As explained, the sample has been selected on the basis of the dependent variable – there must be at least one SIPO patent for the firm to be included (and the sample has been stratified, as explained above). This could raise the possibility of selection bias, however a number of facts mean this is not seen to be a problem. First, a firm that during the entire period has not gained even one SIPO non-inventive patent can be said to be very uninventive indeed. As such, the sample still includes a very wide range on the dependent variable(s), thus a very wide range of inventiveness within the sample. Furthermore, the sample also contains most of China's patent-registering commercial solar PV firms. Meanwhile, our sample also covers the full range of ownership types, both by the proportion of state shareholding and the level of state shareholding between central and local governments.

2) Reverse causation. The assumption expressed in the hypotheses and the model is that the direction of causation runs from ownership to patenting. However any correlation that is found could be the consequence of causation running the other way: e.g. a strong patenting performance leading to a higher foreign shareholding. Again, as with selection bias, the extent of reverse causation is likely to be low. In each direction of causation a clear time lag can be assumed. In the expected direction it is three years (see below). In the "reverse" direction it seems unlikely to be less than two years. Thus where the predicted effect of ownership at time t is on patenting at time t + 3, the "reverse" possibility is that ownership at time t is affected by patenting at time t-2 (and before). The "reverse" effect can only be mistaken for the first effect if there is quite a high correlation between a firm's patenting at time t + 3 and its patenting five years and more earlier (furthermore there can only be a reverse effect if there have been substantial changes in ownership before time t-2). My visual inspection of the sample however indicates that there have been very few substantial changes in ownership (for both selection bias and reverse causation, see testing below).

6.5.1 Cross-section versus panel data regressions

From the outset the research has been structured around cross-section regressions. The sample of 150 is seen to be ample for this purpose, and the variability of the data – independent variables, control variables, and dependent variables – across firms is also large. For cross-section regressions it is also necessary at times to use averages of the annual data, reducing the noise in the dependent variable, for which the annual data is relatively limited. Thus instead of applying the 1 + 2 year lag structure to single years (e.g. ownership for 2005, R&D for 2006, PatPer for 2008) ownership can be averaged where necessary for 2004, 2005, 2006; R&D for 2005, 2006, 2007; and PatPer for 2007, 2008, 2009.

The possibility of running panel data regressions was also considered: this was possible in principle since the data runs from 2000 to 2012. However many firms in the sample were not founded until after 2000, and after 2008 the quality of any dependent variable diminishes because there is less than five years for forward citations (as we discussed in section 4.2.2, Griliches (1981) found pessimistic implications for using overall patent counts as indicators of *short-run* changes in the output that comes from R&D input). Bearing in mind the three year lag between the independent variable and the dependent variable, this did not leave room for the time series element of panel data. Moreover, visual inspection of the data suggested that there was little variation over time in most of the independent variables.

7. Theoretical Framework and Hypotheses

7.1 Theoretical framework – resumé

Our theoretical framework uses a principal-agent model to discern how ownership (specifically state, private or foreign) affects a firm's innovation outcomes, as measured by output and quality of patenting. The forms that this principal-agent model will take are specific to the Chinese innovation environment, as we shall explain. We note that the normal aim of the principal is to maximize profit over some period, in which case innovation is a means to that end (and in a high-technology sector such as solar PV, a rather necessary means).

In the first category, in which the principal is the private owner of a technology firm, the owner of shares is believed to be a person or cohesive group of people. This creates a short chain of agency between principal and agent (the manager or managers of the firm). The principals thus have a clear commercial incentive for their firm to innovate, in the gain they can expect to realise should this innovation be successful. However, we have described the Chinese state's position of discrimination against private firms (in areas such as bank lending, standard setting, and the unofficial realities of the legal protection of intellectual property). This means that although private principals' short chain of causation will allow a strong innovation incentive in the form of potential commercial gain, their firms' relative inability to capture the results of this innovation will in turn disincentivise innovation.

In the second category, in which the whole or majority shareholding principal is the state, the ultimate owner is not a single person or cohesive group of people. Ultimately, the state claims to represent the people of China; however, just as in the western context the trustees of a pension fund act on behalf of the pensioners whom it represents, state ownership creates a longer chain of agency, as the bodies of state act as principals on behalf of the Chinese people. Furthermore, the various state bodies that control majority or wholly state-owned firms are dispersed, which means that the control of any given principal of the principal-agent chain is diluted (as we have seen, at the central level this chain takes in the State Council, ministries, and SASAC; at the local level it includes local governments and local SASACs). This creates an unorthodox situation, in which there is no cohesive principal at the top of the principal-agent chain. This means that although these firms are well-placed in the Chinese innovation system (for protection of intellectual property, bank lending, and other resources), their principals being dispersed (and having responsibility for many other government units and objectives) disincentivises them from carrying out the proper governance or monitoring needed for innovation in individual firms, as does their manager-agents being assessed on many different metrics.

However, this form of principal-agent chain is modified between the contexts of central and local government. We have seen that, in addition to the 'normal' aims of the principal, which make innovation a means to the end of profit, the central government is also interested in innovation as a means to another end: the growth of Chinese firms in high-tech sectors. In the case of central government ownership, the multiple responsibilities of the cadres charged with responsibility as principals (and longer chains of control through successive tiers of state) means they have little time to dedicate to any given responsibility, and must rely on indicators such as crude overall patent outputs. The result is likely to be firms whose innovation is relatively poor, at least in relation to the resources devoted to it. Lower down the echelons of government however, principals are responsible for fewer firms and have shorter chains of control. This means they have a stronger incentive for any given firm to innovate, and may dedicate more attention to these firms (in particular, our framework implies that municipal shareholding, including provincial-level municipalities, will provide a combination of incentivised management and resource capable of achieving superior innovation outcomes than other levels of state ownership).

A third category sees private shareholder principals with majority ownership, and state principals with a minority. This is seen to have the following impact: given majority ownership, the private shareholders maintain their incentive, as described, to monitor innovation in the firm. With minority ownership meanwhile, the state shareholders cannot dominate decision-making, but provide the state resource and legal protection that allows the private owner-principals to pursue innovation without the threat of state appropriation or hindrance.

Finally, our framework takes into account the possible presence of foreign shareholding. Although Aulakh and Gencturk (2000) suggest that in international principal-agent relationships there will be problems of poor control over agents abroad, foreign ownership is still likely to mean superior innovation conditions. As principals, foreign shareholders will have similar incentives to domestic private shareholders, having a commercial incentive for a firm to be genuinely innovative. While investments by a particular foreign fund may be split between numerous portfolio firms, decreasing their incentive to monitor any given firm, this is likely to be balanced by their interest in export-driven sales, more dependent on a firm's innovative capacity. As such, foreign shareholding is seen as following the innovation-driving rationale of domestic private shareholding. The framework is outlined in the diagram below, with different shareholder-principal types, and the forms of agent firm-by-firm in the environment of the Chinese innovation system.

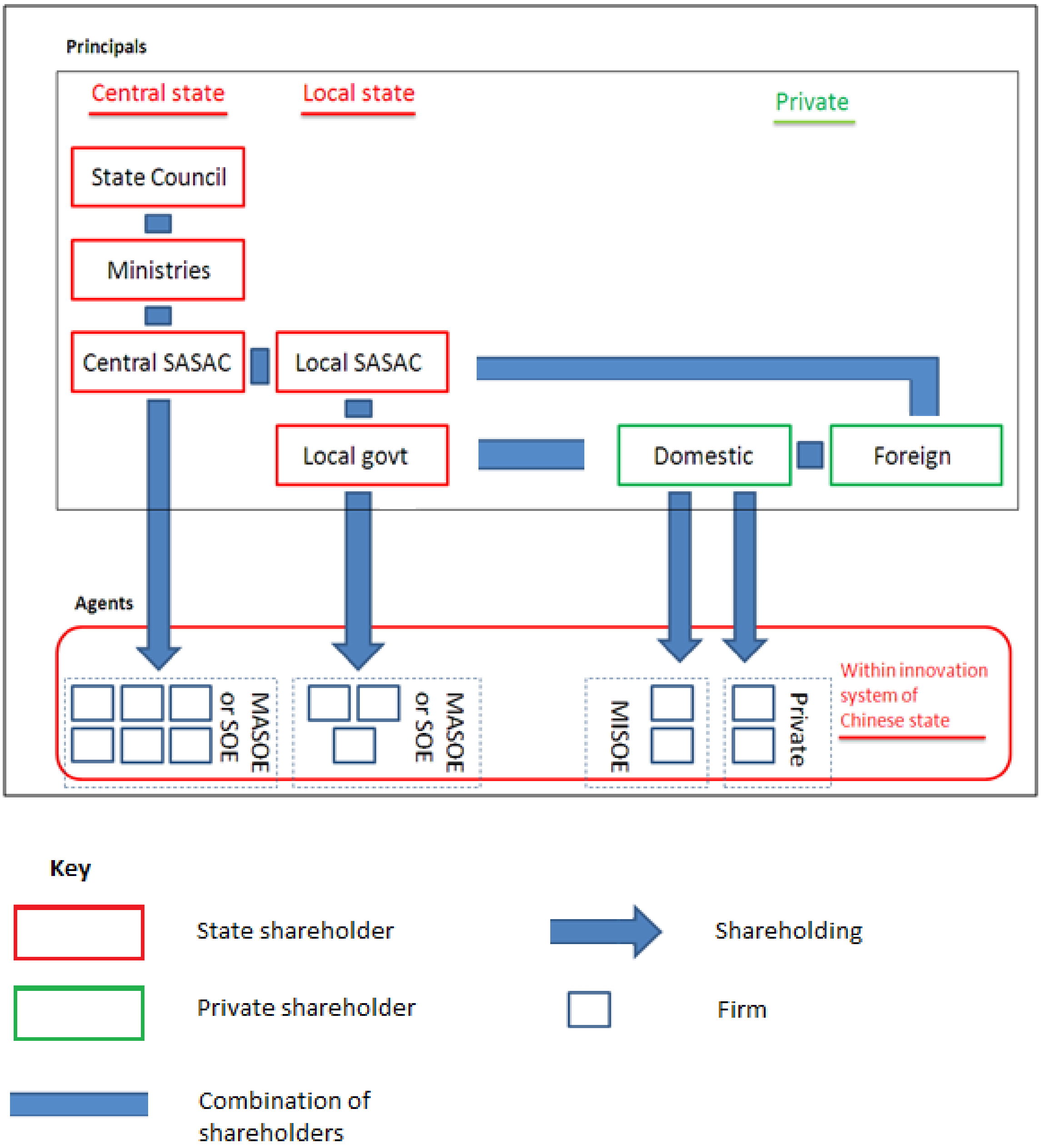


Figure 22: Theoretical framework

7.2 The application of the theoretical framework to the different ownership categories

We now apply the framework to the different ownership categories, defined both in terms of level of state (central vs local) and proportion of state shareholding.

Regarding the effects of central government shareholdings in the majority:

The length of the chain between agent-managers and principals in the case of state-ownership is considerable, compared to private (or foreign) ownership scenarios. Ultimately, the theoretical "principal" is the people of China, whose state assets are then overseen by more principals through the chain of ownership (State Council, SASAC, the Organisation Department, and ministries), who give Party member cadres the task of being agents and managing the actual firms. This longer-chain situation creates more obstacles to agents' incentives to make sensible investments that will bear fruit in innovation, and to their monitoring by the principals (in government) who want that innovation to occur, and thus increases the moral hazard (or hidden actions) created by agents at the expense of principals.

The implication is that central government shareholding is the least conducive to innovation of all forms of shareholding. We should add that for the central state, like large SOEs, smaller business units or single firms under the state have little effect individually on outcome either for a large SOE, or the state's innovation success as a whole. This is disincentivising both for overseeing principals and agent managers (and conversely it makes little difference if they fail). Cadres generally have secure tenure, and long-term firm performance after they cease to be managers seems unlikely to improve their prospects. While in a private scenario agents could normally expect to benefit from the "profits made by the establishment" (from Babbage), which could be through promotion or options, state employees know they will likely be transferred to a different location before they can share in profits from innovation. This means that the "husbandry instruments" (of Smith), in our case investment, are liable to be misused for short-term payoffs.

Although, like other principals, in order to control them the state attempts "measurement of performances" for agents, it can only do so by quantifying innovation, leading to R&D focused on the Leninist-style output measures that get rewards (which include utility patents for example), but which are unsuited to complex, globally competitive innovation. Although Miller (2005) stated that typically "directors [do] not constrain the CEO by specifying a particular procedure", this is exactly what state principals are doing through these demands.

The principal-agent chain we have described means state agents are led to make dubious decisions; this is because the *information asymmetry* situation (Miller, 2005) is more severe. The numerous state principals to which agents may be answerable will have to oversee numerous agents, and assess them on a range of performance metrics as mandated by state rules: demonstrating that a firm is innovating successfully will be only one of these. Miller noted that an *asymmetry in preferences* problem can occur, and for state principals this is also more severe. We have described this as meaning that actions in a principal's interest can harm the agent (Miller, 2005). Successful innovation outcomes for instance may be conducive to the principal's wellbeing, but the long-term investment they need is likely to be detrimental to an agent if they are graded on outcomes that are measurable primarily in the *short-term*. The lack of a "unified principal", with oversight split between different areas of the state, is also liable in this case to be detrimental: it is not credible that an agent's "best response function" can be known (and matching incentives crafted) by a principal, or set of principals, who are spread through various bodies in the state and have large numbers of other agents to monitor. The potential for takeovers, which should provide so-called "discipline of last resort" (Fama, 1980, 288) by focusing managers on succeeding at market-oriented innovation, is also relatively limited in the state context.

Beijing also employs "hierarchical control" to direct innovative effort towards technological fields the state deems most useful for its defined outcome of China's economic growth. However the central state acts in this manner under the belief that it can know which technological areas will be most suitable for achieving this goal (and we have detailed its very specific technological aims), and that its rewards will then lead to the best innovation outcomes within these fields. (Furthermore, Nooteboom (2010, 7) notes the "revelation problem", a.k.a. Arrow's information paradox: "to judge the value of information one must already have it, but then there is nothing left to pay for". In one sense, the state behaves as if it believes it has solved Arrow's paradox, by deciding in advance which areas are most valuable on behalf of company management.)

Nee (2005) describes the motivation problem for central SOE managers, and its relation to innovation. Being "professional bureaucrats in a nonmarket environment" makes SOE directors risk-averse: little premium is put on "innovation and risk taking when the evaluative process emphasises meeting production targets sent down from higher authorities" (Nee, 2005, 59). Nee's "vice chairman of company M" stated: "we do not mind enduring risk if there was a business opportunity. But the government officials are less likely to bear the same risk… even if we had a successful risky investment, the officials would not benefit from this project. But if the risky investment failed, they could be in trouble". Innovation investment by cadres is unlikely to lead to great wealth, so they "strive to advance their careers, to gain higher bonuses, and to expand their organisational power and influence" (Nee, 2005, 59) (because taking innovative risks may jeopardise their firms' survival prospects). In summary, despite considerable resource from central government, these firms' principal-agent chains, including the monitoring measures therein, increase the costs and reduce the benefits of innovation for agents.

Regarding the effects of central government shareholdings in the minority:

Ming and Williamson (2007) find that most Chinese companies that launch products successfully into the global arena (like Lenovo) are "hybrid" firms, with "a mix of public and private ownership". This describes firms in which two types of principal have a similar aim (i.e. for firms to innovate successfully), but which create different agency chains between principal and agent, which then have different effects on outcomes. We have established in our discussion of China's institutional system of innovation how state shareholding puts firms in a better position to protect themselves from IP infringement, thus helping give them an incentive to innovate. Nee (2005, 58) states that "cadre-entrepreneurs [in hybrid firms] have positive incentives for risk taking and innovation, though they are more risk-averse than private entrepreneurs, who stand to profit mightily from successful ventures".

Although, like venture capitalists, state principals wish to monitor agent performance, conflicting aims – and intra-Party nepotism – are likely to limit the effectiveness of monitoring (thus Holmström's

(1979) "noise" effects in performance evaluations). This means for MISOEs, where private ownership is in the majority, the incentives it provides will help cut these noise effects, because agents will be answerable primarily to private principals. Meanwhile, the presence of some state shareholding allows more protection of the IP assets generated by better incentivised and monitored agents.

Private shareholding gives better innovation incentives, partly by simply not specifying how innovation will be measured and rewarded (which as we have seen can lead to agents registering low-quality utility patents and spending money on the *appearance* of innovation, such as new facilities). This also means that agents are more likely to be rewarded for innovations which succeed in the marketplace via genuine originality compared to existing products. So if a private shareholder takes majority control, a re-alignment of incentives for the managers can occur. This means that this particular multi-principal scenario actually simplifies incentives for managers, as their most important relationship then becomes that with the private principal-owner. This is ultimately why a majority private ownership allows agents to follow an incentive structure that is more successful at allowing innovation, while the state's minority stake can further incentivise innovation in this context by granting protection in the Chinese institutional system.

Regarding the effects of sub-central government shareholdings in the minority:

Although most local government-owned firms, or local government shareholding, is shareholding for which local governments are ultimately accountable to central SASAC, in reality central SASAC has little oversight role through its local branches, with the local government itself the real overseeing principal of local shareholdings. This means a shorter principal-agent chain exists than for central government shareholdings, making oversight less opaque, and allowing principals more reliable information on occurrences in firms. This structure alters the incentives for the principals doing the monitoring; having fewer firms to monitor is liable to lead to better investigation and oversight than for central principals, whose scope of responsibilities will in many cases be very large.

For the agents managing firms, this means unwise investments are more likely to be noticed. Local government ownership creates a state shareholding mechanism closer to the venture capital type: arrangements between firms and their local government in either province or municipality will give principals an actual profit incentive (instead of just working for the benefit of "the people"). Besides, these principals will be held more directly to account if their locality does not generate income. Meanwhile the closer monitoring and feedback for agent waste and failure that the venture capital model implies is also present.

Local cadres' primacy in overseeing these firms results in the problematic state multi-principal situation being better controlled, with a smaller group of local cadres taking the place of SASAC, ministries, the State Council and so on. Furthermore, the principals, operating on a smaller scale, will not have thousands of agents to monitor, and stand to benefit from these firms' success. Although the populations of the areas in question are still large, we are likely to see somewhat more trust in principal-agent relations, smaller populations better allowing the "Singapore model" (Zhang, 1998), with both principal and agent receiving more reputational feedback if a firm fails, and better social standing if it succeeds. They are also more likely to be embedded in similar networks, providing more information on each other's real aims and methods.

While central government ownership sees the risk around investment outcomes more "securitised" away, split between numerous principals with limited personal incentive for concern, at more local levels this securitisation is less pronounced because oversight is less dilute. As described in the case of Beijing's Zhongguancun cluster, local government ownership also removes some disadvantages of state ownership while keeping the advantages, including better access to legal protection in local law courts. As we will discuss in our hypotheses, firms in provincial-level cities also typically have considerable resource, both financially and in their connections to local universities and institutions (for innovation generally, there are positive spillovers associated with clustering, such as pools of skilled labour, the learning effects created by sharing information, and the effects of technology demonstration (Fai, 2005)). In other words closer monitoring, plus expertise, gives an advantage.

While locally state-owned firms are given less internal resources than centrally state-owned firms, they tend to operate in more competitive (and market-oriented) sub-industries (Boeing *et al*, 2013), increasing their incentives for R&D collaboration. Furthermore, the local connections that lead to collaboration with other (often locally state-owned) firms in the same area may lead to particularly high collaborative benefits; being owned by the same provincial government can also decrease transaction costs (Boeing *et al*, 2013).

As China's private firms are usually exposed to higher levels of competition than their state-owned counterparts (Boeing *et al*, 2013), they will have greater need for innovation (Boeing *et al* find that having included dummies for ownership type as general control variables they do not observe productivity differences between private and state-owned firms, which demonstrates the need for more exact measures of variations between private and state ownership, such as ours). Moving down the political hierarchy from central to municipal government is "equivalent to [reducing] government owners' control and transferring [SOEs] from social political orientated organisation to market oriented one" (Da, 2010, 47), and as we have seen, the reform period gave local governments "economic incentives to become entrepreneurial, especially in the fiscal reforms that let them retain tax revenue" (Da, 2010, 47). Being granted rights to the residual (fiscal surplus) illustrates Wong's (2000, 8) finding that "*under a range of conditions*, the principal's optimal incentive structure for the agent is one in which the latter receives some share of the residual in payment for his effort, thus giving him a direct stake in the outcome [my italics]". Like the venture capital cases where private capital can be pulled in instances of failure, some local governments have this capacity, whereas the potential for nepotism and blurred aims of the central state is likely to hinder the action of such mechanisms in that ownership context.

Regarding the effects of sub-central government shareholdings in the majority:

We have established that a central state majority shareholding provides relatively abundant resources, while a private shareholding provides incentives and a principal-agent chain more conducive to pro-innovation management decisions. Should this majority state shareholding be sub-central, resource availability is likely not as abundant, although the principal-agent chain is liable to be more effective than in the central case. Having established the potential of private shareholding, should this be a minority, its potential for incentivising innovation, while present, may therefore not be as effective as in the majority-private case.

Regarding the effects of completely private shareholdings:

Private entrepreneurs, as we have discussed, have stronger incentives to innovate, while operating under the hard-budget constraints that promote "more exacting cost-benefit calculations in their investment decisions" (Nee, 2005, 60). Nee implies however that private entrepreneurs are the best incentivised to innovate, but lack the resources of the hybrid firm agent (who may take the lead in innovation because of his position vis-à-vis the state). This inability to protect patented IP in the Chinese legal system combines with their much more limited access to resources, meaning that despite their incentives they often simply lack the necessary resource to both invest in R&D and secure innovation outcomes.

Regarding the effects of the addition of foreign shareholding:

Foreign shareholding constitutes an infusion of private shareholding, as described above, but with added characteristics. Even more than other types, foreign ownership implies investment in firms whose products are intended to compete in the global market, requiring innovation to maintain production of this standard of competitive product.

The vast majority of foreign ownership in the sector is of Chinese firms which are listed on foreign stock exchanges, which have more demanding corporate governance reporting requirements (including R&D information). Foreign markets' superior reporting requirements limit these firms' agents' opportunity to leverage asymmetric information to create moral hazard (hidden action). While the Chinese state carries out its own monitoring to gain control of these information flows, the limited personal interest of cadre-principals compared to foreign private owners (and the potential for nepotistic relations within the state system) limits the effectiveness of this monitoring.

While the Chinese state has conflicting interests at work in the firms of which it is an owner, such as maintaining employment, foreign principals do not *have* to invest in any firm. This allows superior "ultimatum bargaining" (Sappington, 1991) from principal to agent over the investment of resource, which combined with tighter reporting requirements helps stop agents gaming principals through wasteful investment. Although most state principals will be able to "securitise" risks up to a higher level to some extent, foreign principals will be unable to do so. A foreign private investor has the incentive to monitor risks, as he will bear the burden of failed investment; the foreign takeover market also provides the aforementioned "discipline of last resort".

The globalised competition facing foreign principals also forces more interest in genuinely competitive, ideally world-beating, innovation. This leaves them with little or no interest in the "quantitative patenting" on which Chinese state owners have judged their firms' performance, which allows the amassing of utility patents in particular. Meanwhile, local government cadres have been keen to boost the GDP figures on which they are graded (and promoted) by central government. This has led them to fund solar PV manufacturing firms' production facilities for volume production, maintaining jobs and output, which may be at the expense of technologically competitive product in the longer-term. Foreign private investors will likely have little interest in these metrics.

Indeed, Eberhardt *et al* (2011, 21) study the characteristics of recent patenting by Chinese firms, and find that a few firms in the ICT equipment sector account for the vast majority of patents, a concentration that is even more pronounced in USPTO filings: these firms "are very large, relatively young, more R&D intensive, and strongly export oriented". For such firms, "a substantial share of patents covers product innovation, albeit of relatively low-tech character. Process innovations and combinations of product and process innovation covered by patents held by these companies appear to be technologically more innovative and potentially valuable"[20]. Their results suggest that these few, patent-active firms are not just "innovation castles in the air" created by "Chinese public policy directed at increased patenting, but (at least to some extent) innovative companies highly integrated into the global economy". However, as to whether this is evidence for wider technological take-off among Chinese firms, their analysis suggests patenting is concentrated in very few industries and even within them is undertaken by very few companies. While "a number of Chinese companies appear to be truly innovative, potentially even pushing the technology frontier beyond China", there are "very few such companies, and some of the most active among them are foreign-invested. Most companies are thus likely to concentrate on incremental process innovation rather than the generation of "new-to-the-world" innovation" (Eberhardt *et al*, 2011, 21). This small number appears to be unlike in those Asian economies that have successfully escaped the middle income trap.

Regarding the effects of central government shareholding in the majority, on the patenting of *different types of technology*:

For the purposes of these hypotheses, we divided all the types of solar PV technology patented into three categories: core, blue-sky, and related. Core technologies refer to the crystalline silicon technologies, including silicon refining, ingot, wafer, cell, and module manufacture, which form the bulk of the current commercial solar PV market. Blue-sky technologies are those in thin film and other advanced areas which do not yet have a large market, but may in future. Related technologies are those mores straightforward areas, such as technologies which have both PV and solar thermal applications, and which see PV technologies applied to such items as public lighting and architectural features.

So-called "blue-sky" technologies are an area where R&D remains relatively speculative, due to very limited current commercial payoffs. With the market for solar PV currently dominated by poly- and mono-crystalline modules, thin films and other advanced technologies (whether silicon-based or non-silicon such as gallium arsenide films) remain too expensive for market uptake, despite their frequently high efficiency conversion (as a highly developed silicon supply chain has helped maintain low prices for crystalline silicon-based products). Although there will still likely be a good deal of wasted investment, and the same state principal-agent monitoring problems apply, the very fact that few non-state principals will be as interested in these highly speculative areas means that what innovation there is in these fields will be relatively state-dominated.

The result of the speculative nature of these technologies is that they will, at present, be a limited focus for commercial companies' R&D laboratories, as those working on them will need to be less

[20] Bocken Qin (BP Ventures, Beijing), also states that "China's innovation advantage looks to be in process and product, rather than science" (interview, September, 2012).

motivated by predictable revenue streams. These are the innovations in the technological "valley of death", typically the target of government-funded research. These areas, though currently expensive to research, and difficult fields in which to predict future market-winning innovations, can produce paradigm-shifting innovations. As such, at the early stage they are often better suited to national than commercial competition, as governments (often through state firms) try to capture the future dividends of technological ownership.

The principal-agent advantages of the private sector are less useful here; these investments are by their nature relatively output-inefficient, and reducing moral hazard to give a principal more information on agent activity is less likely to lead to desired outcomes, given that principals will have little knowledge advantage over agents. Meanwhile, the advantages of state protection remain useful, as innovators will still require considerable resource and wish to protect patents. Furthermore, although China has been said to have too much "insurance" for SOE employees, this is one area in which it may be useful, as secure employment may encourage experimentation in speculative projects. The role of state organisations in these fields is also demonstrated by other nations' R&D investments (in the US, Defense Department-funded research is investigating smart grid technologies for solar, while Japan is funding research into vanadium technologies).

However, innovation may be limited by firms being urged to follow quantitative innovation targets, while China's central government has also established a quantitative system of measuring academic output, grading researchers on numbers of papers published (which may affect university-established firms). The "research culture" this has produced may not be conducive to time-consuming research into complex, groundbreaking, speculative innovations. Although we are not investigating universities or institutes, but state-owned firms (and other firms), this research system is likely also to have a marked effect on SOEs, as they are likely to partner with these institutes.

Regarding the effects of sub-central government shareholding in the majority, on the patenting of *different types of technology*:

In describing minority-SOEs where sub-central government is the major state shareholder, we have established that these firms are those most likely to demonstrate high inventive output. Given their more global market-oriented product positions, they are likely to be focused on building core technological competences, and better able to do so through the more effective principal-agent relations described. This means both R&D input and inventive output will be focused on the core technological areas of solar PV, and away from the "related" areas that involve the simpler spin-out products that are only loosely based on these core technologies.

7.3 Sub-samples and data available

The *listed firms* comprise 28 firms: this sample comprises all the listed Chinese firms in the solar PV sector (listed both in and outside China), and a number of firms which have been listed and have since de-listed.

The *unlisted firms* comprise the remainder of the sample, which is to say 122 firms.

Data availability is better for listed firms in certain regards, notably:

1) For listed firms, the data on the ownership of shares (private, foreign, state, and different levels of state) is of a high enough quality to present these as continuous variables; for unlisted firms, the data on share ownership only allows the assignment of firms to categories. These are: POE (entirely private), MISOE (minority state-owned), MASOE (majority state-owned), or SOE (entirely state-owned). As we have seen, for MISOEs, MASOEs, and SOEs, these categories have also been subdivided by the level of government which is the owner or the largest owner of a stake (central, provincial, super-municipal, and municipal). (Please note also that we have checked that using this relatively small sample of listed firms is appropriate: Pisano (1994) for example also used a similar sample, of 23 observations, and 5 variables. In our tests the significance values naturally take into account the required degrees of freedom, which are accounted for in any "pass".)

2) For listed firms, data is available on turnover for all relevant years. For unlisted firms, data is only available on staff numbers and not turnover; furthermore, the staff number data is only for the most recent period. This means that where it is necessary to use size as a control variable in testing hypotheses, the potential problem of reverse causation needs to be tested: instead of, or as well as, size affecting patent performance (lagged by two or three years), what will be registered may be partly the effect of patent performance on size (with a lag of some kind). We can test for such an effect however, because we have time series data for the size (by turnover and in most cases by staff numbers) for listed firms. So it is possible to test for the effect of patent performance on size, by looking at the change in size over time in listed firms, and its correlation with previous patent performance. If necessary, this can be used to modify the size data used (this is an example of the way that a sub-sample - listed firms - with rich data, can be used to improve the data available for a larger sample).

3) For listed firms there is sufficiently high quality data for R&D to be presented as a continuous variable for the majority of these firms. (This is derived from R&D expenditure data for most of that majority. For the remainder there is data for R&D staff numbers, from which R&D expenditure is imputed.) For unlisted firms there is no data from which R&D expenditure can be calculated. This raises the possibility of omitted variable bias when patent performance is regressed on the ownership variables. This is discussed in 7.4 below.

We now set out the core arguments underlying the hypotheses, and the hypotheses themselves.

7.4 Core arguments and hypotheses

The hypotheses to be tested are presented in groups below, with the core arguments on which they are based.

Resources and R&D

We have found that the higher the proportion of shares held by the state, the greater the resources available for innovation. Likewise the higher the level of the state which owns a given shareholding, the greater the resources available for innovation. We can thus predict that:

Hypothesis 1a: The higher the state shareholding, the higher the rate of spend on R&D *absolutely*.

Hypothesis 1b: The higher the state shareholding, the higher the rate of spend on R&D *relative to turnover*.

Hypothesis 2a: The higher the level of government which holds the largest state shareholding, the higher the rate of spend on R&D absolutely.

Hypothesis 2b: The higher the level of government which holds the largest state shareholding, the higher the rate of spend on R&D relative to turnover.

These hypotheses are testable only on Listed Firms. R&D expenditure is usable as a dependent variable (DV), or numerator of the DV. The assumed lag of DV on independent variables (IV) is one year. For hypothesis 2 (H2), the levels of government can be shown by dummy variables; so the predicted coefficient on the central government dummy would be highest, the predicted coefficient on the provincial government dummy next, etc. Alternatively the levels of government can be conflated into central and sub-central and the respective shareholdings treated as continuous variables.

Productivity of R&D

We have predicted that the higher the private shareholding, the greater the efficiency with which resources are used for innovation.

Likewise, the more local the level of government which holds any state shareholding, the greater the efficiency with which resources are used for innovation.

This gives us the following hypotheses:

Hypothesis 3a: The higher the private (domestic) shareholding, the better the patenting performance for each unit of R&D spent.

Hypothesis 3b: The higher the foreign shareholding, the better the patenting performance for each unit of R&D spent.

These too can only be tested on Listed Firms, with Patent Productivity (PatPro: that is, PatPer divided by R&D) as DV. The assumed lag of the DV on IV is three years: Ownership at t=0, R&D at t=1, Pat Per at t=3.).

It is notable that this formulation, with PatPro as DV, in effect treats any of the ownership variables as a *moderating* variable for R&D: it moderates the effect of R&D on patenting performance. (To see this one must do a simple transformation of the equation: multiply PatPro by its denominator, R&D, to get PatPer as DV; and then of course multiply all the terms on the other side of the equation by R&D, which replaces the ownership variables by interaction terms, and introduces R&D multiplied by the constant.) This is true also for H3e and H4 below, which also use PatPro as DV.

Alternatively, PatPer can be used as dependent variable, with or without R&D as one of the independent variables:

Hypothesis 3c: The higher the combined private and foreign shareholding (total private shareholding), and the higher the R&D spent, the better the patenting performance.

Hypothesis 3d: The higher the combined private and foreign shareholding (total private shareholding), the better the patenting performance.

These represent two of the standard tests required to find whether R&D can be treated as a mediating variable (see below).

Hypotheses 3a and 3b are also combined in another version:

Hypothesis 3e: The higher the combined private and foreign shareholding (total private shareholding), the better the patenting performance for each unit of R&D spent.

We generate also **Hypothesis 4: The lower the level of government which holds any state shareholding, the better the patenting performance for each unit of R&D spent.**

Again this is testable only on Listed Firms, with PatPro as DV. As for H2, the levels of government can be shown by dummy variables; so the predicted coefficient on the central government dummy would be highest, the predicted coefficient on the provincial government dummy next, etc. Alternatively the levels of government can be conflated into central and sub-central and the respective shareholdings treated as continuous variables. What we have chosen to do is to take the total state share as 100 and divide it between central and sub-central government. We have then used sub-central government's share as the independent variable.

(Lags as Hypothesis 3.)

Ownership and Patenting Performance

We now proceed to the hypotheses which can be tested with the full sample of listed and unlisted firms – and therefore without R&D as an independent variable.

First, we have noted that foreign shareholding is likely to be associated with a stronger focus on innovation of international relevance. This yields

Hypothesis 5: (the effect of foreign shareholding): The higher the foreign shareholding, the higher the output of more inventive patents. (The DV is the "more inventive" PatPer factor divided by the "less inventive" factor. Lags as Hypothesis 3.)

Next, it is true by definition that Patent Performance is equal to the **quantity** of R&D multiplied by its **productivity** in terms of patents. We have argued that the quantity of R&D is a function of ownership, such that state shareholding, and specifically **central state shareholding**, makes for higher R&D. Among the unlisted firms this is likely to be highly non-linear, since POEs have very poor access to funding. (It will be argued below that *listed* POEs are untypical in this respect.) There is one the other hand no reason to think that 100% SOEs have much better access to funding than MASOEs (majority SOEs) or even MISOEs: if there is a strong state shareholding then that makes the essential connection with banks or other sources of funding. We have argued likewise that the productivity of R&D is also a function of ownership, but with a quite different relationship: in this case it is the existence of a **strong private shareholding** which makes for high productivity. Again the effect is likely to be non-linear: a SOE (entirely state-owned) firm is likely to be highly unproductive, and a MASOE (majority state-owned) may well be, but there is no strong reason to believe that a MISOE (in which the private shareholding is dominant) will be significantly less productive than a POE. It follows (taking quantity and productivity together) that we have

Hypothesis 6: Patent performance is a non-linear function of the ratio of state to private shareholding, therefore highest for intermediate values.

One should recall that for the full sample we do not have data such that this ration can be expressed as a continuous variable. In any case there may well be threshold effects, between our four categories of POEs, MISOEs, MASOEs, and SOEs. We therefore have

Hypothesis 6a: The output of "less inventive" patents is a non-linear function of the ratio of state to private shareholding, highest for MISOEs. (Using dummy variables for shareholding categories, with the predicted coefficient highest for MISOEs. Lags as Hypothesis 3.)

Hypothesis 6b: The total output of patents is a non-linear function of the ratio of state to private shareholding, therefore highest for MISOEs. (Using dummy variables for shareholding categories, with the predicted coefficient highest for MISOEs. Lags as Hypothesis 3.)

Hypothesis 6c: The output of "more inventive" patents is a non-linear function of the ratio of state to private shareholding, therefore highest for MISOEs. (Testable on All Firms, with Pat Per as the DV, and using dummy variables for shareholding categories, with the predicted coefficient highest for MISOEs. Lags as Hypothesis 3.)

We also generate a relatively "agnostic" pair of hypotheses on the effect of level of government, from the two opposing tendencies – for central government shareholding to increase quantity of R&D, and sub-central government to increase its productivity:

Hypothesis 7: The effect of level of government on patenting performance.

Hypothesis 7a: The total output of patents is the higher, the higher the level of government which has the largest state shareholding.

Hypothesis 7b: The total output of patents is the higher, the lower the level of government which has the largest state shareholding.

(Lags as Hypothesis 3).

Ownership and Direction of Patenting Performance.

Solar PV patents can be divided into three broad categories: "core", "blue sky", and "related". "Core" patents are in the areas which can be expected to generate most profit in the short and medium term (i.e. up to five years), but accordingly are difficult fields in which to generate a competitive edge, and therefore these patents will be gained most by firms which are being driven hard for profit and at the same time are reasonably well-resourced (the technologies that fall into this category are silicon and ingot manufacturing, wafers, modules, and system components such as inverters). "Blue sky" patents will pay off, if at all, in the longer term (e.g. thin film PV), and are therefore the most likely to be sought, and obtained, by very well-resourced firms which are not under much immediate pressure for profit. "Related" patents are in areas which are relatively low-tech, and as such will be registered by relatively low-tech firms, and by firms which are seeking to gain patents simply for the sake of patents, i.e. to make a good impression on their principals. They include apparatus that is simply derived from solar PV, such as solar PV street lights and suchlike.

Hypothesis 8: The effect of level of government on the *direction* of patenting performance.

Hypothesis 8a: Majority or 100% state-owned enterprises (MASOEs or SOEs) where central government is the major shareholder will be associated with a relatively high proportion of patent output in "blue sky" technology categories.

Hypothesis 8b: Minority SOEs where sub-central government is the major state shareholder will be associated with a relatively high proportion of patent output in "core" technology categories.

Hypothesis 8c: Minority SOEs where sub-central government is the major state shareholder will be associated with a relatively low proportion of inventive output in "related" technology categories.

(PatPer (suitably subdivided into categories) as the DVs. Lags as Hypothesis 3.)

It has been suggested that (in particular) the regression whose results support H6a, might suffer from omitted variable bias. In statistics, we can state that omitted-variable bias occurs when a model incorrectly leaves out one or more important causal factors. The bias occurs when the model compensates for the missing factor by overestimating or underestimating *the effect* of another factor.

The suspicion here will be that the omitted variable in question is R&D, and that the overestimation will be of the effect of ownership type: more specifically, that the superiority of MISOEs in generating PatPer has been overestimated. It is clearly probable that R&D is an important causal factor in PatPer (and it is shown to be in the test of H3c). It is possible that R&D is relatively highly correlated with ownership type (this turns out not to be the case for listed firms, but as was explained, the kind of private firm that manages to become listed is rather exceptional). The majority of unlisted POEs will be considerably underfunded, which will inevitably reduce their R&D. However, we can "cover ourselves" by considering the two possibilities:

R&D is substantially correlated with ownership type (plausibly, it is lower for POEs).

R&D is not substantially correlated with ownership type.

We can then follow through on both assumptions in turn:

If R&D *is* substantially correlated with ownership type, we need to consider why this is. Is it because ownership type affects R&D, or is it because R&D affects ownership type? Or is it because another factor affects both?

Does R&D affect ownership type? We have a lag of one year with R&D – R&D in t+1 for ownership in year t, which is some protection against causation in this direction, but a better argument is the obvious implausibility of this question. Ownership is a relatively stable and entrenched factor, which cannot change on a whim, which means there is no clear reason why changes in R&D should lead to changes in ownership. (Although one could create a scenario in which an increase in R&D leads to some innovative success which could make a firm more attractive to buy, there can be no clear prediction regarding what ownership direction this would mean, and the process would take years, meaning an increase in R&D in t+1 could not cause an ownership change in t.)

Is there another factor which affects both R&D and ownership? This is less implausible: age and location could in principle do so: however, they are used frequently as control variables, and their correlations with R&D and ownership are not high. Size clearly affects R&D, but it is difficult to see how it can affect ownership, even if ownership could affect size. Again, we use it as a control variable, so it is not itself an omitted variable, so it can then matter little that R&D is left out. (We can also keep in mind that where a common factor A affects both B and C, the resulting correlation between B and C is likely to be weaker than between A and B, and A and C: roughly the product of the two.)

The only reasonable suggestion is that **ownership type affects R&D**, because we have a clear causal chain: being private, other things being equal, severely reduces access to funding (strongly supported by the literature), and having severely reduced access to funding reduces R&D (also clear, and strongly supported by the literature). It is only because of the existence of this well-known causal chain that we predict the substantial correlation: if one disbelieves this, one has no reason to expect there to be a substantial correlation, and we move to the alternative assumption. But if the correlation arises thus, it is not logical to conclude that the effect of ownership type on PatPer has been over-estimated. What the correlation would pick up is the effect of ownership type on R&D. Since we already assume that R&D affects PatPer, we would then have an effect of ownership type on PatPer *through* R&D – in other words *R&D would be a mediating variable*.

Tests exist to establish that "X" is a mediating variable, e.g. a procedure *through induction* that we do not need to follow, because we proceed *through deduction.* These tests were followed for the listed firms, in the following order: in H1 we regress R&D on the independent variable (ownership) alone, in H3c we regress PatPer on the independent variable with R&D, and in H3d we regress PatPer on the independent variable alone (please see the note following the regression for Hypothesis 3d for an explanation of what occurs).

We do not need to establish however that it is mediating: we merely need to consider what follows if it is, and with mediating variables the position is clear: we are entitled to remove the mediating variable to examine the effect of the (mediated) independent variable. If we leave the mediating and mediated variables in together this is not an appropriate test of the total effect of the mediated variable – some of its effect will be "stolen" by the mediating variable.

In this case if we had R&D data for the whole sample, then used it as another independent variable, alongside ownership dummies and controls, then, following assumption 1 above, this would lead to an *underestimation* of the effect of ownership on PatPer, because R&D would "steal" some of the effect of ownership; as a test of a hypothesis on the effects of ownership on total patent performance, the equation would be inappropriate. It would be a more appropriate test of a different hypothesis: the effects of ownership on the efficiency with which R&D is used.

Let us make the alternative assumption:

R&D is not substantially correlated with ownership type.

Then it is unlikely that it will have any substantial effect, one way or the other, on the apparent impact of ownership on Pat Per. There is then no omitted variable bias[21]

[21] To quote from a recent article by Clarke (2005, 348-9): "If the logic of control variables is flawed, experimental control must be achieved in another way. How this can be done is no mystery. In their seminal econometrics text, Hanushek and Jackson (1977) discuss how to use research design in place of using control variables to address potential omitted variable bias. These include basing specification on theory", as I have, and "finding "natural" experiments, and "controlling" for unmeasured effects through careful sample stratification". The article also states: "To these we can add the explicit use of competing theories and the choice of research hypothesis (Rosenbaum, 1999; Freedman, 1991)." I have done this by considering the possible explanations of correlation with an omitted variable.

8. Data Analysis

The following section details how we use the quantitative data to test the hypotheses.

8.1 Preparatory econometric data analysis

8.1.1 Coding

Prior to entering data (into SPSS) to begin quantitative analysis, all variables were coded in the correct format. This involved coding the names of each variable, and assigning numbers to all the responses which were not already in numerical form. These variables were as follows:

The first variable in the dataset was ID, and a number was assigned to each case (i.e. each solar PV firm), from 1 to 150 (please refer to the appendices for the list of firm IDs and other coding details). Next, the independent variables were coded, in the following way.

The shareholding-related variables were coded as follows:

Variable:	**Code**:	**Value**:
Percentage of firm private domestic	PrivDomPercent	[Percent as number]
Percentage of firm foreign	FPercent	[Percent as number]
Percentage of firm central state held	StateCentralPercent	[Percent as number]
Percentage of firm provincial state held	StateProvPercent	[Percent as number]
Percentage of firm super-municipally state held	StateSuperMuniPercent	[Percent as number]
Percentage of firm municipal state held	StateMuniPercent	[Percent as number]

These shareholding-related variables were therefore coded for each year along this same pattern, for example: PrivDomPercent2006, etc.

The variables for the outcome of shareholding for each firm (i.e. the result in ownership of the combined percentages for a given year) were coded as follows:

Outcome:	**Code**:	**Value**:
Private	POE	1
Central state fully owned	CentralSOE	2
Central state majority owned	CentralMASOE	3

Central state minority owned	CentralMISOE	4
Provincial state fully owned	ProvSOE	5
Provincial state majority owned	ProvMASOE	6
Provincial state minority owned	ProvMISOE	7
Municipal state fully owned	MuniSOE	8
Municipal state majority owned	MuniMASOE	9
Municipal state minority owned	MuniMISOE	10
Super-municipal state owned	SuperMuniSOE	11
Super-muni state majority owned	SuperMuniMASOE	12
Super-muni state minority owned	SuperMuniMISOE	13

As above, the outcome variables were coded for each year using this pattern: e.g. Outcome2006, etc.

Meanwhile, when we need to avoid categorising firms by the 13 categories above (where combining data on state shareholding proportion and data on state level as above creates too much noise), we separate them in the following way (please note that we have done this for firms' ownership averages for 2005-2009, due to the requirements of Hypothesis 8 in which they are used):

To test a firm's state shareholding along the state ownership level:

OwnaveStateLevel20052009

Outcome:	**Value:**
Central	1
Provincial	2
Municipal	3
Super-municipal	4

To test the proportion of state shareholding:

OwnaveStateProportion20052009

Outcome:	**Value:**
SOE	1
MASOE	2
MISOE	3

POE	4	

To test **R&D-related** variables, the following codes were used:

Variable:	**Code:**	**Value:**
R&D staff number	RDStaff	[Number]
Total staff	TtalStaff	[Number]
R&D staff as percentage of total staff	RDStaffofTtalStaff	[Number]

The variables were coded for each year along the same pattern, e.g. RDStaff2006, etc.

To test the **control variables**:

Variable:	**Code:**	**Value:**
Location by province	LocationProvIncome	[Number]
Current age of firm	AgFirm	[Number]
Subsidiary	Subsid	[Yes (1) or No (0)]
Listed	Listed	[Yes (1) or No (0)]
Agglomeration	Agglom	[Yes (1) or No (0)]

Here, only listed firms needed to be coded for each year, e.g. Listed2006, etc.

The **patent-related** variables were coded as follows:

Variable:	**Code**:	**Value**:
Total patents for the firm	PatentTtal	[Number]
Inventive patents for the firm	PatentInvent	[Number]
Non-inventive patents for the firm	PatentNonInvent	[Number]
Forward citations of patents for the firm	PatentCite	[Number]
Patent family registrations per firm (domestic)	PatentFam	[Number]

Patent family registrations outside China (non-US)	PatentFamF	[Number]
Patent family registrations outside China (US)	PatentFamUS	[Number]

As above, the patent-related codes were coded for each year along the same pattern, for example: PatentTtal2006, etc.

Abbreviated variable names:

For ease of understanding the output, the names of the variables above were abbreviated as follows.

The following table illustrates the variable names used in the output tables below, (the third column, *Abbreviated variable name in output*), with the *Original variable name in SPSS regressions*, and the *Meaning of variable*.

Original variable name in SPSS regressions	**Meaning of variable**	**Abbreviated variable name in output**
State proportion 2004-6	1= SOE, 2= MASOE, 3= MISOE 4=POE	State proportion (2004-6)
State proportion 2008-9	1= SOE, 2= MASOE, 3= MISOE 4=POE	State proportion (2008-9)
Average percentage of ownership by the state for each firm (averaged for 2007-2009)	State shareholding as a percentage	State percentage (2007-2009)
SOEs	Entirely state-owned enterprises	SOEs
MASOEs	Majority state-owned enterprises	MASOEs
MISOEs	Minority state-owned enterprises	MISOEs
POEs	Entirely privately-owned enterprises	POEs
State level 2004-6	1= Central, 2= Provincial, 3= Super-municipal, 4=Municipal	Level of state (2004-6)
State level 2008-9	1= Central, 2= Provincial, 3= Super-municipal, 4=Municipal	Level of state (2008-9)
OwnaveStateLevel4CodesCentral	In category if firm has state ownership and a majority of this ownership is central state	Level of state Central
OwnaveStateLevel4CodesProvincial	In category if firm has state ownership and a majority of this ownership is provincial state	Level of state Provincial
OwnaveStateLevel4CodesSuperMuni	In category if firm has state ownership and a majority of this ownership is super-municipal state	Level of state Super-municipal
OwnaveStateLevel4CodesMuni	In category if firm has state ownership and a majority of this ownership is municipal state	Level of state Municipal
CENTRAL is Average largest shareholder by level of the state for each firm (averaged for 2007-2009) (As CATEGORICAL DUMMY variable)	Central state is the largest shareholder (2007-9) (as a categorical variable)	Central state largest shareholder (2007-9) (categorical)
NON-CENTRAL is Average largest shareholder by level of the state for each firm (averaged for 2007-2009) (As CATEGORICAL DUMMY CENTRAL VS NON-CENTRAL variable)	Non-central state is the largest shareholder (2007-9) (as a categorical variable)	Non-central state largest shareholder (2007-9) (categorical)

Percent of the firm owned by the central state average 2007-2009	Central state shareholding as a percentage	Central state percentage (2007-9)
Percent of the firm owned by the non-central state average 2007-2009	Non-central state shareholding as a percentage	Non-central state percentage (2007-9)
Average percentage of ownership by private shareholders for each firm (averaged for 2007-2009)	Private shareholding as a percentage	Private percentage (2007-9)
Foreign shareholding 2004-6	Foreign shareholding as a percentage	Foreign percentage (2004-6)
Foreign shareholding 2008-9	Foreign shareholding as a percentage	Foreign percentage (2008-9)
Average percentage of ownership by foreign shareholders for each firm (averaged for 2007-2009)	Foreign shareholding as a percentage	Foreign percentage (2007-9)
Shareholding percentage foreign annual average 2005-2009, using only the years for which some shareholding is registered for the firm	Foreign shareholding as a percentage	Foreign percentage (2005-6)
Average percentage of ownership by private plus foreign shareholders for each firm (averaged for 2007-2009)	Private plus foreign shareholding as a percentage	Private plus foreign shareholding as a percentage (2007-9)
Annual average output of factor 1 for each firm 2008-2012	Annual average output of factor 1 for each firm 2008-2012	Ave factor 1 output (2008-12)
Annual average output of factor 2 for each firm 2008-2012	Annual average output of factor 2 for each firm 2008-2012	Ave factor 2 output (2008-12)
Annual average output of both factors for each firm 2010-12	Annual average output of both factors for each firm 2010-12	Ave both factors output (2010-12)
Annual average output of both factors for each firm 2010-12 divided by R&D spend 2008-10 in million RMB	Annual average output of both factors for each firm 2010-12 divided by the firm's R&D spend 2008-2010 in million RMB	Ave both factors output (2010-12) per R&D spend (RMBm 2008-10)
Factor 1 for firms with historic staff numbers for 2006-2009	Total output of factor 1 for those firms with staff figures for 2006-2009	Factor 1 when staff numbers (2006-2009)
Factor 2 for firms with historic staff numbers for 2006-2009	Total output of factor 2 for those firms with staff figures for 2006-2009	Factor 2 when staff numbers (2006-2009)
F1&2 combined 2003-5	Total output of factors 1 and 2 combined for 2003-2005	Factor 1&2 combined (2003-5)
F1&2 combined 2008-9	Total output of factors 1 and 2 combined for 2008-2009	Factor 1&2 combined (2008-9)
The percentage of both factors made up by tech type C	The percentage of the output of both factors made up by tech type C	Percent factors tech type C

The percentage of both factors made up by tech type R	The percentage of the output of both factors made up by tech type R	Percent factors tech type R
Firm R&D budget average 2008 to 2010	Firm R&D budget average 2008 to 2010	R&D budget (2008-10)
Firm R&D budget as a percentage of revenue 2008 to 2010	Firm R&D budget as a percentage of revenue 2008 to 2010	R&D budget as percent of revenue (2008-10)
Total number of staff in the firm 2008	Total number of staff in the firm 2008	Firm staff (2008)
Average staff numbers for 2006-2009 for firms with historic data	Average annual number of staff for 2006-2009 for firms with this historic data	Firm staff (2006-9)
Total number of staff in the firm (current), or total for PV arm of firm if also non-PV	Total number of staff in the firm (current), or total for PV arm of firm if also non-PV (current)	Firm staff or firm PV arm staff (current)
Age of the firm in 2009	Age of the firm in 2009	Firm age (2009)
Annual GDP per capita for firm HQ province	Annual GDP per capita for firm HQ province	Firm HQ province GDP per capita
Agglomeration ratings for each firm (how many firms inc. that one from the sample within 100 miles)	Agglomeration ratings for each firm (from our sample how many firms, including the firm itself, present within 100 miles)	Firm agglomeration rating

Table 6: Variable Names in Output

8.1.2 Creating the data file

This process created the SPSS workbook called VariablesMain, which involved the upload of all variables onto an SPSS workbook, and labelling the coded variables with a descriptive label for reference purposes. Continuous data was set as “Scale” measures, and categorical data was set as “Nominal” measures.

8.1.3 Screening the data: checking categorical and continuous variables

The next stage was to check the dataset for errors. Primarily, this involved checking for values that were outside the possible range of values for a given variable.

Categorical variables were checked by analysing minimum and maximum values for acceptability, then checking for valid and missing cases. Continuous variables are analysed for acceptable minimum and maximum values, then for undistorted mean values.

8.1.4 Preliminary analyses: categorical variables and continuous variables (skewness and kurtosis)

Cronbach's Alpha:

Please note the Cronbach's Alpha testing was not deemed necessary in our case. Cronbach's Alpha exists to assess consistency, or whether scales "hang together", but this is usually applied to relatively nebulous measures (such as what may be measured by "life satisfaction" scales (Pallant, 2013), i.e. rather debatable metrics). Our data however is known to "hang together", because it is measuring something more straightforward: patent measures are indeed related, as are shareholding, etc.

8.1.5 Factor analysis

Factor analysis was used to converge the data in the patent variables into "clumps", i.e. groups among the intercorrelations of a set of variables. This is done to reduce variables to a smaller, more manageable set, prior to their use in multiple regression techniques (or, for example, analysis of variance). First, for the factor analysis I used averages for the 2009-2012 measurements for inventive patents, non-inventive patents, patent citations, patent families (domestic), patent families (foreign non-US) and patent families (foreign US). This was done to allow for later three-year time lag analysis, as we will discuss.

The six items, for all 150 cases, were subjected to principal components analysis (PCA), using SPSS version 21, but before performing PCA, the suitability of data for factor analysis was assessed. Inspection of the correlation matrix showed the presence of numerous coefficients of .3 and above. Upon carrying out Kaiser-Meyer-Olkin (or KMO, Kaiser, 1970, 1974) testing and Bartlett's Test of Sphericity (Bartlett, 1954), the KMO value was .672, exceeding the recommended minimum value of .6, and the Bartlett's value was significant (Sig) at .000, below the required minimum of .05 on the Sig value, both therefore supporting the factorability of the correlation matrix.

Principal components analysis revealed the presence of 2 components with eigenvalues above 1, explaining 60.086% and 23.319% of the variance respectively. An inspection of the screeplot revealed a break after the second component. Using Catell's (1966) scree test, it was decided to retain two components for further investigation. Having conducted the scree test, and given that only two components had been selected, it was decided not to use parallel analysis, as principal components analysis and the scree test were sufficient (Pallant, 2013).

The two-component solution explained a total of 83.405% of the variance, with Component 1 contributing 60.086% and Component 2 contributing 23.319%. Meanwhile, the Component Correlation Matrix showed that there was a mildly positive correlation between the two factors (r= .315).

As this value is above .3, to aid in the interpretation of these two components, Oblimin rotation was performed. In the Pattern Matrix, the rotated solution revealed, in the Pattern Matrix, three variables loading only on Component 1 (Non-Inventive Patents, Inventive Patents, and Patent Citations, at .969, .886, and .745 respectively); and two variables loading only on Component 2 (US patent families; and

Foreign patent families, at .949 and .926 respectively). It also reveals one variable loading on both Component 1 and Component 2 (Domestic patent families, at .675 and .420 for Component 1 and 2 respectively).

In the Structure Matrix, Oblimin rotation demonstrated one variable loading only on Component 1 (Non-inventive patents, at .876); four variables loading on both Component 1 and 2 (Inventive Patents, Patent families, Patent citations, and Foreign patent families, at .930, .808, .792, .419 for Component 1, and .418, .633, .384, .966 for Component 2); and one variable loading on only Component 2 (US Patent families, at .930).

As Pallant (2013) notes, as factor analysis is a data exploration technique, the interpretation of its outcomes are open to interpretation under our own judgment, instead of following hard and fast statistical rules. As such, we follow the outcome of the Pattern Matrix table, which gives three variables loading on Component 1, and two variables loading on Component 2 (please refer to the Pattern Matrix table below in reference to the following passages). The variable which could be debated is Domestic patent families, loading at .675 and .420 for Components 1 and 2 respectively. Therefore, we elected not to place this variable into either component.

In conclusion, the interpretation of the two components showed the variables Non-inventive patents, Inventive patents, and Patent citations loading on Component 1, and the variables Patent families foreign, and Patent families US loading on Component 2. The results of this factor analysis support the use of the two factors as separate scales, the first factor referring to *lower inventiveness*, the second factor to *higher inventiveness*. The following table demonstrates the factor analysis described.

	Component 1	Component 2
Non-inventive patents for the firm average 2009-2012	0.969	
Inventive patents for the firm average 2009-2012	0.886	
Patent citations for the firm average 2009-2012	0.745	
Patent family entries average 2009-2012	0.675	0.42
US patent family entries average 2009-2012		0.949
Foreign patent family entries average 2009-2012		0.926

Table 7: Oblimin Rotation: Pattern Matrix

8.1.6 Reverse Causation

Finally, before testing the hypotheses, it was necessary to check for reverse causality on certain variables to be used in some of the hypotheses below (here we follow the reverse causation test recommended by Antonakis *et al* (2010), instead of the Granger test more commonly used for time series data, which is not appropriate here due to our data for each test involving only two time periods). This began with the “staff numbers” variable, for which we take the current number of staff for each firm (or, if the firm is a conglomerate with various arms, the solar PV arm of the firm). This is because the current staff number is available for the vast majority of firms, whereas due to the limitations of Chinese data, historical data is not always available; the risk of using the control variable in this form is that we do not allow for the possible effect that higher historical PatPer may have on the staff numbers through causing a firm to grow, thus employing more people. Therefore, using a representative sub-sample of 20 firms for which this historical staff data was available, reverse causality tests were carried out as follows.

The tests were carried out separately for Factor 1 and Factor 2. Multiple regressions were carried out firstly with average staff numbers 2006-9 as the dependent variable, and Factor 1 in 2011 as the independent variable (please note that although the variable is described as “Factor 1 when staff numbers (2006-2009)”, this means the factor for 2011 is only sought for these firms, not that the factor itself is for the years 2006-2009); then the regression was carried out vice-versa. The same procedure was then used for Factor 2.

The same reverse causation tests were then repeated for: PatPer and foreign shareholding; PatPer and proportion of state shareholding; and PatPer and the level of state shareholding (the hypotheses involving different technology types are not tested for reverse causality, given that the effects on patenting are already tested with PatPer and state level, and PatPer and state proportion, and technology type is simply a subset of PatPer).

In the first regression, Factor 1 had a significance of .798, demonstrating no significant impact on staff numbers (the full coefficients were: unstandardised B: 17.890; unstandardised standard error: 68.719; standardised coefficient beta: .061; t: .260; significance: .798); Factor 2 generated a result of .909, also showing no significance (the full coefficients were: unstandardised B: -20.969; unstandardised standard error: 181.613; standardised coefficient beta: -.027; t: -.115; significance: .909). Mahalanobis and Cook’s distances (heteroscedasticity tests) were judged not to be relevant here.

The results were as follows:

Test number	Test name	Dependent variable	Independent variable	Beta	Sig.	N
1	PatPer & Company size	Firm staff (2006-9)	Factor 1 when staff numbers (2006-2009)	.061	.798	20
2	PatPer & Company size	Firm staff (2006-9)	Factor 2 when staff numbers (2006-2009)	-.027	.909	20
3	PatPer & Foreign shareholding	Foreign percentage (2008-9)	Factor 1&2 combined (2003-5)	-.038	.690	150
4	PatPer & State shareholding	State proportion (2008-9)	Factor 1&2 combined (2003-5)	-.050	.595	150
5	PatPer & Level of state shareholding	Level of state (2008-9)	Factor 1&2 combined (2003-5)	.061	.617	150

Table 8: Reverse causation results summary table

The results were also judged to be logically satisfactory, because although Chinese solar PV firms are being pushed to patent by government in the expectation that this will help drive future growth, until now these firms have been buffeted by various other phenomena, such as trade tariffs and an ongoing price war, that the influence of patenting alone has not *yet* been significant, which means reverse causality is avoided. As described, reverse causality also had to be tested for: PatPer and foreign shareholding; PatPer and proportion of state shareholding; and PatPer and the level of state shareholding. All tests were passed without detecting reverse causality (see appendices for full reverse causation test tables).

8.1.7 Interpolated figures

Total staff:

Because a small proportion of our firms did not have total staff numbers available, it was necessary to create interpolated figures for these firms (this only applied to 15 firms in total). From investigation via these firms' websites, telephoning the firms, and from interview data, these firms were judged to be either small or large, with a current staff figure of 200 used for small, and 2500 for large firms, derived from firms for which data was available.

R&D budgets:

Of the listed firms, some have published full R&D data for the relevant years (2008-2010), and others are interpolated straightforwardly from their full 2008-2010 R&D staff data. A minority of firms require more detailed interpolation. As there is too much industry variance to interpolate crudely from an industry mean, this has had to follow more exact procedures.

For some of the firms I have good R&D staff data for the relevant years (which can be averaged for 2008-10); for others I have good R&D data for the relevant years; for others I have R&D budget and/or R&D staff data that covers other years. Where possible I interpolate first from available R&D budget figures; otherwise I interpolate from R&D staff figures if they are available for 2008-2010. I do not create interpolations for those firms lacking either any R&D budget figures whatsoever or lacking R&D staff figures. The interpolations were as follows:

Firm ID 18 (row 7 in SPSS): I improve the interpolated averaged R&D budget 2008-2010 figure I have by calculating the 2008-10 R&D staff average; then use the mean of the standard staff to budget ratio to create a new 2008-2010 average R&D budget figure for this firm.

Firm ID 20 (row 8): the available R&D budget figure for this firm was for 2011, so the firms with both 2011 R&D budget data and 2008-2010 R&D budget data were used and a ratio created for the change from the 2008-2010 average to 2011. An average of these ratios was created, then this was applied to this firm to establish the new figure.

Firm ID 26 (row 12): the same procedure was used.

Firm ID 32 (row 13): the interpolation has two methods. First, the firm's full 2008-10 R&D staff numbers are averaged, then the R&D staff to R&D budget mean ratio for all firms is used to create an average R&D budget figure. Then this firm's available 2010 R&D budget figure was used in the same procedure as the two firms above. An average was then made of these two budget figures, and this was used.

Firm ID 74 (row 23): this is imputed from the 2010 R&D staff number. I first took the firms with full 2008-2010 R&D staff numbers; I then established their staff number average for 2010. An average ratio was then created of the 2008-2010 R&D staff to the 2010 R&D staff. I applied this ratio to this firm's 2010 staff number, and took this new average 2008-2010 staff figure, applying the standard mean ratio of the R&D staff to R&D budget for the 2008-2010 period to obtain the new R&D budget figure.

Firm row ID 84 (row 27): using the R&D staff number for 2009, the same process as for the firm above was used.

Firm ID 88 (row 28): this firm has R&D budget figures available for 2010-13, so the 2010 R&D budget figure was used, and an average for 2008-10 was created using the average ratio of the 2010 R&D budget and the 2008-2010 R&D budget.

Firm ID 90 (row 29): using the R&D staff number for 2009, the above procedure was followed as for the firms with ID 74 and ID 84.

Firm ID 108 (row 31): using the published data for R&D staff for 2008-9, those firms with full 2008-10 R&D staff data were used to generate the ratios between their 2009 and 2010 figures. This ratio was averaged, then applied to my 2009 figure to create the interpolated 2010 figure. This was used to create a new average of this 2008-10 staff figure set, and the standard mean R&D staff to R&D budget ratio was applied to obtain the R&D budget.

Firm ID 113 (row 32): the firm’s available R&D staff figure for 2011 was used, following the same procedure as for firm ID 74.

8.2 Hypotheses: calculations and results

Before we explain the calculation of Hypothesis 1 (and the other hypotheses), we should describe the assembly of the data that is specific to hypotheses 1 to 4 in particular (hypotheses 1-4 being tested only on listed firms). This falls into the independent variables, which are in ownership (shareholding) data; control variables; and the dependent variables, being R&D and patenting information.

First we should deal with the time-lags involved. Although this data is unsuitable for panel usage, we employ a lag to allow for the manifestation of the effect of the independent variable/s (and controls) on dependent variables. In hypotheses 1 to 4, we follow a lag from the independent variable (ownership) and controls at t0, to R&D at t+1, to patent output at t+3. Given that using patent data for the years 2010-2012 gives the richest output data, which reduces noise, this means R&D data for 2008-2010 is used, and ownership data for 2007-2009. Furthermore, averaging is necessary if these years are to be used, given that each variable is thus using a three-year sample of data.

The necessary patent data for 2010 to 2012 was created by taking the numbers of inventive patents, non-inventive patents, and citations for the relevant years for each firm (making up factor 1), and the foreign patent families (non-US) and US patent families (making up factor 2), multiplying by the relevant factor weightings, and creating averages for each firm for the sample period (of factor 1 output; factor 2 output; and combined factor output).

Regarding the control variables, some adjustment must be made between any control variables that had been assembled for current data, and the need for previous time periods. For age of the firm this was straightforward. For agglomeration, it was judged that although the numbers of firms in an exact locale may differ slightly in previous time periods, the distribution of firms in different regions in China will not differ significantly, and as such the current agglomeration variable can be applied just as well. For the number of staff in a firm (the firm size control variable), staff numbers for 2008 (given the R&D variable being an average for 2007-2009) are used (and in the minority of cases where an exact staff number for a firm for that year was not known, an imputation was made by generating the average ratio for change in staff number from 2008 to the most recent figure – using firms where both are known – and applying this to the firms where the 2008 figure needs to be obtained).

Please note that some of the hypotheses see a slightly lower number of firms tested than others, due to the lack of data availability on some metrics; also, in some regressions certain control variables show lower N numbers than other variables, which is due to that data not being available for all firms. Given that we have checked the reliability of all listed firms in our relatively small listed firm sample, we only remove firms that breach recommended Mahalanobis or Cook's values if this is stated and explained. In the hypotheses outputs, the following tables will be shown, unless stated otherwise: *Descriptive Statistics, Correlations,* and *Coefficients*.

Hypothesis 1

First, the regression for hypothesis 1 in the following form will be tested:

Hypothesis 1a: The higher the state shareholding, the higher the rate of spend on R&D, *absolutely*

Then the hypothesis in the second form will be run:

Hypothesis 1b: The higher the state shareholding, the higher the rate of spend on R&D, *relative to turnover*

Hypothesis 1a: The higher the state shareholding, the higher the rate of spend on R&D, *absolutely*

The hierarchical multiple regression was carried out as follows:

Hypothesis 1a: Testing the Relationship between State Shareholding and Absolute R&D Spend:

Table 9: Descriptive statistics and pairwise correlations (N= 28)

	Mean	Standard deviations	R&D budget (2008-10)	Firm HQ province GDP per capita	Firm age (2009)	Firm staff (2008)	Firm agglomeration rating	State percentage (2007-2009)
R&D budget (2008-10)	21476216.77	25984056.33	1.000					
Firm HQ province GDP per capita	57996	18006.071	-.345*	1.000				
Firm age (2009)	14.36	9.546	-.048	-.204	1.000			
Firm staff (2008)	2927.33	2445.038	.365*	-.395*	-.307*	1.000		
Firm agglomeration rating	22.68	20.497	-.165	.668*	-.345*	.091	1.000	
State percentage (2007-2009)	27.49798	36.664138	.234	-.256*	.368*	-.156	-.231	1.000

*= Significant at 5%

Hypothesis 1a

Table 10: Coefficients

Coefficients										
	Model 1					Model 2				
	Unstandardized Coefficients		Standardized Coefficients	T	Sig.	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta			B	Std. Error	Beta		
(Constant)	30366443.269	31365975.818		.968	.343	17578727.804	32243217.219		.545	.591
Firm HQ province GDP per capita	-257.173	469.535	-.179	-.548	.589	-97.841	476.224	-.068	-.205	.839
Firm age (2009)	-59346.640	582373.953	-.022	-.102	.920	-258577.035	590966.180	-.095	-.438	.666
Firm staff (2008)	3134.645	2717.481	.295	1.154	.261	3864.394	2724.363	.364	1.418	.170
Firm agglomeration rating	-101392.289	376964.018	-.080	-.269	.790	-153402.837	372401.711	-.121	-.412	.684
State percentage (2007-2009)						198223.491	146851.341	.280	1.350	.191
R square	.184					.246				
R square change	.184					.062				
Sig F change	.301					.191				

a. Dependent Variable: R&D budget (2008-10)

Therefore, as the table demonstrates, the result of the regression was that the effect of the independent variable was supported to significance, giving a Beta value of .280 and a Significance value of .191.

Hypothesis 1b: The higher the state shareholding, the higher the rate of spend on R&D, *relative to turnover*

The hierarchical multiple regression for this second version of the hypothesis was as follows (first the regression with all control variables is illustrated, then with only the one qualifying control variable remaining):

<u>Hypothesis 1b: Testing the Relationship between State Shareholding and R&D Spend Relative to Turnover</u>

<u>Hypothesis 1b</u>
<u>Table 11: Descriptive statistics and pairwise correlations (N= 25)</u>

	Mean	Standard deviation	R&D budget as percent of revenue (2008-10)	Firm age (2009)	Firm agglomeration rating	Firm HQ province GDP per capita	Firm staff (2008)	State percentage (2007-2009)
R&D budget as percent of revenue (2008-10)	2.29699	3.633448	1.000					
Firm age (2009)	14.36	9.716	.185	1.000				
Firm agglomeration rating	25.24	20.218	.017	-.384*	1.000			
Firm HQ province GDP per capita	59444.68	18224.036	.108	-.290*	.662*	1.000		
Firm staff (2008)	2864.81	2219.683	-.329*	-.201	.144	-.331*	1.000	
State percentage (2007-2009)	30.57773	37.672759	.250	.391*	-.357*	-.344*	-.159	1.000

*= Significant at 5%

Hypothesis 1b

Table 12: Coefficients

Coefficients[a]

	Model 1					Model 2				
	Unstandardized Coefficients		Standardized Coefficients	T	Sig.	Unstandardized Coefficients		Standardized Coefficients	T	Sig.
	B	Std. Error	Beta			B	Std. Error	Beta		
(Constant)	3.224	4.573		.705	.489	1.696	4.869		.348	.731
Firm age (2009)	.061	.086	.162	.700	.492	.040	.089	.107	.446	.661
Firm agglomeration rating	.033	.058	.185	.571	.575	.033	.059	.186	.571	.575
Firm HQ province GDP per capita	-1.671E-05	.000	-.084	-.244	.810	-1.201E-06	.000	-.006	-.017	.987
Firm staff (2008)	-.001	.000	-.350	-1.331	.198	.000	.000	-.300	-1.114	.279
State percentage (2007-2009)						.022	.023	.225	.936	.361
R square	0.139					0.177				
R square change	0.139					0.038				
Sig F change	0.534					0.361				

a. Dependent Variable: R&D budget as percent of revenue (2008-10)

Hypothesis 1b

Table 13: Descriptive statistics and pairwise correlations for reduced control variables (N= 25)

	Mean	Standard deviation	R&D budget as percent of revenue (2008-10)	Firm age (2009)	Firm agglomeration rating	Firm HQ province GDP per capita	State percentage (2007-2009)
R&D budget as percent of revenue (2008-10)	2.29699	3.633448	1.000				
Firm age (2009)	14.36	9.716	.185	1.000			
Firm agglomeration rating	25.24	20.218	.017	-.384*	1.000		
Firm HQ province GDP per capita	59444.68	18224.036	.108	-.290*	.662*	1.000	
State percentage (2007-2009)	30.57773	37.672759	.250	.391*	-.357*	-.344*	1.000

*= Significant at 5%

Hypothesis 1b

Table 14: Coefficients for reduced control variables

Coefficients[a]

	Model 1					Model 2				
	Unstandardized Coefficients		Standardized Coefficients	T	Sig.	Unstandardized Coefficients		Standardized Coefficients	T	Sig.
	B	Std. Error	Beta			B	Std. Error	Beta		
(Constant)	-1.090	3.286		-.332	.743	-2.214	3.394		-.652	.522
Firm age (2009)	.087	.086	.233	1.017	.321	.057	.089	.152	.641	.529
Firm agglomeration rating	-.003	.053	-.017	-.057	.955	.004	.052	.020	.068	.946
Firm HQ province GDP per capita	3.721E-05	.000	.187	.662	.515	4.681E-05	.000	.235	.831	.416
State percentage (2007-2009)						.027	.023	.279	1.175	.254
R square	.063					.124				
R square change	.063					.061				
Sig F change	.706					.254				

a. Dependent Variable: R&D budget as percent of revenue (2008-10)

As the table demonstrates, the hypothesis was not supported, giving a Beta value of .279, with a Significance value of .254.

Hypothesis 2

As for hypothesis 1, hypothesis 2 was tested in its two versions. First we test the first version of this hypothesis, being:

Hypothesis 2a: The higher the level of government which holds the largest state shareholding, the higher the rate of spend on R&D *absolutely*.

Then the second version, being:

Hypothesis 2b: The higher the level of government which holds the largest state shareholding, the higher the rate of spend on R&D *relative to turnover*.

Hypothesis 2a: The higher the level of government which holds the largest state shareholding, the higher the rate of spend on R&D *absolutely*.

(Please note that repeated regressions to account for control variables that do not reach required correlations are not set out from this point, for the remainder of the listed firms' hypotheses 1 to 4). The first version was tested using a hierarchical multiple regression, as follows:

Hypothesis 2a: Testing the Relationship Between Level of State and Absolute R&D Spend

Table 15: Descriptive statistics and pairwise correlations (N= 20)

	Mean	Standard deviation	R&D budget (2008-10)	Firm age (2009)	Firm agglomeration rating	Central state largest shareholder (2007-9) (categorical)	Non-central state largest shareholder (2007-9) (categorical)
R&D budget (2008-10)	25336772.2810	28943177.11872	1.000				
Firm age (2009)	11.20	10.685	-.061	1.000			
Firm agglomeration rating	21.70	19.609	-.227	-.448*	1.000		
Central state largest shareholder (2007-9) (categorical)	.60	.503	-.064	.270	.169	1.000	
Non-central state largest shareholder (2007-9) (categorical)	.40	.503	.064	-.270	-.169	-1.000*	1.000

*= Significant at 5%

As the table below demonstrates, although the hypothesis was supported by the Beta value, with non-central shareholdings giving a Beta value of -.055, the significance value was lower than required, at .837.

Hypothesis 2a

Table 16: Coefficients

Coefficients[a]

	Model 1					Model 2				
	Unstandardized Coefficients		Standardized Coefficients	T	Sig.	Unstandardized Coefficients		Standardized Coefficients	T	Sig.
	B	Std. Error	Beta			B	Std. Error	Beta		
(Constant)	41706566.714	15256162.685		2.734	.014	44337496.182	20134302.220		2.202	.043
Firm age (2009)	-551747.294	703227.321	-.204	-.785	.443	-616336.931	787208.807	-.228	-.783	.445
Firm agglomeration rating	-469629.155	383196.053	-.318	-1.226	.237	-499125.234	418984.809	-.338	-1.191	.251
Non-central state largest shareholder (2007-9) (categorical)						-3168765.858	15176022.874	-.055	-.209	.837
R square	0.085					0.087				
R square change	0.085					0.002				
Sig F change	0.472					0.837				

a. Dependent Variable: R&D budget (2008-10)

Hypothesis 2b: The higher the level of government which holds the largest state shareholding, the higher the rate of spend on R&D *relative to turnover*.

The second version was tested using a hierarchical multiple regression as follows. Please note that as shown in the table, the independent variable was also expressed as Central vs. Non-central, using dummy variables, for the reasoning described above.

Hypothesis 2b: Testing the Relationship Between Level of State and R&D Spend Relative to Turnover

Table 17: Descriptive statistics and pairwise correlations (N= 20)

	Mean	Standard deviation	R&D budget as percent of revenue (2008-10)	Firm HQ province GDP per capita	Firm age (2009)	Firm staff (2008)	Firm agglomeration rating	Central state largest shareholder (2007-9) (categorical)	Non-central state largest shareholder (2007-9) (categorical)
R&D budget as percent of revenue (2008-10)	2.926	3.981	1.000						
Firm HQ province GDP per capita	58177.000	18997.812	.166	1.000					
Firm age (2009)	10.895	10.888	.171	-.308	1.000				
Firm staff (2008)	2318.695	1841.788	-.272	-.626*	-.149	1.000			
Firm agglomeration rating	22.789	19.512	.109	.646*	-.434*	-.173	1.000		
Central state largest shareholder (2007-9) (categorical)	.632	.496	.277	-.081	.322*	-.237	.106	1.000	
Non-central state largest shareholder (2007-9) (categorical)	.368	.496	-.277	.081	-.322*	.237	-.106	-1.000*	1.000

*= Significant at 5%

Hypothesis 2b

Table 18: Coefficients

Coefficients[a]

	Model 1					Model 2				
	Unstandardized Coefficients		Standardized Coefficients	T	Sig.	Unstandardized Coefficients		Standardized Coefficients	T	Sig.
	B	Std. Error	Beta			B	Std. Error	Beta		
(Constant)	2.770	7.157		.387	.705	.126	8.350		.015	.988
Firm HQ province GDP per capita	-5.739E-06	.000	-.027	-.058	.955	2.577E-05	.000	.123	.229	.822
Firm age (2009)	.075	.111	.205	.675	.510	.054	.118	.147	.457	.655
Firm staff (2008)	.000	.001	-.228	-.600	.558	.000	.001	-.115	-.270	.791
Firm agglomeration rating	.036	.074	.176	.483	.637	.010	.085	.051	.122	.905
Central state largest shareholder (2007-9) (categorical)						1.667	2.547	.207	.654	.524
R square	0.111					0.14				
R square change	0.111					0.428				
Sig F change	0.778					0.524				

a. Dependent Variable: R&D budget as percent of revenue (2008-10)

Therefore this hypothesis was not supported satisfactorily. As the table demonstrates, although the Beta value reached only .207, the significance value was low, at just .524.

Hypothesis 3a

Hypothesis 3a stated that *the higher the private shareholding, the better the patenting performance for each unit of R&D spent.*

In order to test this hypothesis, we needed to divide patent performance (PatPer) by R&D budget. This was done by arranging each R&D budget (choosing the 2008-2010 average figure) in millions of RMB, then dividing the patent performance (the combined output of Factors 1 & 2 for 2010-2012) by this figure. As the control variables did not reach the recommended correlation values, the hierarchical multiple regression was then tested without them. This was tested as follows:

Hypothesis 3a: Testing the Relationship Between Private Shareholding and Patenting Performance for Each Unit of R&D Spent

Table 19: Descriptive statistics and pairwise correlations (N= 24)

	Mean	Standard deviation	Ave both factors output (2010-12) per R&D spend (RMBm 2008-10)	Firm age (2009)	Firm agglomeration rating	Firm HQ province GDP per capita	Firm staff (2008)	Private percentage (2007-9)
Ave both factors output (2010-12) per R&D spend (RMBm 2008-10)	.946	1.539	1.000					
Firm age (2009)	13.750	9.857	.012	1.000				
Firm agglomeration rating	22.958	20.677	.000	-.316*	1.000			
Firm HQ province GDP per capita	56381.083	18553.645	.124	-.289*	.723*	1.000		
Firm staff (2008)	3230.216	2486.561	-.175	-.247	.051	-.352*	1.000	.
Private percentage (2007-9)	53.367	34.492	.233	-.442*	.031	.211	.122	1.000

*= Significant at 5%

Hypothesis 3a

Table 20: Coefficients

Coefficients[a]

	Model 1					Model 2				
	Unstandardized Coefficients		Standardized Coefficients	T	Sig.	Unstandardized Coefficients		Standardized Coefficients	T	Sig.
	B	Std. Error	Beta			B	Std. Error	Beta		
(Constant)	.581	2.197		.264	.794	.283	2.196		.129	.899
Firm age (2009)	-.001	.040	-.004	-.015	.988	.017	.043	.111	.407	.689
Firm agglomeration rating	-.009	.027	-.118	-.320	.753	.002	.029	.033	.084	.934
Firm HQ province GDP per capita	1.410E-05	.000	.170	.414	.684	3.418E-07	.000	.004	.010	.993
Firm staff (2008)	-6.809E-05	.000	-.110	-.377	.710	.000	.000	-.185	-.621	.542
Private percentage (2007-9)						.013	.012	.302	1.135	.271
R square	0.04					0.104				
R square change	0.04					0.064				
Sig F change	0.935					0.271				

Dependent Variable: Average both factors output (2010-12) per R&D spend (RMBm 2008-10)

The regression shown by the table above means the hypothesis remained unproven, with a Beta value of .302, and a Significance value of .271.

Hypothesis 3b

Hypothesis 3b stated that the higher the foreign shareholding, the better the patenting performance for each unit of R&D spent.

To test this hypothesis, we also needed to divide patent performance (PatPer) by R&D budget. This was done by arranging each R&D budget (choosing the 2008 figure) in millions of RMB, then dividing the patent performance (the combined output of Factors 1 & 2 for 2010-2012) by this figure.

This hypothesis was tested first with the same control variables used above. Again, these did not reach the recommended correlation values, so the hypothesis was then tested without them, as described in the table below. This hierarchical multiple regression was carried out as follows.

Hypothesis 3b: Testing the Relationship Between Foreign Shareholding and Patenting Performance Per R&D Spend

Table 21: Descriptive statistics and pairwise correlations (N= 23)

	Mean	Standard deviation	Ave both factors output (2010-12) per R&D spend (RMBm 2008-10)	Firm age (2009)	Firm agglomeration rating	Firm HQ province GDP per capita	Firm staff (2008)	Foreign percentage (2007-9)
Ave both factors output (2010-12) per R&D spend (RMBm 2008-10)	.987	1.560	1.000					
Firm age (2009)	13.522	10.013	.027	1.000				
Firm agglomeration rating	23.913	20.593	-.030*	-.300	1.000			
Firm HQ province GDP per capita	56480.435	18964.104	.122*	-.288*	.736	1.000		
Firm staff (2008)	3347.969	2473.080	-.213	-.228	-.001	-.368*	1.000	
Foreign percentage (2007-9)	16.366	20.838	.226	-.072*	.437	.058	.242	1.000

*= Significant at 5%

Hypothesis 3b
Table 22: Coefficients

Coefficients[a]

	Model 1					Model 2				
	Unstandardized Coefficients		Standardized Coefficients	T	Sig.	Unstandardized Coefficients		Standardized Coefficients	T	Sig.
	B	Std. Error	Beta			B	Std. Error	Beta		
(Constant)	.654	2.216		.295	.771	-.310	2.134		-.145	.886
Firm age (2009)	-1.515E-05	.040	.000	.000	1.000	-.003	.038	-.021	-.086	.932
Firm agglomeration rating	-.014	.028	-.181	-.485	.634	-.045	.031	-.599	-1.448	.166
Firm HQ province GDP per capita	1.687E-05	.000	.205	.489	.631	3.837E-05	.000	.467	1.121	.278
Firm staff (2008)	-8.686E-05	.000	-.138	-.473	.642	.000	.000	-.168	-.616	.546
Foreign percentage (2007-9)						.037	.020	.500	1.893	.075
R square	0.06					0.224				
R square change	0.06					0.164				
Sig F change	0.883					0.075				

Dependent Variable: Ave both factors output (2010-12) per R&D spend (RMBm 2008-10)

As the table demonstrates, with a Beta value of .500 and a Significance of .075, the hypothesis was supported to significance.

Hypothesis 3c

For hypothesis three, the first of two tests was carried out regressing PatPer as the dependent variable, with *R&D spend* and *Private & Foreign shareholding* (% of total) as two separate independent variables (with the control variables as above). This hierarchical multiple regression was as follows:

Hypothesis 3c: Testing the Relationship Between Foreign & Private Shareholding and R&D and Patenting Performance

Table 23 Descriptive statistics and pairwise correlations (N= 24)

	Mean	Standard deviation	Ave both factors output (2010-12)	Firm HQ province GDP per capita	Firm age (2009)	Firm staff (2008)	Firm agglomeration rating	Private plus foreign shareholding as a percentage (2007-9)	R&D budget (2008-10)
Ave both factors output (2010-12)	5.198	8.534	1.000						
Firm HQ province GDP per capita	56381.083	18553.645	.000	1.000					
Firm age (2009)	9.792	9.811	.001	-.297*	1.000				
Firm staff (2008)	3230.216	2486.561	.170	-.352*	-.238	1.000			
Firm agglomeration rating	22.958	20.677	.177	.723*	-.322*	.051	1.000		
Private plus foreign shareholding as a percentage (2007-9)	69.033	38.591	.317*	.222	-.441*	.254	.271	1.000	
R&D budget (2008-10)	27446992.826	35026816.467	.555*	-.430*	.002	.470*	-.127	-.091	1.000

*= Significant at 5%

Hypothesis 3c
Table 24: Coefficients

Coefficients[a]	Model 1					Model 2				
	Unstandardized Coefficients		Standardized Coefficients	T	Sig.	Unstandardized Coefficients		Standardized Coefficients	T	Sig.
	B	Std. Error	Beta			B	Std. Error	Beta		
(Constant)	4.495	11.474		.392	.700	-10.705	8.956		-1.195	.248
Firm HQ province GDP per capita	.000	.000	-.165	-.408	.688	.000	.000	.090	.294	.772
Firm age (2009)	.071	.218	.082	.327	.747	.207	.165	.238	1.257	.226
Firm staff (2008)	.000	.001	.115	.402	.692	-.001	.001	-.235	-1.064	.302
Firm agglomeration rating	.131	.150	.316	.873	.393	.069	.109	.167	.632	.536
Private plus foreign shareholding as a percentage (2007-9)						.108	.041	.487	2.613	.018
R&D budget (2008-10)						.000	.000	.769	3.950	.001
R square	.076					.570				
R square change	.076					.495				
Sig F change	.814					.001				

Dependent Variable: Ave both factors output (2010-12)

This means that as the table shows, with a Beta value of .769, and a strong Significance value of .001, R&D expenditure (and combined private and foreign shareholding) were both supported to significance as independent variables.

Hypothesis 3d

Again for hypothesis three, the second of two tests was carried out, regressing PatPer as the dependent variable, with *Private & Foreign shareholding* (% of total) as the independent variable (with the control variables as above). This hierarchical multiple regression was as follows:

Hypothesis 3d: Testing the Relationship Between Foreign & Private Shareholding and Patenting Performance

Table 25: Descriptive statistics and pairwise correlations (N= 32)

	Mean	Standard deviation	Ave both factors output (2010-12)	Firm HQ province GDP per capita	Firm age (2009)	Firm staff (2008)	Firm agglomeration rating	Private plus foreign shareholding as a percentage (2007-9)
Ave both factors output (2010-12)	4.412	7.494	1.000					
Firm HQ province GDP per capita	57843.500	17677.677	-.019	1.000				
Firm age (2009)	8.594	8.933	.036	-.278*	1.000			
Firm staff (2008)	2799.636	2415.554	.192	-.309*	-.081	1.000		
Firm agglomeration rating	25.125	21.234	.108	.643*	-.237*	.118	1.000	
Private plus foreign shareholding as a percentage (2007-9)	75.363	35.276	.233*	.235*	-.463*	.122	.280*	1.000

*= Significant at 5%

Hypothesis 3d

Table 26: Coefficients

Coefficients[a]	Model 1					Model 2				
	Unstandardized Coefficients		Standardized Coefficients	T	Sig.	Unstandardized Coefficients		Standardized Coefficients	T	Sig.
	B	Std. Error	Beta			B	Std. Error	Beta		
(Constant)	1.746	7.515		.232	.818	-2.669	8.084		-.330	.744
Firm HQ province GDP per capita	.000	.000	-.017	-.060	.953	.000	.000	-.038	-.132	.896
Firm age (2009)	.061	.167	.073	.365	.718	.159	.179	.190	.888	.382
Firm staff (2008)	.001	.001	.179	.804	.428	.000	.001	.151	.686	.499
Firm agglomeration rating	.041	.096	.115	.424	.675	.028	.095	.078	.292	.773
Private plus foreign shareholding as a percentage (2007-9)						.062	.045	.290	1.357	.186
R square	.050					.112				
R square change	.050					.063				
Sig F change	.840					.186				

Dependent Variable: Ave both factors output (2010-12)

Therefore with a Beta value of .290, and a Significance value of .186, combined private and foreign shareholding was also supported as significant in isolation.

Hypothesis 3e

The final test on the listed firm regressions (hypotheses 1 to 4) involved testing ownership as a moderating variable (moderating the impact of R&D expenditure on innovation). This was demonstrated using the hierarchical multiple regression below, in which the impact on the dependent variable PatPro (patent performance divided by R&D expenditure) of the independent variable (domestic) private and foreign ownership combined was regressed.

Hypothesis 3e
Table 27: Descriptive statistics and pairwise correlations (N=24)

	Mean	Standard deviation	Ave both factors output (2010-12) per R&D spend (RMBm 2008-10)	Firm HQ province GDP per capita	Firm age (2009)	Firm staff (2008)	Firm agglomeration rating	Private plus foreign shareholding as a percentage (2007-9)
Ave both factors output (2010-12) per R&D spend (RMBm 2008-10)	.94614	1.538667	1.000	.124	.009	-.175	.000	.338
Firm HQ province GDP per capita	56381.08	18553.645	.124	1.000	-.297	-.352	.723	.222
Firm age (2009)	9.79	9.811	.009	-.297	1.000	-.238	-.322	-.441
Firm staff (2008)	3230.22	2486.561	-.175	-.352	-.238	1.000	.051	.254
Firm agglomeration rating	22.96	20.677	.000	.723*	-.322	.051	1.000	.271
Private plus foreign shareholding as a percentage (2007-9)	69.03	38.591	.338	.222	-.441*	.254	.271	1.000

*= Significant at 5%

Hypothesis 3e

Table 28: Coefficients

Coefficients[a]

	Model 1					Model 2				
	Unstandardized Coefficients		Standardized Coefficients	T	Sig.	Unstandardized Coefficients		Standardized Coefficients	T	Sig.
	B	Std. Error	Beta			B	Std. Error	Beta		
(Constant)	.584	2.108		.277	.785	-.233	2.006		-.116	.909
Firm HQ province GDP per capita	1.406E-05	.000	.169	.412	.685	5.360E-06	.000	.065	.167	.869
Firm age (2009)	-.001	.040	-.005	-.020	.984	.023	.039	.146	.586	.565
Firm staff (2008)	-6.838E-05	.000	-.111	-.380	.708	.000	.000	-.233	-.838	.413
Firm agglomeration rating	-.009	.027	-.118	-.320	.753	-.009	.026	-.117	-.341	.737
Private plus foreign shareholding as a percentage (2007-9)						.019	.010	.479	1.980	.063
R square	.040					.212				
R square change	.040					.172				
Sig F change	.935					.063				

Dependent Variable: Ave both factors output (2010-12) per R&D spend (RMBm 2008-10)

The impact of private and foreign shareholding combined showed a Beta value of .479, and a Significance value of .063. The moderating effect of ownership was therefore supported to significance.

Hypothesis 4

Hypothesis 4, the lower the level of government which holds any state shareholding, the better the patenting performance for each unit of R&D spent, was tested first with the control variables used above, and as these did not reach recommended correlation values, tested without, as shown in the table below. Patent Performance (PatPer) was divided by the R&D spend as for hypothesis 3a and 3b above, the dependent variable therefore being *Ave both factors output (2010-12) per R&D spend (RMBm 2008-10)*. The hierarchical multiple regression was carried out as follows:

Hypothesis 4: Testing the Relationship Between Level of State and Patenting Performance Per R&D Spend
Table 29: Descriptive statistics and pairwise correlations (N= 20)

	Mean	Standard deviation	Ave both factors output (2010-12) per R&D spend (RMBm 2008-10)	Firm HQ province GDP per capita	Firm age (2009)	Firm staff (2008)	Firm agglomeration rating	Central state percentage (2007-9)	Non-central state percentage (2007-9)
Ave both factors output (2010-12) per R&D spend (RMBm 2008-10)	.522	.944	1.000						
Firm HQ province GDP per capita	57972.950	18513.616	-.023	1.000					
Firm age (2009)	11.200	10.685	-.213	-.311*	1.000				
Firm staff (2008)	2256.619	1814.033	-.012	-.611*	-.165	1.000			
Firm agglomeration rating	21.698	19.609	-.158	.637*	-.448*	-.128	1.000		
Central state percentage (2007-9)	.600	.503	-.434*	-.064	.270	-.182	.169	1.000	
Non-central state percentage (2007-9)	.400	.503	.434*	.064	-.270	.182	-.169	-1.000*	1.000

*= Significant at 5%

Hypothesis 4
Table 30: Coefficients

Coefficients[a]

	Model 1					Model 2				
	Unstandardized Coefficients		Standardized Coefficients	T	Sig.	Unstandardized Coefficients		Standardized Coefficients	T	Sig.
	B	Std. Error	Beta			B	Std. Error	Beta		
(Constant)	1.371	1.647		.832	.418	1.754	1.598		1.098	.291
Firm HQ province GDP per capita	.000	.000	.012	.027	.979	.000	.000	-.287	-.605	.555
Firm age (2009)	-.034	.026	-.386	-1.331	.203	-.024	.026	-.268	-.927	.369
Firm staff (2008)	.000	.000	-.114	-.315	.757	.000	.000	-.318	-.855	.407
Firm agglomeration rating	-.017	.017	-.354	-1.013	.327	-.003	.018	-.064	-.166	.870
Non-central state percentage (2007-9)						.801	.523	.427	1.532	.148
R square	.139					.263				
R square change	.139					.124				
Sig F change	.664					.148				

Dependent Variable: Ave both factors output (2010-12) per R&D spend (RMBm 2008-10)

This means that with a Beta value of .427 and a Significance of .148 in the table, the impact of the independent variable was supported to significance.

Hypothesis 5

The first hypothesis for all firms (listed and unlisted) was hypothesis H5. **This proposed that the higher the foreign shareholding, the higher the output of more inventive patents** (the dependent variable being the "more inventive" PatPer factor, Factor 2). This also lags as in hypothesis three. This was tested as follows.

A measure was created for all firms of their foreign shareholding as a percentage of total shareholding, averaged 2005-2009, but using only those years for each average for which some shareholding is registered (these are the years from which there is a +3 year time lag to patenting for that particular firm). The dependent variable was an average annual output of Factor 2, averaged for each firm for 2008-12.

A hierarchical multiple regression was carried out using the following control variables: annual GDP of firm province, staff number, age of firm, and the agglomeration rating previously described. Although total staff had the strongest Sig. value of .000, which is to be expected, the independent variable of foreign shareholding maintained a significance value of .011, passing our required value of .1, with result that the hypothesis was confirmed.

No outliers, assessed by either Mahalanobis or Cook's distances were removed; this was because for those firms with an apparently excessive Mahalanobis distance (that is firm IDs 15, 19, 32, 51 and 72), none had an excessive leverage (i.e. none had a Cook's distance of 1.0 or over). Meanwhile the only firm with a high Cook's distance (firm ID 2, at 1.06543), had a low Mahalanobis value of 8.65704 (it should be noted that future hypotheses see these outliers removed if they show high Mahalanobis values, suggesting excessive leverage on the outcome).

The results of the hierarchical multiple regression are outlined as follows:

Hypothesis 5: Testing the Relationship Between Foreign Shareholding and Output of More Inventive Patents

Table 31: Descriptive statistics and pairwise correlations

	Mean	Standard deviation	N	Ave factor 2 output (2008-12)	Firm HQ province GDP per capita	Age of the firm	Firm staff or firm PV arm staff (current)	Firm agglomeration rating	Foreign percentage (2005-6)
Ave factor 2 output (2008-12)	.062	.377	150	1.000					
Firm HQ province GDP per capita	61084.08	17708.45	150	.042	1.000				
Age of the firm	10.37	8.59	140	.080	-.179*	1.000			
Firm staff or firm PV arm staff (current)	1997.63	3668.379	150	.182*	-.102	.238*	1.000		
Firm agglomeration rating	25.31	19.727	150	.170*	.533*	-.156*	.075	1.000	
Foreign percentage (2005-6)	8.403	19.242	145	.243*	.071*	-.093	.158*	.102	1.000

*= Significant at 5%

Hypothesis 5

Table 32: Coefficients

Coefficients[a]

	Model 1					Model 2				
	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Unstandardized Coefficients		Standardized Coefficients	T	Sig.
	B	Std. Error	Beta			B	Std. Error	Beta		
(Constant)	-.051	.132		-.385	.701	-.073	.129		-.568	.571
Firm HQ province GDP per capita	.000	.000	-.030	-.290	.773	.000	.000	-.039	-.392	.696
Age of the firm	.003	.004	.068	.760	.448	.004	.004	.095	1.079	.283
Firm staff or firm PV arm staff (current)	.000	.000	.149	1.676	.096	.000	.000	.108	1.216	.226
Firm agglomeration rating	.004	.002	.185	1.808	.073	.003	.002	.175	1.745	.083
Foreign percentage (2005-6)						.004	.002	.220	2.578	.011
R square	.063					.109				
Adjusted R square	.034					.074				

a. Dependent Variable: Ave factor 2 output (2008-12)

However, as the Correlations table above reveals, none of the control variables we used had the required relationship with the dependent variable (*preferably* above .3). As such we are justified in running the regression again, as a simple linear regression without the control variables. This gave a significance value of 0.003, which is significant at both 2-tailed and 1-tailed significance values (as shown in table 34 below).

This was carried out as follows:

Hypothesis 5

Table 33: Descriptive statistics and pairwise correlations for reduced control variables

	Mean	Standard deviation	N	Ave factor 2 output (2008-12)	Foreign percentage (2005-6)
Ave factor 2 output (2008-12)	.062	.377	150	1.000	
Foreign percentage (2005-6)	8.403	19.242	145	.243*	1.000

*= Significant at 5%

Hypothesis 5

Table 34: Coefficients for reduced control variables

Coefficients[a]										
	Model 1					Model 2				
	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta			B	Std. Error	Beta		
(Constant)	.022	.033		.648	.518					
Foreign percentage (2005-6)	.005	.002	.243	2.997	.003					
R square	.059									
Adjusted R square	.053									
a. Dependent Variable: Ave factor 2 output 2008-10										

Next, the Casewise Diagnostics table highlighted firms with ID 2 and 21 as outliers; Firm ID 2 has a problematic Cook's distance of 2.48474, and 21 an acceptable distance of .35914 (following the removal of Firm ID 2, one firm in the new Casewise Diagnostics table, now at ID 20, had a Cook's value above 1, but this was only 1.083, so it was left in place). The final significance value (in the table below) was thus .110, significant at 1-tailed significance values (the full coefficients were: unstandardised B: .002; unstandardised standard error: .001; standardised coefficient beta: .134; t: 1.606; significance: .110). The hypothesis was therefore supported to significance.

The results were as follows:

Hypothesis 5

Table 35: Descriptive statistics and pairwise correlations for reduced control variables with outliers removed

	Mean	Standard deviation	N	Ave factor 2 output (2008-12)	Foreign percentage (2005-6)
Ave factor 2 output (2008-12)	.038	.243	148	1.000	
Foreign percentage (2005-6)	7.406	17.238	143	.134*	1.000

*= Significant at 5%

Hypothesis 5

Table 36: Coefficients for reduced control variables with outliers removed

Coefficients[a]										
	Model 1					Model 2				
	Unstandardized Coefficients		Standardized Coefficients	T	Sig.	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta			B	Std. Error	Beta		
(Constant)	.024	.022		1.098	.274					
Foreign percentage (2005-6)	.002	.001	.134	1.606	.11					
R square	.018									
Adjusted R square	.011									
a. Dependent Variable: Ave factor 2 output (2008-12)										

Hypothesis 6

Hypothesis 6a

The hypothesis was that **the total output of factor 1 patenting is a non-linear function of the ratio of state to private shareholding, therefore highest for intermediate values** (and especially MISOEs), i.e. that firms with a combination of private and state shareholding would demonstrate a higher output than purely private or purely state firms. We tested this hypothesis using standard multiple regression. This was tested as follows.

Standard Multiple Regression:

A multiple regression was carried out by dividing the state proportion variable into 4, using separate ownership variables for each category, of SOE, MASOE, MISOE, and POE. As the table below demonstrates, for the dependent variable Ave factor 1 output (2008-12), a significance value of .078 was revealed for MISOEs (reaching valid significance below .1), followed by SOEs at .253 (note that the SOE significance value was negative, meaning SOE ownership had a negative impact on output), and POEs at .347. (The full coefficients for MISOEs were: unstandardised B: .666; unstandardised standard error: .366; standardised coefficient beta: .164; t: 1.819; significance: 0.71). The hypothesis was therefore supported to significance.

In dealing with outliers, the following occurred: as it is only necessary to remove outliers with a Cook's distance value over 1 (see Pallant, 2013; only these are liable to have excessive leverage on the rest of the sample), Yingli (firm ID 3) and CECEP (firm ID 19) were the only firms with Cook's distance values over 1. Upon removing Yingli and CECEP, the Cook's distance value for Trina (firm ID 1) rose to over 1.

Upon removing Trina, no further firms' Cook's distance values were over 1, and MISOEs retained their superior absolute and relative significance value, which was then .071 (as shown in the coefficients table below), with significance value reaching recognised absolute levels (followed by .335 for POEs and .750 for SOEs). This working is illustrated below:

Hypothesis 6a: Testing the Relationship Between Patent Output and the Ratio of State to Private Shareholding

Table 37: Descriptive statistics and pairwise correlations

	Mean	Standard deviation	N	Ave factor 1 output (2008-12)	Firm staff or firm PV arm staff (current)	SOEs	MASOEs	MISOEs	POEs
Ave factor 1 output (2008-12)	1.664	2.75	150	1.000					
Firm staff or firm PV arm staff (current)	1997.63	3668.379	150	.436*	1.000				
SOEs	.11	.319	149	-.066	.176*	1.000			
MASOEs	.33	.471	147	-.142*	-.174*	-.252*	1.000		
MISOEs	.15	.363	149	.212*	.177*	-.153*	-.292*	1.000	
POEs	.41	.493	149	.020	-.083*	-.299*	-.578*	-.356*	1.000

*= Significant at 5%

Hypothesis 6a

Table 38: Coefficients

Coefficients[a]										
	Model 1					**Model 2**				
	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta			B	Std. Error	Beta		
(Constant)	.750	.362		2.073	.040					
Firm staff or firm PV arm staff (current)	.000	.000	.432	5.634	.000					
SOEs	-.818	.713	-.095	-1.147	.253					
MISOEs	1.138	.641	.150	1.776	.078					
POEs	.450	.477	.081	.943	.347					
R square	.228									
Adjusted R square	.206									
a. Dependent Variable: Ave factor 1 output (2008-12)										

Summary of final regression with outliers removed:

Hypothesis 6a

Table 39: Coefficients with outliers removed

Coefficients[a]

	Model 1					Model 2				
	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta			B	Std. Error	Beta		
(Constant)	.916	.206		4.441	.000					
Firm staff or firm PV arm staff (current)	.000	.000	.300	3.676	.000					
SOEs	-.128	.402	-.028	-.319	.750					
MISOEs	.666	.366	.164	1.819	.071					
POEs	.260	.268	.088	.968	.335					
R square	.135									
Adjusted R square	.110									

a. Dependent Variable: Ave factor 1 output (2008-12)

Hypothesis 6b:

For the dependent variable Annual average output of *both* factors for each firm 2008-2012, a significance value of .115 was revealed for MISOEs (illustrated below), followed by SOEs at .242 and POEs at .268.

In dealing with outliers, the following occurred: as it is only necessary to remove outliers with a Cook's distance value over 1 (see Pallant, 2013; only these are liable to have excessive leverage on the rest of the sample), Yingli (firm ID 3) and CECEP (firm ID 19) were the only firms with Cook's distance values over 1. Upon removing Yingli and CECEP, the Cook's distance value for Trina (firm ID 1) rose to over 1. As the table below shows, upon removing Trina, no further firms' Cook's distance values were over 1, and MISOEs retained their relative significance value at .166 (followed by .250 for POEs and .705 for SOEs). In ascending order of impact on PatPer, the categories were: SOEs, MASOEs, POEs, and MISOEs. The full coefficients for MISOEs were: unstandardised B: .579; unstandardised standard error: .416; standardised coefficient beta: .126; t: 1.392; significance: .166. The hypothesis was therefore supported to significance, although not strongly.

This working is illustrated below:

Hypothesis 6b

Table 40: Descriptive statistics and pairwise correlations for second regression (both factors)

	Mean	Standard deviation	N	Annual average output of both factors for each firm 2008-2012	Firm staff or firm PV arm staff (current)	SOEs	MASOEs	MISOEs	POEs
Annual average output of both factors for each firm 2008-2012	1.726	2.894	150	1.000					
Firm staff or firm PV arm staff (current)	1997.63	3668.379	150	.438*	1.000				
SOEs	.11	.319	149	-.069	.176*	1.000*			
MASOEs	.33	.471	147	-.146*	-.174*	-.252*	1.000*		
MISOEs	.15	.363	149	.193*	.177*	-.153*	-.292*	1.000*	
POEs	.41	.493	149	.040	-.083	-.299*	-.578*	-.356*	1.000

*= Significant at 5%

Hypothesis 6b

Table 41: Coefficients for second regression (both factors)

Coefficients[a]										
	Model 1					Model 2				
	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta			B	Std. Error	Beta		
(Constant)	.741	.381		1.947	.054					
Firm staff or firm PV arm staff (current)	.000	.000	.439	5.720	.000					
SOEs	-.882	.750	-.097	-1.176	.242					
MISOEs	1.069	.674	.134	1.585	.115					
POEs	.558	.502	.095	1.112	.268					
R square	.228									
Adjusted R square	.207									

a. Dependent Variable: Annual average output of both factors for each firm 2008-2012

Summary of final regression with outliers removed:

Hypothesis 6b

Table 42: Coefficients for second regression (both factors) with outliers removed

Coefficients[a]										
	Model 1					Model 2				
	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta			B	Std. Error	Beta		
(Constant)	.889	.234		3.795	.000					
Firm staff or firm PV arm staff (current)	.000	.000	.322	3.952	.000					
SOEs	-.173	.457	-.033	-.379	.705					
MISOEs	.579	.416	.126	1.392	.166					
POEs	.352	.305	.105	1.155	.250					

a. Dependent Variable: Annual average output of both factors for each firm 2008-2012

Please note that although the measures for MISOEs reach significance in the first regression, the other measures (e.g. against SOEs and POEs) are still valid for this hypothesis, as we are assessing the *relative* outcomes of each shareholding category against the others. Note also that the staff number control variable was used alone due to the correlations with other controls (illustrated in the *Appendix Hypothesis 6b full correlations table*).

Hypothesis 6c

Hypothesis 6c stated that that the output of *"*more inventive" patents is a non-linear function of the ratio of state to private shareholding, therefore highest for intermediate values. However this was not supported to significance (for the dependent variable Ave factor 2 output (2008-12), positive significance was not reached for any category of the ownership independent variable).

Hypothesis 7

Hypothesis 7: suggested that the effect of level of government on patenting performance.

Hypothesis 7a predicted that **the total output of patents is the higher, the higher the level of government which has the largest state shareholding; Hypothesis 7b** predicted that **the total output of patents is the higher, the lower the level of government which has the largest state shareholding.** Neither of these hypotheses were supported to significance.

Hypothesis 8

Hypothesis 8a predicted that **majority or 100% state-owned enterprises (MASOEs or SOEs) where central government is the major shareholder will be associated with a relatively high proportion of patent output in "blue sky" technology categories.** This hypothesis was not supported to significance.

Hypothesis 8b: Core technologies:

The proposition was that, among firms with some state ownership, a smaller proportion of the combined patent factors (Factors 1 and 2) were made up of "core technologies" among those with central state ownership than among those with local state ownership, tested with four codes (central, provincial, super-municipal, and municipal), i.e. central state shareholding was "worse" at generating core patents. This was demonstrated in the following manner (please note that the ANOVAs carried out are simply exploratory, preceding the regressions).

A one-way between-groups measures ANOVA (analysis of variance) with planned comparisons was conducted to compare the scores of central, provincial, super-municipal, and municipal state shareholding (the independent variable) on the proportion of the combined patent factors (Factor 1 and 2), obtained through the factor analysis, that is composed of "core technologies" (this being the dependent variable). In the planned comparison, the groups were given the following coefficients:

Group 1 (Central): -3
Group 2 (Provincial): 1
Group 3 (Super-Municipal): 1
Group 4 (Municipal): 1

These groups refer to the four types of state shareholding, by central, provincial, super-municipal, and municipal government (super-municipal referring to the cities of Beijing, Shanghai, Tianjin, and Chongqing, sometimes called the "provincial-level" cities).

The ANOVA test obtained a significance value of 0.61. Please note that, as with other hypotheses, the significance value is placed at .1 (instead of the more common .05) due to the relatively small sample size. Therefore there was a significant result for the influence of the independent variable.

Although ANCOVA (analysis of covariance) is typically carried out to establish the effect of covariants (which in this case would be the age of the firm, size of the firm, and GDP of the province in which the firm is headquartered), this would not be revealing in this case. This is because these control variables would be entered to judge whether they were helping firms gain achievements in patenting beyond other firms (for instance, how a firm's age might help it accrue special competence). However, in analysing core technologies we analyse the "standard" area of solar PV manufacture, as opposed to blue sky technologies which, falling in the fields of gallium and cadmium compounds and amorphous silicon for example, will on the whole represent greater scientific advancement (in other words, while blue sky technologies represent generally greater technological advancement, core technologies do not, representing simply the more "standard" focus of commercially-oriented solar PV manufacturing). As a result, for a firm to be, for example, larger or older than its peers would be a question for the proportion of its patenting in blue sky technologies, but not the standard core fields. Furthermore, we are not analysing the absolute numbers of core patents generated (which could also be influenced by the control variables), but the proportion. The hypothesis was therefore supported to significance.

The results are displayed in Appendix 21: *ANOVA testing for Hypothesis 8b core technologies*.

Hypothesis 8c: related technologies:

The proposition was that, among firms with some state ownership, a larger proportion of the combined patent factors (Factors 1 and 2) were made up of "related technologies" among those with central state ownership than among those with local state ownership tested with three codes (central, provincial, and combined municipal). This was demonstrated as follows.

A one-way between-groups measures ANOVA (analysis of variance) with planned comparisons was conducted to compare the scores of central, provincial, and combined municipal state shareholding (the independent variable) on the proportion of the combined patent factors (Factor 1 and 2), obtained through the factor analysis, that is composed of "related technologies" (the dependent variable). In the planned comparison, the groups were given the following coefficients:

Group 1 (Central): 2
Group 2 (Provincial): -1
Group 3 (combined Municipal, being Super-Municipal and Municipal): -1

These groups refer to the three types of state shareholding, by central, provincial, and combined super-municipal and municipal government (i.e. all city government taken as one type).

The ANOVA test obtained a significance value of .097 Please note that, as with other hypotheses, the significance value is place at .1 (instead of the more common .05) due to the relatively small sample size. Therefore there was a significant result for the influence of the independent variable.

As with *hypothesis 8b core technologies*, ANCOVA (analysis of covariance) was not carried out in this case. The reasoning is the same, and in this case that high proportions of related technologies are not an achievement beyond other firms, given that they are the most technologically basic solar PV area, being composed of equipment (such as household items, street lights, and garden lamps) that contains spun-off solar PV technologies. As above, we are also analysing a proportion, not absolute numbers. The hypothesis was therefore supported to significance.

The results are displayed in Appendix 22: *ANOVA testing for Hypothesis 8c related technologies*.

Standard Multiple Regressions:

Following the ANOVA testing, hypotheses 8a and 8b above were tested using standard multiple regression.

Hypothesis 8b:

First, for Hypothesis 8b, the correlations between the dependent variable and the possible control variables were tested. This confirmed our decision not to use control variables for the ANOVA testing above.

Following the correlations check, the multiple regression was used on the categorical dependent variable that, as in Hypothesis 6, had been split into four dummy variables to allow multiple regression testing to analyse the different coefficients between shareholding levels (as a simple linear regression). The regression demonstrated a greater *minus* significance value for central shareholding, thus confirming that local (non-central) shareholdings are more likely to generate core patents. Please note that although absolute significance (on a 2-tailed basis) was not reached for central shareholding in this case, as we are assessing the *relative* significances of the different shareholding levels. Meanwhile as the table below demonstrates, significance is reached on a 1-tailed basis. Therefore the hypothesis is still supported to significance. (The full coefficients for central shareholdings were: unstandardised B: -19.880; unstandardised standard error: 8.344; standardised coefficient beta: -.288; t: -2.383; significance: .019).

The multiple regression was carried out as follows:

Hypothesis 8b: Testing the Relationship Between Level of Government and Patenting of Tech Type C

Table 43: Descriptive statistics and pairwise correlations

	Mean	Standard deviation	N	Percent factors tech type C	Level of state Central	Level of state Provincial	Level of state Super-municipal	Level of state Municipal
Percent factors tech type C	78.401	31.675	150	1.000				
Level of state Central	.3	.459	88	-.239*	1.000			
Level of state Provincial	.34	.477	88	.188*	-.466*	1.000*		
Level of state Super-municipal	.14	.345	88	-.016	-.257*	-.286*	1.000	
Level of state Municipal	.23	.421	88	.061	-.351*	-.390*	-.215*	1.000

*= Significant at 5%

Hypothesis 8b

Table 44: Coefficients

Coefficients[a]	Model 1					Model 2				
	Unstandardized Coefficients		Standardized Coefficients	T	Sig.	Unstandardized Coefficients		Standardized Coefficients	T	Sig.
	B	Std. Error	Beta			B	Std. Error	Beta		
(Constant)	86.635	5.685		15.238	.000					
Level of state Central	-19.880	8.344	-.288	-2.383	.019					
Level of state Super-municipal	-9.491	10.636	-.103	-.892	.375					
Level of state Municipal	-4.688	8.989	-.062	-.521	.603					
R square	.067									
Adjusted R square	.033									

a. Dependent Variable: Percent factors tech type C

Hypothesis 8c related technologies:

Next, for Hypothesis 8c: related technologies, the correlations between the dependent variable and the possible control variables were tested. This also confirmed our decision not to use control variables for the ANOVA testing above.

Following the correlations check, as with *core technologies,* the multiple regression was used on the categorical dependent variable that, as in Hypothesis 6, had been split into four dummy variables to allow multiple regression testing to analyse the different coefficients between shareholding levels (also a simple linear regression). The regression demonstrated a greater significance value for central than non-central (local) shareholdings, i.e. that this form of shareholding is more likely to generate (the generally less technologically advanced) related technologies. Please note that although absolute significance (on a 2-tailed basis) was not reached for central shareholding in this case, as we are assessing the *relative* significances of the different shareholding levels. Meanwhile, significance is reached on a 1-tailed basis. Therefore the hypothesis is still supported by the table. (The full coefficients for central shareholdings were: unstandardised B: .9530; unstandardised standard error: 6.132; standardised coefficient beta: .190; t: 1.554; significance: .124).

Furthermore, although the absolute significance value shown in the ANOVA table (in the appendices) appears relatively poor, this testing of the *related* technologies question aims to establish by implication the shareholding type that is most likely to cause higher proportions of the *blue-sky* technology type (demonstration of which is problematic given the relatively small numbers for blue-sky patenting in a sample of our size). As we have demonstrated the causation by central state shareholding of both *core* and *related* technology types, it follows that non-central (local) technology types cause the only remaining technology type into which solar PV patents can fall, *blue-sky* technologies.

The multiple regression was carried out as follows:

Hypothesis 8c: Testing the Relationship Between Level of Government and Patenting of Tech Type R

Table 45: Descriptive statistics and pairwise correlations

	Mean	Standard deviation	N	Percent factors tech type R	Level of state Central	Level of state Provincial	Level of state Super-municipal	Level of state Municipal
Percent factors tech type R	10.841	22.989	150	1.000				
Level of state Central	.3	.459	88	.174*	1.000			
Level of state Provincial	.34	.477	88	-.106	-.466*	1.000		
Level of state Super-municipal	.14	.345	88	.061	-.257*	-.286*	1.000	
Level of state Municipal	.23	.421	88	-.119	-.351*	-.390*	-.215*	1.000

*= Significant at 5%

Hypothesis 8c

Table 46: Coefficients

Coefficients[a]	Model 1					Model 2				
	Unstandardized Coefficients		Standardized Coefficients	T	Sig.	Unstandardized Coefficients		Standardized Coefficients	T	Sig.
	B	Std. Error	Beta			B	Std. Error	Beta		
(Constant)	7.467	4.179		1.787	.078					
Level of state Central	9.53	6.132	.190	1.554	.124					
Level of state Super-municipal	6.86	7.817	.103	.878	.383					
Level of state Municipal	-1.66	6.607	-.030	-.251	.802					
R square	.043									
Adjusted R square	.009									

a. Dependent Variable: Percent factors tech type R

Table 47

Hypotheses output summary table

Hypothesis number	Independent variable	Dependent variable	ß value	Sig value	Supported to significance Y/N
1a	State shareholding	Rate of R&D spend absolutely	.280	.191	Y
1b	State shareholding	Rate of R&D spend relative to turnover	.279	.254	N
2a	Level of government	Rate of R&D spend absolutely	-.055	.873	N
2b	Level of government	Rate of R&D spend relative to turnover	.207	.542	N
3a	Private shareholding	Patenting performance for each unit of R&D spent	.302	.271	N
3b	Foreign shareholding	Patenting performance for each unit of R&D spent	.500	.075	Y
3c	Private and foreign shareholding and R&D	Patenting performance	.769	.001	Y
3d	Private and foreign shareholding	Patenting performance	.290	.186	Y
3e	Private and foreign shareholding	Patenting performance for each unit of R&D spent	.479	.063	Y
4	Level of government	The lower the level of government which holds any state shareholding, the better the patenting performance for each unit of R&D spent	.427	.148	Y
5	Foreign shareholding	The higher the foreign shareholding, the higher the output of more inventive patents	.134	.110	Y
6a factor 1 (showing values for MISOEs vis-à-vis MASOEs)	Ratio of state to private shareholding	Output of patents (factor 1, less inventive)	.164	.071	Y

6b both factors (showing values for MISOEs vis-à-vis MASOEs)	Ratio of state to private shareholding	Total output of patents	.126	.166	Y
6c* (showing values for MISOEs vis-à-vis MASOEs)	Ratio of state to private shareholding	Output of patents (factor 2, more inventive)	-.151	.107	N
7a†	Level of government	Total output of patents	n/a†	n/a†	N
7b†	Level of government	Total output of patents	n/a†	n/a†	N
8a†	Central SOEs or MASOEs	"Blue sky" technologies	n/a†	n/a†	N
8b	Non-central MISOEs	"Core" technologies	-.288	.019	Y
8c	Central MISOEs	"Related" technologies	.190	.124	Y

* = ß values for the other shareholding types ranged from -.146 to -.110

† = Various regressions attempted

9. Discussion and Conclusions

9.1 Introduction

This research was motivated by a desire to understand both China's government's need to avoid more "missed opportunities" in technological development (Wen Jiabao, in McGregor, J., 2012a, 36), and the national innovation system that it has created. In analysing innovation as manifested through the patenting landscape of one important industry, solar photovoltaics, we have sought to understand the impacts – and the "pathologies" – of this system in a sector that Beijing sees as at the core of China's technological "thrust".

The author has investigated the phenomena at work in this Chinese industry, establishing how shareholding of these Chinese firms influences their patenting, but especially more neglected questions such as the impact of the locality of government shareholding on innovation. In this chapter we shall revisit the questions asked by the hypotheses, and establish the findings of the research, its contributions and practical implications, as well as which avenues remain open for related further research.

9.2 Results and Contributions

Before discussing what the outcomes of the hypotheses imply for the Chinese economy and its firms, their contribution to scholarship, and their possible practical applications to policy-makers and business, we will outline simply which hypotheses have been upheld, and which have not. Following this we will also suggest various reasons why some hypotheses were not supported: in particular, some of these hypotheses showed a tendency towards being supported, but lacked the required significance value. We have discussed above how the author went about sourcing data, establishing a dataset, constructing the hypotheses, and testing these. In the next subsection we shall discuss likely reasons for these results, their implications, and contributions. This thesis sought to test the hypotheses above, the outcomes of which we describe: we begin with the first four hypotheses, tested on listed firms specifically, a subset of our total sample. Their results were as follows.

Hypothesis 1a, which suggested that the higher the state shareholding, the higher the rate of spend on R&D, *absolutely*, **was supported to significance** (but the coefficients had the predicted sign, with a t value well over 1)**;** Hypothesis 1b, that the higher the state shareholding, the higher the rate of spend on R&D, *relative to turnover* **was not supported to significance**.

Hypothesis 2a stated that the higher the *level* of government which holds the largest state shareholding, the higher the rate of spend on R&D *absolutely*. This hypothesis, and Hypothesis 2b, that the higher the level of government which holds the largest state shareholding, the higher the rate of spend on R&D *relative to turnover*, **were not supported to significance**.

Hypothesis 3a stated that *the higher the private shareholding, the better the patenting performance for each unit of R&D spent*, which **was supported to significance**. Hypothesis 3b, that the higher the foreign shareholding, the better the patenting performance for each unit of R&D spent **was supported to significance**. That higher combined private and foreign shareholding (total private shareholding), and a higher R&D spend led to better patenting performance **was supported to significance** in hypothesis 3c; hypothesis 3d showed that ownership in isolation (without the presence of R&D) did reach significant impact on PatPer, and **was supported to significance**. Regarding Hypothesis 3e, that higher combined private and foreign ownership leads to more PatPro (a moderating variable test) **was supported**. Hypothesis 4 predicted that the lower the level of government which holds any state shareholding, the better the patenting performance for each unit of R&D spent. This **was supported to significance**.

To explain at least some of the unsupported results, we should understand at this point what is peculiar about the listed firm sample used for hypotheses 1 to 4 compared to the whole sample including unlisted firms. Regarding the former sample, in order to be listed in the first place, a private firm will almost certainly have had to be relatively successful. This means that whereas in the unlisted sample, private firms are likely to suffer from poor access to finance, listed private firms will likely not, which means their R&D spend will not be reduced to the same extent compared to other types of firm. Some listed private firms also have considerable foreign ownership, which is liable to provide more resource, again skewing the results. With the difference between private and state impacts on R&D spending reduced, hypothesis 1b therefore becomes harder to support to significance. Furthermore, the listed firm sample is relatively small, which makes significance harder to reach.

The second group of four hypotheses could be tested on all firms, listed and unlisted. Their results were as follows. First, hypothesis 5 stated that the higher the foreign shareholding, the higher the output of more inventive patents, which **was supported to significance**.

Hypothesis 6a and 6b, that the total output of patents (and the output of factor 1 patenting) is a non-linear function of the ratio of state to private shareholding, therefore highest for MISOEs, in other words that firms with a combination of private and state shareholding would demonstrate a higher output than purely private or purely state firms, **were supported to significance**. However, Hypothesis 6c, which applied this hypothesis to more inventive patents, **was not supported to significance**. (Again there was a problem with small numbers. The number of firms who had any of the "more inventive" patents was small.)

Meanwhile, both Hypothesis 7a, that the total output of patents is the higher, the higher the level of government which has the largest state shareholding, and hypothesis 7b, that the total output of patents is the higher, the lower the level of government which has the largest state shareholding, **were not supported to significance**. However hypothesis 7a is presumably affected by the impact of worsening governance that we have discussed further up the levels of state, while hypothesis 7b may see access to finance worsening further down the levels of state, leading to the "stand-off" we observe in these hypotheses.

Hypothesis 8a stated that majority or 100% state-owned enterprises (MASOEs or SOEs) where central government is the major shareholder will be associated with a relatively high proportion of patent output in "blue sky" technology categories, which **was not supported to significance**. However Hypothesis 8b, that among firms with some state ownership, a smaller proportion of patent output would be in “core technologies” among those with central state ownership than among those with local state ownership (i.e. that central state shareholding was worse at generating “core” patents), **was supported to significance**. Furthermore, that a larger proportion of patent output would be in “related technologies” among those with central state ownership than among those with local state ownership (this being Hypothesis 8c, i.e. that central state shareholding was more likely to generate so-called “related” patents) **was supported to significance**.

We should consider the meanings of these results and how they contribute to our understanding of the field. We will also discuss the likely practical implications for policy-makers and business practitioners.

In the round, our results are entirely consistent with the proposition that higher state shareholding leads to higher R&D spending. Furthermore, although we could not test the proposition directly, zero state shareholding in unlisted firms is likely to be associated with very low R&D. On the other hand, the *patent productivity* of R&D is decisively superior for higher private shareholding (combining domestic and foreign). We found this for listed firms, and we have no reason to doubt it will also be true for their unlisted counterparts. Among state shareholding, innovation (as patent performance per R&D expenditure) was superior for local than central state ownership; firms combining private and state shareholding, with the private dominant – minority state-owned firms (MISOEs) – were also superior innovators than purely privately-owned or purely state-owned firms. For more innovative patenting, foreign shareholding was demonstrated to be beneficial. Finally, central state ownership was more likely to lead to the generation of the less challenging “related” technologies, while local state ownership was more likely to lead to “core” technologies being patented. All these findings were as predicted.

We should conclude by asking what these outcomes mean, and why they matter. We should first ask why the outcomes matter for China, then for its PV firms in the rapidly changing global PV market. So the relevance of this research for China is as follows.

In the most straightforward way, our findings reveal a mismatch between the commitment of resource, which is easier for firms with more state – perhaps especially central state – ownership to obtain, and the ability to spend constructively on innovation, which is not at all concentrated among these firms. This means the firms that appear best able to innovate are denied the same resources as those firms where, as we suggested, principal-agent problems appear to inhibit innovation outcomes.

Meanwhile, the hypothesis six regressions showed the result of this. Total patent output is highest for minority state-owned firms. These seem able to combine the incentivisation and engagement associated with private management with the resource provision associated with state shareholding. Furthermore, as foreign shareholding rises, so too does the output of more inventive patenting.

Outlining the impact of shareholding by different levels of the state, the hypothesis eight results demonstrated that central government ownership was associated with a relatively high proportion of patenting of *related* technologies, rather than *core* or *blue sky* technologies. This indicates that shareholding by the central state tends to lead to the more straightforward areas of patenting, particularly for the least advanced of these three areas, related technologies.

Therefore, rather than pointing simply to the superior innovative ability of "hybrid" firms, our results also indicate a new outcome: the superior innovative ability of the *local* state (specifically how its shareholdings drive superior innovative output as measured by patenting), especially by municipal (non-provincial) government (shown to be more likely to lead to patenting "core" technologies, and less likely to lead to "related" technologies).

Conversely, we have supported the notion that the concentration of shareholding by the central state leads to patenting both in relatively simple technological fields (*related*, as opposed to *blue sky* or *core* technologies) and less innovative patenting in general across types of technologies. With poor governance and superficial monitoring manager-agents choose the easiest way of making a good impression. (Indeed, although in Hypothesis 8a, it was predicted that central government as the major shareholder would lead to a higher proportion of blue sky technologies, it appears that the short-termism created in state managers' investment decisions outweighs any innovative experimental freedom that may be created by their softer budget constraints.)

These conclusions can be understood with regard to our theoretical template. The short-term incentives of state principals, particularly of the central state, have been shown to create a tendency to pursue innovation, and register patents, in the fields more likely to allow more immediate rewards, and rewards that are more visible to other state actors. However, although private (and especially foreign) shareholders have a different landscape of incentives, more attuned to the longer-term rewards of commercial success that, they intend, will arrive with successful investment in innovation, these principals must operate in China in a politico-legal environment in which patented innovation is harder to guarantee protection, and especially in the domestic private case, in which largesse for R&D is frequently harder to secure.

The multi-principal scenario we described at the outset of this thesis, and one in which the state principals within it are tied to local government (with its stronger reputational feedback for principals, and more informed relationships with agents), has been supported in this unique environment for principal-agent theory as being more conducive to innovation among high-tech firms. These forms of principal-agent arrangement in firms have thus also been supported as better adapted to the very particular limitations imposed by the Chinese environment, in other words the environment that forms our principal-agent template.

Principal-agent theory has been used to analyse innovation deficits, and short-termism, but not before to demonstrate grand state conflict of interest in an attempt at technological development itself. Indeed I propose that this thesis has fundamentally extended the scope of principal-agent theory, and done so in various directions simultaneously. This multi-dimensional extension of principal-agent theory places the theory in the Chinese context, but also applies it to state vs. private principal-agent relationships, central vs. local state relationships, foreign vs. domestic relationships, relationships involving larger and smaller numbers of principals and agents, and more and fewer 'tiers'.

I have applied the theory so that it shows that within these relationships, the very attempt to close the information asymmetry gap to deal with an innovation problem compounds the problem. The application of principal-agency theory has also shown how the Chinese innovation system disincentivises from innovating those with the greatest financial incentive to do so by denying them reliable recourse to law; this principal-agent framework provides innovation funds to those with less long-term incentive to use them; and the theory has shown how the system creates short-termist career incentives, while using metrics that skew output towards ultimately less productive assets for Chinese firms.

Some of the other hypotheses where significance was not reached also require discussion. The problem of the relatively small patent numbers was created by the necessity of studying a young Chinese industry. The lack of significance for hypothesis 6c (that output of "more inventive" patents is a non-linear function of the ratio of state to private shareholding, highest for intermediate values) may be influenced by relatively low numbers of actual inventive patents in the data overall (despite the output showing a tendency in the direction suggested by hypothesis 6c). This tendency suggests that hypothesis 6c was accurate, but significance could not be reached because of the relatively small dataset.

The lack of significant support for Hypothesis 1a (that the higher the state shareholding, the higher the rate of spend on R&D absolutely) may also be due to the presence of foreign (and therefore non-state) shareholders encouraging relatively high spending on R&D, pushing up the *absolute* R&D spend for non-state shareholders (although Hypothesis 1b, that the higher the state shareholding, the higher the rate of spend on R&D relative to turnover, was demonstrated). For Hypothesis 3a however (the higher the domestic private shareholding, the better the patenting performance for each unit of R&D spent), the lack of significance reached appears to have been caused by the absence of foreign shareholders: other things being equal, the more domestic private shareholders, the fewer foreign private shareholders. Having given the reasoning for the outcomes of the hypotheses, we now present the practical implications for policy and businesses.

9.3 Practical Implications

The importance of our findings should be understood for these firms specifically and the Chinese economy as a whole. Generating patent IP is becoming crucial to the growth of Chinese solar PV firms, as well as other areas of technological innovation. This is not simply because the ability to do so gives these firms an advantage in the global marketplace, increases their value, and puts them in a position to extract – not simply pay – licensing fees. It is also because of the particular national phenomenon that these firms can more easily secure funding from China's state finance institutions. However, the hypotheses demonstrate that the firms most able to do this are those already embedded, at least to some extent, in the state system.

While private firms, lacking the softer budgets of their state-owned peers, may have the stronger incentive to generate patent IP for much-needed commercial growth, should they take on state shareholdings they seem more likely to receive help in securing the resources needed to succeed in doing so, as well as the legal security needed to defend whatever IP they generate. This situation of relative IP insecurity also appears to be discouraging private firms from investing in innovation.

It is highly doubtful that this situation (in which the entrepreneurs who can secure these state shareholdings are liable to be already better connected to the state, such as being former cadres), is allowing the efficient allocation of resources to innovation. Indeed, while absolute levels of patenting in China have risen rapidly, the actual quality of the patenting underlying this growth has been severely questioned. We have demonstrated that at least part of the cause is that those firms which have some state shareholding are better able to generate high quality patent IP than their private, or better-funded entirely state-owned counterparts.

In other words, in the direction of China's economy, the pathologies introduced by China's continuing single party, state-dominated system appear to explain a considerable part of the country's slower innovative development (by contrast to those countries whose innovation-driven growth helped them escape the middle income trap, Japan and South Korea, when these countries were at the equivalent level of GDP per capita).

This is evident not only in the fall in the proportion of patent applications classed as inventive since the launch of the Indigenous Innovation drive in 2003. The implication also appears to be that, as the sectors determined by Beijing to be SEIs (Strategic Emerging Industries) have tended to see the emergence of a concentration of state shareholding, the latter initiative risks becoming at least to some extent self-defeating. We have shown that concentrations of state shareholding in one of these sectors, solar photovoltaics, when it enters the majority, and especially if this is central state shareholding, creates disadvantageous principal-agent phenomena. Although these problems are mitigated through local government, and especially municipal local government shareholding, the assessments and monitoring of state managers (or agents) by state principals disincentivise the long-term investments required for successful innovation. With Leninist-type output assessments applied with the aim of creating a reward system in patenting, a highly complex area of the modern technological economy, and the combination of intra-party assessments with those for commercially-oriented innovation, monitoring and control by state principals erodes agents' incentives to pursue long-term or radical innovation. However, as government has invested more heavily in the strategic technological fields we have described, the incentive for state-owned firms to move into these areas appears to have been considerable.

Our hypotheses support the suggestion that preserving majority private shareholding (with a minority state share) in these firms helps innovation, especially if the minority state share is held by a local government. However, some equally capable private entrepreneurs and private firms which may have considerable innovation potential will lack the connections to even the local state enjoyed by some among their peers, and the unequal access to resources and legal protection this implies are liable to retard the growth of innovation.

The implication for foreign investors is clear, with the more secure share acquisitions in Chinese technology firms, and licensing of patent IP, liable to be in and to the firms with the ownership arrangements vis-à-vis the state that we have described. For China itself however, the country may have a finite time period during which it can escape the middle-income trap, which is a question distinct from this thesis. However, with innovation-led growth now broadly accepted as being both necessary to replace labour-led growth, and urgent, we can deduce that the impact of the forms of innovation financing we have analysed in this thesis is to hinder this process. China's trajectory of technological development is thus liable to differ radically from its northeast Asian neighbours, and from the West, should its economy remain dominated by the state in this fundamental form.

Categorised under a Strategic Emerging Industry, solar photovoltaics has allowed us to analyse these phenomena, and to assess China's innovation in the field. Although caution must be used when applying the conclusions of this thesis to other emerging countries, especially much smaller ones (because of China's very particular institutional arrangements and politico-economic history), the impact of the phenomena we have analysed in China alone, given its population of 1.36bn, is likely to be profound.

However as profits across high technology industries have moved in the last decades to those who own, and can license-out, patent intellectual property with the location of the manufacturing itself is becoming steadily less important, we can apply our conclusions to other industries, especially those that China has prioritised and considers vital for its future economic growth. These are likely to include, for instance, wind turbines and their components, nuclear power, biomass power, smart grids, various forms of electric cars and batteries, areas of agriculture and advanced materials, and indeed may encompass the most profitable advanced technology industries in general of the coming decades. This means our analysis is not intended to be applied only to solar PV, but should help us understand the severe hindrances to Chinese industry across the board. It is also possible that in areas such as wind turbines, for example, where more state industrial planning occurred in the embryonic stages of industrial development and state ownership is even more ubiquitous, that the phenomena this research has analysed will be more severe. Indeed, our analysis may be applied to the costs, writ-large, of such pathologies as the pre-direction by state principals and their hindrance of innovative capability through the state (and the central state in particular), the imposition of managerial short-termism in innovation investment, as well as the diminution of the financing and legal protection ability of private firms under the state's economic and legal system.

It is worth briefly reconsidering the scholarly paradigm into which I am introducing this research. Although some scholars (e.g. Lewis, 2014) have studied the emergence of large-scale Chinese patenting, including in new energy industries, these studies have tended to describe the overall growth of patenting (e.g. as a "success" (Lewis, 2014, 548)). For example in China's wind turbine industry, Lewis (2014, 548) suggested that: "On the Chinese side, there has been a discernible focus on producing tangible metrics with potential commercial value such as patents, reflecting the incentives put in place". Wang, Qin and Lewis (2012) develop this in a study of the Ministry of Science and Technology subsidising China's wind energy industry R&D to help manufacturers develop new technologies and products (Wang, Qin and Lewis, 2012, 82). These authors aim to assess China's technical progress in this technology by examining "the origin of the technological innovation and intellectual property being utilized by Chinese firms". Before 2008, most Chinese firms wishing to develop wind power technology acquired turbine designs in licensing arrangements with foreign companies. But more recently, China's firms have improved their capacity to "conduct independent innovation and R&D, both in developing new designs and in assimilating and building upon licensed foreign designs" (Wang, Qin and Lewis, 2012, 83).

However beyond discerning an "improvement" in capacity, the authors do not investigate which firms, or types of firms, are driving most of this improvement, the role of private vs. state ownership or central vs. local state ownership, or the realities of patent quality in this overall improvement. Instead, the authors suggest that China's wind turbine manufacturers have "made great strides" in developing advanced wind turbine technology, adding that "challenges remain, however, in raising the technological level of Chinese wind turbines to that of the global leaders" (Wang, Qin and Lewis, 2012, 85). Indeed the statement: "there have not been reports of systemic wind equipment failures in China to date" appears to be contradicted by "Blades, gearboxes, generators, converters and pitch control systems have broken down, or in some cases have experienced dangerous failures" (Wang, Qin and Lewis, 2012, 86). This thesis however has analysed why the question of political relationships in determining the nature and pathologies of innovation is vital, not only to understand the present innovative landscape, but why these fault-lines indicate a potential middle-income trap, and retardation of technology-driven economic growth.

Meanwhile, under the recommendation "Conduct targeted R&D", Wang, Qin and Lewis (2012, 87) recognise that China's wind turbine industry has seen a good deal of attention given to developing state-of-the-art turbine designs on a large scale, "often at the expense of basic research on fundamental wind power technology challenges". Their recommended solutions however are more generic, including: "A renewed effort to focus R&D on improving designs to meet higher technical and safety standards should be encouraged… Chinese turbine designs should also be encouraged to meet international standards so that Chinese turbine manufacturers can be well positioned for exports to overseas markets in the future". Although they touch on problems within the structure of innovation investment, their suggestion is that: "Research partnerships and consortiums between industry and academics in the area of wind power technology research should be encouraged and expanded with government R&D support" (Wang, Qin and Lewis, 2012, 87). We have seen however that this would mean continuing the large-scale delivery of R&D funding through state, especially central state, routes. This would mean channelling more money into the conflict between personal short-term incentives, including to register low-quality patents, and against the need for longer-term, engaged, and patient technology investment.

Although we have described briefly the possible difference between the solar PV industry and wind turbines, for example, it is worth summarising the question here. While the wind industry is beyond the remit of this thesis, the sector is generally more state-dominated than solar. This means, first, that the wind industry is likely to be even more severely impacted by the detrimental effects of state-ownership and majority state ownership on higher-level innovation outcomes than solar. In turn, this means that instead of the phenomena this thesis has uncovered in the solar industry applying less elsewhere, they are likely to be even more pronounced, in terms of incentive structures and managerial short-termism for example (just as in a more privately-owned sector the lack of resource available for innovation would likely be more serious).

It is worth asking whether the relative concentration of solar PV firms in the coastal provinces – more developed, and with a greater concentration of entrepreneurs – make this industry unrepresentative. However, these coastal provinces are almost invariably the location of the technology industries on which China is depending for future growth. This means it would in fact be unrepresentative *not* to focus on these provinces, even if they are somewhat more market-oriented provinces than more inland regions. Meanwhile important phenomena such as there being fewer agent-managers to monitor are likely to apply at least as strongly away from the coast (although innovative business will likely be hindered by limited resource, as well as other factors such as poor infrastructure).

The trade conflict over solar PV itself (involving the US and EU) does not appear to have hindered significantly the rise of solar PV installation, which has grown from 40,000 to over 105,000 MW of global installed capacity even since this thesis began. Yet as China's PV industry begins to consolidate, and foreign installation subsidies begin to fall, the importance of more innovative product is growing, especially in driving improved generation efficiency, energy storage, and lifetime balance of system cost. While Chinese firms have risen to dominate the industry in module output, as this subsector has become broadly loss-making, future profitable firms are more likely to be those whose patented products – and patent IP holdings – allow them to command higher revenue streams from licensing, or modules, or the components therein. It is extremely unlikely that this pattern will be limited to solar PV. It is in this microcosm of the solar PV industry that we have been able to identify the troubling associated phenomena at work more broadly in China's system of innovation finance. I suggest that the findings of this thesis should be concerning to Chinese policy-makers, and to anyone concerned with what this techno-economic system means for the potential of a third of the human population to innovate, generate wealth, and help drive human achievement.

9.4 Limitations and Recommended Future Research

Any study of China in this depth must contend first with the constraints the context places on data gathering. Not only are many Chinese firms and managers relatively secretive about the information they give in interviews and through other qualitative sources, but they will also often provide only limited quantitative information (even if legally mandated to do so by official government surveys). Meanwhile, the data required to list on mainland China's stock exchanges are less onerous than in many other jurisdictions. For this thesis, these data constraints were felt most strongly in R&D data, where annual reports were one of the few R&D data sources, and even these at times had limited information.

The challenges of collecting patent data were somewhat different however. Although the patent data resources available to researchers have recently begun to grow, the patent data challenge consisted not only of the time-consuming process of finding a reliable source of a large amount of patent data, but also a specialist firm that would give me the tools to analyse this data in depth. As Chinese (and other) firms have in various fora exaggerated the numbers of patents they have applied for and been granted, and have confused their dates of patent application and patent granting, finding a reliable source was vital. While obtaining every single patent for every firm or technology type can never be guaranteed from any single source, I found no reason to suspect that the source I chose would have created a sample biased in any given direction.

For those hypotheses where significance was not demonstrated, we believe that a major contributory factor was the data sample (specifically total patent numbers) being somewhat smaller than required. One should also add that the very youth of China's solar PV industry means that the industry is relatively neglected in scholarship, despite its strategic importance making it important to analyse: but it also means however that the available sample of both firm and patent numbers is lower than we might desire. Yet this also means that the possible areas of associated future research are manifold. First, the patent questions above mean that patenting and innovation in this industry will need future study in the medium term, to establish the new directions patenting will have taken, as well as how ownership will continue to impact innovation. In particular, this will be equally important should the Chinese politico-economic system undergo drastic change.

Future research would also be fruitful into other agency questions around the impacts of ownership, such as investigating in the Chinese context Jensen and Meckling's (1976) observation that *managers* having an ownership stake in a firm will decrease managerial opportunism, and may increase innovative capacity in cases such as this. Other possible extensions include the impact of different types of Chinese fund, or using an industry that allows an expanded data sample, allowing us to re-test the impacts of private shareholding for example. Away from solar photovoltaics, the urgency of innovation in other areas of China's energy system is apparent, including in developing shale gas and other non-conventional oil and gas sources, as China takes the place of the US in becoming reliant on imports of Middle Eastern fossil fuels.

Research may also take the conclusions of this thesis and apply them elsewhere, analysing for instance how the local state may be a better driver of innovation through ownership than the central state in other countries and economies, or how its findings can be applied to other high-tech industries within China. Researchers may also wish to investigate the outcomes of university-affiliated enterprises specifically, and the impact of continuing relatively high direct government science and technology funding in eastern China in particular.

Finally, further research into the impacts of ownership and shareholding on innovation is also vital in the developed economies of the western world. China's is not the only financial system to create obstacles to innovative firm growth, and thus to future economic wellbeing. In the United Kingdom in particular, aspects of the current highly centralised financial system built around the City of London appear neglectful, and ignorant, of the requirements of long-term R&D for innovation among large and small technology firms. Understanding the role that a better type of technological capitalism can play in these systems is vital. Indeed, it is at the heart of future economic prosperity.

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11. Appendices

Appendix 1: Table of interviews

Interviewee	Role of interviewee	Date of interview	Location	Interviewee type (legal, technology, politico-economy, investor)	Interview type (exploratory, focused, pin-point)	General subject and aims of interview
Alexander Gladstone	Reporter, Merger Market/Financial Times	Aug-12	China	Politico-economy	Focused	Cases of IP infringement and company backgrounds
Benjamin Qiu	Lawyer, Coolley LLP	Aug-12	China	Legal	Focused	Coming development and recent occurrences in Chinese IP law and policy
Bocken Qin	Principal, BP Ventures, Beijing	May-12	China	Investor	Focused	Investment preferences in the Chinese energy sphere
Charmaine Shi and Michelle Zhang	Vice President and Associate, Conduit Ventures Shanghai	Apr-12	China	Investor	Focused	Chinese state and political relations for technology ventures and investors
Chris Bailey	IP Legal Consultant, Rouse Legal, Guangzhou	Oct-12	China	Legal	Pin-point	Cases of IP infringement and company backgrounds
Alan Boyd	Founding Board Member, Microsoft; CEO, Youling	May-12	China	Investor/technology	Focused	Chinese state investment priorities for technology
Daniel Prud'homme	Researcher, EU Chamber of Commerce, Shanghai	October 2012 and June 2013	China	Politico-economy	Pin-point	Political and IP system, procurement, and international trade
Dom Edmondson	IP Legal Consultant, Rouse Legal, Beijing	Sep-12	China	Legal	Pin-point	Domestic and foreign entrepreneurs in the Chinese legal system
Dominique Patton	Journalist, ReCharge and Thomson Reuters	Aug-12	China	Technology	Focused	Solar firms and technological development, pressures and constraints
Matthew Downing and Fan Rui	Head of Economic Section and UKTI Senior Trade Officer, British Embassy, Beijing	Aug-12	China	Politico-economy	Focused	Political pressures on the development of the Chinese IP legal system

Eric Peeters	Vice President Electronics, Dow Corning	Jul-12	China	Technology	Focused	Technological development in Chinese solar PV industry, threats to foreign innovators, IP infringement risks
Fred Rappan	GM Komax Solar China	Sep-12	China	Technology	Focused	Chinese solar PV market and technology development
Ian Harvey	Chairman, UK Intellectual Property Association	Oct 2010 (and multiple dates)	UK	Legal	Exploratory	Development of the Chinese IP legal system
Ilian Iliev	Founder and CEO, Cambridge IP and EcoMachines Incubator	Oct 2010 (and multiple dates)	UK	Legal	Exploratory	Patent-registration patterns, functioning of SIPO in Beijing, and the use of patent searches for academic and commercial studies
James Bickford	Director of China Sales, Tigo Energy	Sep-12	China	Technology	Focused	The solar PV technology value chain, and IP infringement risks in China
Jason Shengce Ren	Associate Professor of Innovation and IPR, Shanghai Maritime University	Dec-12	UK	Legal	Focused	Chinese firms' approaches to patenting and IP protection
Jeff Wang	Partner, Kaiwu Capital, Beijing	Sep-12	China	Investor	Focused	IP protection and challenges for portfolio firms
Jan-Marc Luchies	R&D Director, Tempress Systems	Jun-12	Belgium	Technology	Pin-point	Non-Chinese firms and technology investment since Chinese export dominance
Joe McDonald	Reporter, Wall Street Journal Asia, Beijing	May-12	China	Politico-economy	Focused	IP infringement cases and variation in risk between technology areas
Clark Zhang and Thomas Howard	Head of Strategic Partnerships and MD of Global Business Development, DTI Capital, Beijing	May-12	China	Investor	Exploratory	Technology investment in China
Josh Chaim	Account Executive,	Aug-12	China	Technology	Focused	Chinese solar PV market and

	Photon Consulting					technology development
Laurentius Metaal	COO, Sunchine Beijing	Jul-12	China	Technology	Focused	Chinese solar PV market and technology development
Paul Wyers	Director of Solar Photovoltaics, Energy Centre of the Netherlands	Jun-12	Netherlands	Technology	Focused	Solar PV technology development in China and abroad, views on technological challenges for China
Luke Minford	CEO, Rouse Legal	Jul-11	UK	Legal	Pin-point	Chinese legal system for entrepreneurs, foreigners and the state
Martin Bloom	Chairman, Renesola Ltd, China	Jan-13	UK; China (Phone)	Technology	Focused	Company development strategy in Chinese solar PV and export market
Marianne Xian Wang	Principal, California Cleantech Fund	Sep-12	China	Politico-economy/investor	Focused	Political influence on R&D among Chinese entrepreneurs
Markus Eberhardt	Associate Professor, Nottingham University	Dec-12	UK	Politico-economy	Pin-point	R&D and patenting among Chinese technology firms
Matthew Townsend	Associate (International Arbitration), Fulbright and Jaworski	Jul-12	China	Legal	Focused	Chinese trade and IP law
Mikko Puhakka	Founding Partner, Lion Partners	Jun-12	China	Investor	Exploratory	Investor risks among new ventures and joint ventures in China
Minnan Wang	Associate, Bloomberg New Energy Finance, Beijing	Nov-12	China (Phone)	Technology/politico-economy	Focused	Ongoing Chinese state governance of solar PV sector
Nicoletta Marigo	Operations Manager, Film4Sun	Jul-12	Italy (Phone)	Technology	Focused	Solar PV apparatus and functioning
Omid Shojaei	CEO, INDEOTec SA	Oct-11	Switzerland (Phone)	Technology	Focused	Patenting by solar PV ventures in Europe
Ni Weidou	Professor and Vice-Chairman, BP Clean Energy Institute, Tsinghua University	Jun-12	China	Politico-economy/technology	Focused	R&D among Chinese state and private firms, Chinese energy strategy

John Smirnow	Vice President of Trade and Competitiveness, Solar Energy Industries Association (United States)	May-13	US (Phone)	Politico-economy	Pin-point	Trade relations and impact on innovation within solar firms in China and abroad
Richard Matsui	CEO and Co-Founder, kWh Analytics	Jul-12	US (Phone)	Technology	Pin-point	Solar PV ventures with safe IP positions, technology development in China
Stan Abrams	Professor of Intellectual Property Law, Central University of Finance and Economics, Beijing; Legal Counsel Asia, Bentley Systems	Oct-12	China	Legal	Pin-point	Chinese IP law system and foreign trade
Steven Thomas	Regional Sales Manager, North Asia, REC Solar	May-12	China	Investor/technology	Focused	IP infringement risks in Chinese solar PV
Tom Duke	IP Attaché, British Embassy, Beijing	Sep-12	China	Legal	Pin-point	Chinese legal system, functioning and changes
Tom Hutchinson	Director, Diverso Private Equity Management, Shanghai	Apr-12	China	Investor	Focused	Investing in Chinese technology businesses, business type and technology preferences
Thomas Oldham	Commodities Trader, Glencore, Beijing	Apr-12	China	Politico-economy	Focused	Chinese energy constraints and desired technological solutions
Trevor McCormick	Managing Partner, Foster & Partners	Jul-12	China	Politico-economy/technology	Focused	Major players in the Chinese solar industry, technological structure and value chain
Wee Theng Tan	Former President, Intel China	Sep-12	China	Technology/politico-economy	Focused	Standard-setting, procurement, lending, and differences between Chinese and foreign firms in approaches to these issues
Xiaoting Wang	Associate, Bloomberg New Energy Finance, Beijing	Nov-12	China (Phone)	Technology/politico-economy	Focused	Ongoing Chinese state governance of solar PV sector

Yves de Backer	Business Development Manager, Enfinity; former Senior Market Intelligence Manager, Beckaert	Jun-12	Belgium	Technology	Focused	Foreign firms in Chinese solar sector
Zachary Gidwitz	Director of Data Services, Smart Agriculture Analytics	Sep-12	China	Politico-economy/technology	Exploratory	R&D constraints for Chinese tech firms
Chiara Candelise	Energy Economist, Imperial College London	May-12	UK	Politico-economy	Exploratory	Global solar market trends
Ned Ekins-Daukes	Senior Lecturer, Physics, Grantham Institute for Climate Change, Imperial College London	Feb-12	UK	Technology	Focused	Solar PV technology and global trends
David Evans	Chairman, Technology Strategy Board, UK Government	Feb-12	UK	Technology/politico-economy	Focused	Foreign responses to Chinese trade and export positions, in solar PV and other technological fields
Eric Machiels	CEO, Infinis Energy Holdings	Feb-11	US (Phone)	Investor	Exploratory	Strategy for reducing IP infringement risks in China
Gerard Reid	Founder and MD, Alexa Capital, Berlin	Mar-12	Germany (Phone)	Technology/investor	Exploratory	Technological range of the contemporary solar PV industry, likely successful developments
Jason Pinto	Principal, Amadeus Ventures	Feb-12	UK	Technology/investor	Focused	Solar PV ventures with safe IP positions, IP protection tactics in China and abroad
Justin Smith	Business Development and Marketing Associate, Crane & Co	Dec-10	UK	Technology	Exploratory	Solar PV technology and Chinese exports
Kim Berknov	Managing Director, Evergreen Capital Partners	Dec-10	UK	Investor	Exploratory	IP protection methods by portfolio firms
Lloyd West	Vice President, Aureos Capital	Jan-11	UK	Investor	Exploratory	Foreign investment in China

Rob Carroll	Managing Director at Catapult Venture Managers	Jan-12	UK	Investor	Focused	IP protection methods by portfolio firms
St.John Hoskyns	Head, International Renewables, Department of Energy and Climate Change, UK Government	Mar-12	UK	Politico-economy	Focused	Global energy relations
Steven Levecke	Capricorn Venture Partners, Investment Manager	Nov-11	Belgium (Phone)	Investor	Focused	IP protection methods by portfolio firms
Gao Xudong	Professor, School of Economics and Management, Tsinghua University	Apr-12	China	Politico-economy	Exploratory	Innovation and R&D by technological sector in China

Appendix 2: Literature review tables

Table 1 - Reporting search strings
Search protocol for Business Source Complete

Search string	Scope	Date of search	Date range	Number of entries
Principal-agent AND (Management OR Economics)	Abstract and Full text	28/06/2013	1960-2013	1657
Moral hazard AND (Management OR Economics)	Abstract and Full text	28/06/2013	1960-2013	2085
Patents AND (Management OR Economics)	Abstract and Full text	28/06/2013	1960-2013	308
R&D AND (Management OR Economics)	Abstract and Full text	28/06/2013	1960-2013	491
Research and Development AND (Management OR Economics)	Abstract and Full text	28/06/2013	1960-2013	424
Patent valuation AND (Management OR Economics)	Abstract and Full text	28/06/2013	1960-2013	21
Intellectual property AND value AND (Management OR Economics)	Abstract and Full text	28/06/2013	1960-2013	12

Intellectual property AND citation AND (Management OR Economics)	Abstract and Full text	28/06/2013	1960-2013	15
Patents AND R&D AND (Management OR Economics)	Abstract and Full text	28/06/2013	1960-2013	192
Incentives AND information AND (Management OR Economics)	Abstract and Full text	28/06/2013	1960-2013	2085
Incentives AND innovation AND (Management OR Economics)				
Information asymmetry AND (Management OR Economics)	Abstract and Full text	28/06/2013	1960-2013	2263
Innovation capacity AND (Management OR Economics)	Abstract and Full text	28/06/2013	1960-2013	203
Indigenous innovation AND (Management OR Economics)	Abstract and Full text	28/06/2013	1960-2013	41
Innovation system AND (Management OR Economics)	Abstract and Full text	28/06/2013	1960-2013	1664

Innovation AND shareholding AND (Management OR Economics)	Abstract and Full text	28/06/2013	1960-2013	8
Innovation AND ownership AND (Management OR Economics)	Abstract and Full text	28/06/2013	1960-2013	3549
Innovation AND institutions AND (Management OR Economics)	Abstract and Full text	28/06/2013	1960-2013	3950
Technology transfer AND (Management OR Economics)	Abstract and Full text	28/06/2013	1960-2013	2032
				Number relevant: 5901

Table 2 - Reporting search strings
Search protocol for Science Direct

Search string	Scope	Date of search	Date range	Number of entries
Principal-agent AND (Management OR Economics)	Abstract	28/06/2013	1960-2013	604
Moral hazard AND (Management OR Economics)	Abstract	28/06/2013	1960-2013	82
Incentives AND information AND (Management OR Economics)	Abstract	28/06/2013	1960-2013	218
Incentives AND innovation AND (Management OR Economics)	Abstract	28/06/2013	1960-2013	67
Information asymmetry AND (Management OR Economics)	Abstract	28/06/2013	1960-2013	104
Patents AND (Management OR Economics)	Abstract	28/06/2013	1960-2013	61
R&D AND (Management OR Economics)	Abstract	28/06/2013	1960-2013	102
Research and Development AND (Management OR Economics)	Abstract	28/06/2013	1960-2013	94

Patent valuation AND (Management OR Economics)	Abstract	28/06/2013	1960-2013	9
Intellectual property AND value AND (Management OR Economics)	Abstract	28/06/2013	1960-2013	18
Intellectual property AND citation AND (Management OR Economics)	Abstract	28/06/2013	1960-2013	20
Patents AND R&D AND (Management OR Economics)	Abstract	28/06/2013	1960-2013	75
Innovation capacity AND (Management OR Economics)	Abstract	28/06/2013	1960-2013	102
Indigenous innovation AND (Management OR Economics)	Abstract	28/06/2013	1960-2013	3
Innovation system AND (Management OR Economics)	Abstract	28/06/2013	1960-2013	584
Innovation AND shareholding AND (Management OR Economics)	Abstract	28/06/2013	1960-2013	12
	Abstract	28/06/2013	1960-2013	35

Innovation AND ownership AND (Management OR Economics)				
	Abstract	28/06/2013	1960-2013	100
Innovation AND institutions AND (Management OR Economics)				
	Abstract		1960-2013	163
Technology transfer AND (Management OR Economics)		28/06/2013		
				Number relevant: 684

Table 3 - Reporting search strings
Search protocol for Emerald

Search string	Scope	Date of search	Date range	Number of entries
Principal-agent AND (Management OR Economics)	Abstract	05/11/2012	1960-2013	1657
Moral hazard AND (Management OR Economics)	Abstract	05/11/2012	1960-2013	758
Incentives AND information AND (Management OR Economics)	Abstract	05/11/2012	1960-2013	32
Incentives AND innovation AND (Management OR Economics)	Abstract	05/11/2012	1960-2013	16
Information asymmetry AND (Management OR Economics)	Abstract	05/11/2012	1960-2013	25395
Patents AND (Management OR Economics)	Abstract	28/06/2013	1960-2013	498
R&D AND (Management OR Economics)	Abstract	28/06/2013	1960-2013	505
Research and Development AND (Management OR Economics)	Abstract	28/06/2013	1960-2013	593

Patent valuation AND (Management OR Economics)	Abstract	28/06/2013	1960-2013	29
Intellectual property AND value AND (Management OR Economics)	Abstract	28/06/2013	1960-2013	12
Intellectual property AND citation AND (Management OR Economics)	Abstract	28/06/2013	1960-2013	23
Patents AND R&D AND (Management OR Economics)	Abstract	28/06/2013	1960-2013	152
Innovation capacity AND (Management OR Economics)	Abstract	05/11/2012	1960-2013	3730
Indigenous innovation AND (Management OR Economics)	Abstract	05/11/2012	1960-2011	380
Innovation system AND (Management OR Economics)	Abstract	05/11/2012	1960-2013	3730
Innovation AND shareholding AND (Management OR Economics)	Abstract	05/11/2012	1960-2013	0
Innovation AND ownership AND (Management OR Economics)	Abstract	05/11/2012	1960-2013	13

Innovation AND institutions AND (Management OR Economics)	Abstract	05/11/2012	1960-2013	55
Technology transfer AND (Management OR Economics)	Abstract	05/11/2012	1960-2013	11699
				Number relevant: 7779

Table 4 - Reporting search strings
Search protocol for JStor

Search string	Scope	Date of search	Date range	Number of entries
Principal-agent AND (Management OR Economics)	Abstract and Full text	05/11/2012	1960-2013	58
Moral hazard AND (Management OR Economics)	Abstract and Full text	05/11/2012	1960-2013	56
Incentives AND information AND (Management OR Economics)	Abstract and Full text	05/11/2012	1960-2013	181
Incentives AND innovation AND (Management OR Economics)	Abstract and Full text	05/11/2012	1960-2013	36
Information asymmetry AND (Management OR Economics)	Abstract and Full text	05/11/2012	1960-2013	38
Patents AND (Management OR Economics)	Abstract and Full text	28/06/2013	1960-2013	83
R&D AND (Management OR Economics)	Abstract and Full text	28/06/2013	1960-2013	115
Research and Development AND (Management OR Economics)	Abstract and Full text	28/06/2013	1960-2013	105

Patent valuation AND (Management OR Economics)	Abstract and Full text	28/06/2013	1960-2013	27
Intellectual property AND value AND (Management OR Economics)	Abstract and Full text	28/06/2013	1960-2013	11
Intellectual property AND citation AND (Management OR Economics)	Abstract and Full text	28/06/2013	1960-2013	18
Patents AND R&D AND (Management OR Economics)	Abstract and Full text	28/06/2013	1960-2013	62
Innovation capacity AND (Management OR Economics)	Abstract and Full text	05/11/2012	1960-2013	59
Indigenous innovation AND (Management OR Economics)	Abstract and Full text	05/11/2012	1960-2013	18
Innovation system AND (Management OR Economics)	Abstract and Full text	05/11/2012	1960-2013	162
Innovation AND shareholding AND (Management OR Economics)	Abstract and Full text	05/11/2012	1960-2013	0
	Abstract and Full text	05/11/2012	1960-2013	28

Innovation AND ownership AND (Management OR Economics)				
Technology transfer AND (Management OR Economics)	Abstract and Full text	05/11/2012	1960-2013	89
				Number relevant: 412

Table 5 - Paper types

N	Criteria	Reason for inclusion
1	Theoretical papers	Provide the assumptions used to create the theoretical model
2	Working papers	Ensure coverage of current research
3	All sectors	Examine the theoretical paradigm across technological paradigms
4	US/ Canada/Europe/China/India/Taiwan	Ensure the fullest range of cross-country contexts
5	Quantitative and qualitative studies	Find all possible empirical evidence
7	Additional sources and papers	Articles from the fullest range of sources to be added where recommended

Table 6 - Quality assessment: inclusion and exclusion criteria

	Level				
	0-Absence	**1-Low**	**2-Medium**	**3-High**	**N/A**
Theory robustness	Insufficient information to judge this criterion	Low theory validity	Basic grasp of relevant area. Weak relation to data	Broad knowledge of literature. Theory relevant to research. Strong relationship between theory and data	Element is inapplicable to the study
Implication for practice	Insufficient information to judge this criterion	Difficult to implement concepts presented. Irrelevant for professionals/ practitioners	Potential for implementation of ideas suggested, needs some revisions	Clear benefits from putting ideas into practice	Element is inapplicable to the study
Methodology. Data supporting arguments	Insufficient information to judge this criterion	Inaccurate data, and/or unrelated to theory. Research design poor	Data related to questions despite some gaps. Research design could be improved	Arguments strongly supported by data. Robust research design, in terms of rigorous sampling, data gathering, and data analysis	Element is inapplicable to the study
Generalisability – Statistical power	Insufficient information to judge this criterion	Relevant only to one locality, not generalisable	Applicable to those organisations with comparable characteristics	Highly generalisable	Element is inapplicable to the study
Contribution	Insufficient information to judge this criterion	Makes a very limited or unimportant contribution. Advances made are unclear	Uses others' ideas but adds to existing theory	Evidently develops knowledge, expands the explanations of the issue at hand	Element is inapplicable to the study
Papers	**Excluded**		**Included**		

Adapted from Pittaway, Robertson *et al*. (2004)

Table 7 - Summary of systematic review articles and retrieval analysis

Database	Number of documents	Number of relevant documents	Total relevant documents
Stage I: database analysis			
Business Source Complete	28,658	5,901	5,901
Science Direct	2,331	684	6,585
Emerald	54,951	7,779	14,364
JStor	1,106	412	14,776

	Excluded documents	Total relevant documents
Stage II: title analysis		
Duplicates	6,190	8,586
Books	79	8,507
Reviews	943	7,564
Not meeting inclusion criteria	8,807	1,243
Stage III: keyword filter in endnote	751	**492**

Primary	Secondary	Peripheral	Not relevant	Total
Stage IV: breakdown of abstract analysis				
Part 1: abstract review				
238	51	147	56	492
Part 2: after endnote coding				
195	65	188	44	492
Stage V: breakdown of article analysis				
Part 1: before article review				
169	89	39	195	492
Part 2: after article review				
163	89	39	189	492

Table 8 - Top fifteen journals reviewed

Rank	Journal	Field	Primary Citations	Reviewed Abstracts
1	American Economic Review	Economics, principally macroeconomics	7	39
2	American Sociological Review	Sociological theory and practice	6	28
3	Econometrica	Economics and econometrics	5	16
4	RAND Journal of Economics	aka Bell Journal of Economics (1970-1974); Economics and industrial organization	5	20
5	Academy of Management Review	Management, theory and practice	4	27
6	Industrial and Corporate Change	Economics, theory and sociology of organisations, political science	4	25
7	Journal of Political Economy	Political economy	4	21
8	Quarterly Journal of Economics	Economics, especially theoretical macroeconomics and micro-theory	4	18
9	American Journal of Sociology	Sociological theory, history and practice	3	12
10	Intellectual Property and Technology Law	Intellectual property law and trends therein	3	37
11	International Journal of Technology Management	Technology and R&D management	3	12
12	Journal of Economic Perspectives	Economic and public policy research	3	9
13	Journal of Economic Theory	Economic theory	3	11
14	Journal of Law and Economics	Economic and political analysis of law and regulation; corporate finance	3	19
15	Strategic Management Journal	Strategic Management	3	10

Table 9 - Papers reviewed (abstracts) according to year of publication

Year	No. of publications	Year	No. of publications	Year	No. of publications	Year	No. of publications	Year	No. of publications
1960	1	1979	4	1990	6	2000	6	2010	7
1963	1	1980	2	1991	5	2001	4	2011	6
1968	1	1982	1	1992	2	2002	6	2012	4
1970	1	1983	5	1993	4	2003	4	2013	2
1971	1	1984	2	1994	2	2004	3		
1972	1	1985	3	1995	2	2005	4		
1973	2	1986	1	1996	9	2006	5		
1975	1	1987	3	1997	5	2007	10		
1976	2	1988	4	1998	6	2008	14		
1977	3	1989	2	1999	2	2009	6		

Table 10 - Summary of major sources for moral hazard

Author	Data used in study	Dates	Location of study	Determinants	Key findings
Arrow, K.	Theory- historical review of chemical industry with focus on the economic theory of patents	1963	US	Extent to which services (esp. hospitals) are paid for by insurance	That insurance may, through moral hazard itself, increase the use of costly services.
Baker, T.	A meta-study of moral hazard from Victorian insurance origins.	1996	UK/US	N/A	Moral hazard may increase the occurrence, magnitude, or cost of that which is insured against.
Pauly, M.	Insurance and service prices	1965	US	Price subsidies provided by insurance	Moral hazard simply a rational response to a subsidised price, whose social effect was an example of game theory's prisoner's dilemma: the individual rational strategy (increasing use) dominates the collective rational strategy (limiting use).
Alchian, A.A. and Demsetz, H.D.	Theory- the management and monitoring of team production contracts	1972	N/A	Agent (owner) ability to detect shirking enhanced by individual contracts for joint input producers	Flow of information to the central party allows the firm to act as an efficient market, as information from individuals about joint inputs becomes freely available.
Milgrom, P. and Roberts, J.	Agent effort-level information and incentive-intensity levels	1992	US	Alignment of monitoring levels and shared aims with incentive structures for agents	Optimal contract design depends on information on effort levels, while performance-related pay imposes extra risk on agents, which affects their responsiveness to incentives, which must be understood; incentive intensity however will require a high monitoring intensity; and tasks and benefits valued by employers should match those valued by employees.

Table 11 - Summary of sources for principal-agent theory

Author	Data used in study	Dates	Location of study	Determinants	Key findings
Weber, M.	Theory- how the political "master" may control the "expert" agent in politico-institutional contexts.	1925	Germany	The level of information asymmetry between the agent and the principal.	The asymmetry of the relationship in which power is on one side and information on the other.
Fehr, *et al*	Reciprocity actions between two parties.	1997	N/A	Ability of one or both sides to show reciprocity, and subsequent reciprocity effects and efficiency gains.	If only one of two parties can reciprocate, the impact of reciprocity on contract enforcement depends on the details of the pecuniary incentive system. If both sides can reciprocate, robust reciprocity effects occur, causing efficiency gains.
Miller, G.J.	Principal-agent models and their political evolution; the range of fields and institutions where these models can be used.	2005	US	The six features required to be present for a principal-agent model to exist.	The preference of the agent for an incentive package with slightly more than their own opportunity cost.
Laffont, J.J. and Martimort, D.	Theory- "take it or leave it" contract offers, in environments with reliable courts of law.	2002	N/A	Ability of principals to create sufficiently controlling contracts to define agent behaviour outcomes	Without information asymmetry, principals can control agents, even those with different objectives, by creating appropriate contracts.

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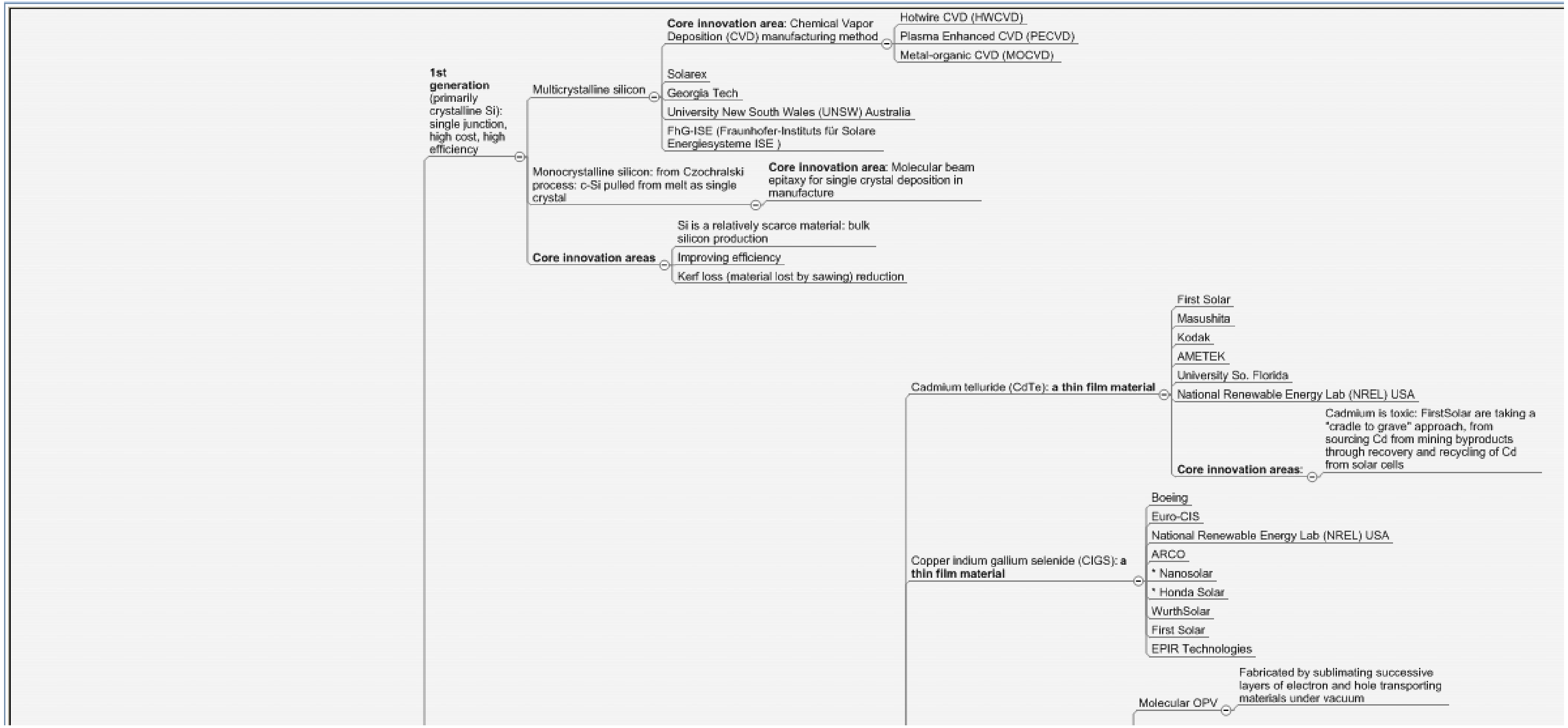
Table 12 - Summary of sources for innovation and ownership

Author	Data used in study	Dates	Location of study	Determinants	Key findings
Da, T.	Central and local state shareholdings and firm profitability	2010	China	Concentration and type of government ownership from central to local government and firm outcomes	Levels of profitability positively correlated to increasingly local levels of the state in China.
Feng, K.	Level of technological learning and firms supported or unsupported by the state	2010	China	Effect of state budgetary support on firms' technological learning	State budgetary support has a negative correlation with a firm's growth in technological learning.
Girma, S. and Gong, Y.	Executive appointments and R&D expenditure	2008	China	Appointment of firms' executives by the state and level of investment in R&D	Firms whose executives were state-appointed saw on average lower expenditures on R&D.
Kshetri, N.	Rate of firms' IP creation and government lobbying for court system improvement	2009	China	Propensity of firms to register intellectual property and to exert pressure on government for ability to protect	IP generation has led to increased pressure on the government to speed the improvement of the domestic court system.
Perez, C. and Soete, L.	Rate of technological growth and industry stage of maturity	1988	N/A	Rate of advancement of a technology and stage of maturity of that technology	Improvements achieved slowly in first stages, then accelerate, before slowing down again.

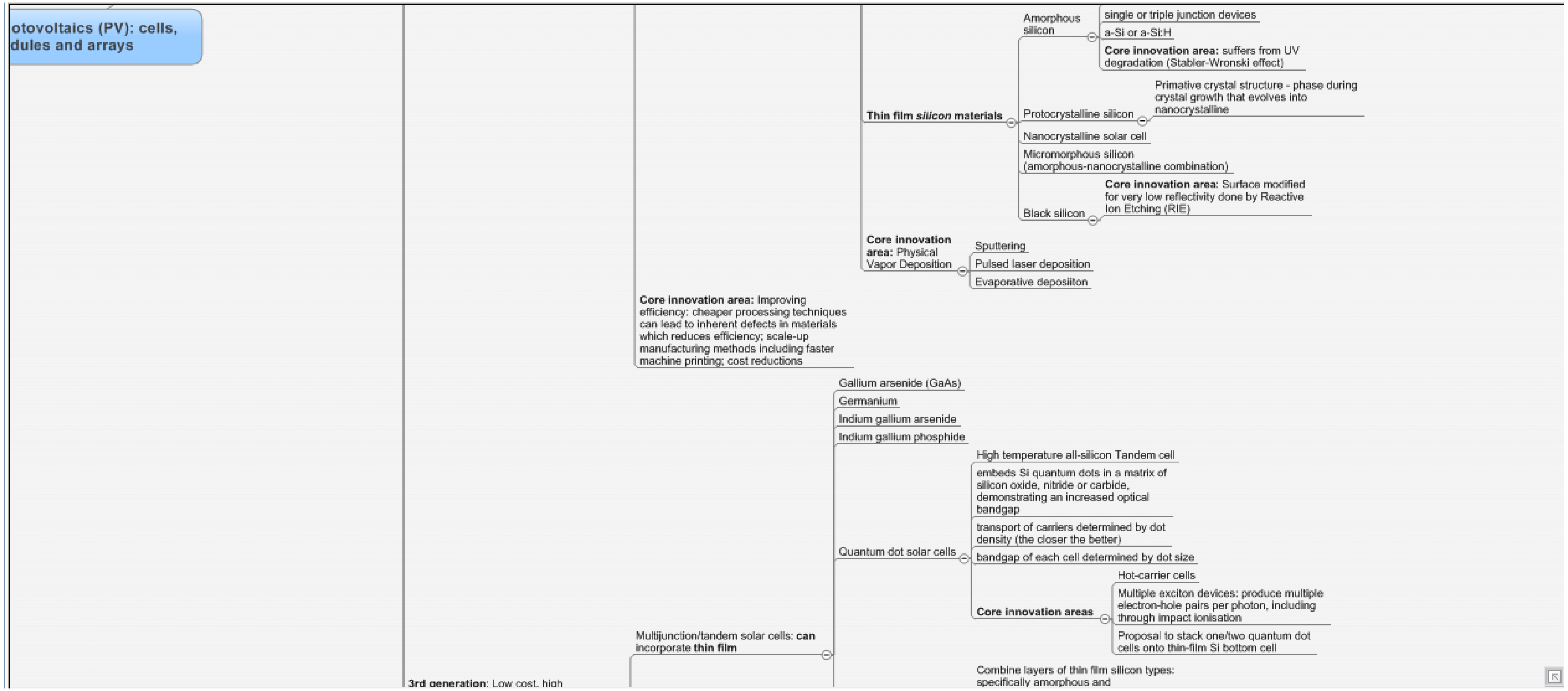
Table 13 - Summary of sources for patenting and R&D studies

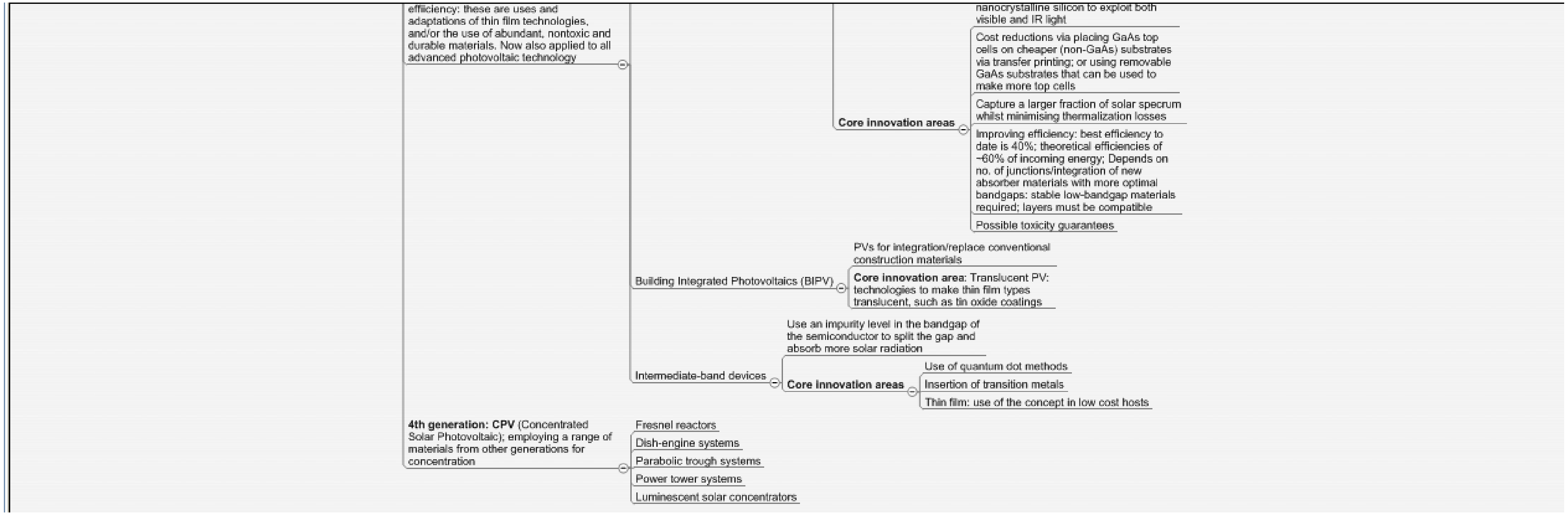
Author	Data used in study	Dates	Location of study	Determinants	Key findings
Cockburn, I.M. and Griliches, Z	Industry and appropriation in stock market valuation of R&D and patents	1987	US/general	Tendencies to patent per R&D spending; inter-industry differences therein.	Lower tendency to patent per R&D spend is seen not only in higher spending industries, but also in those industries featuring heavy government financial support for R&D.
Fai, F.M.	IP data in the analysis of Chinese technological capabilities	2005	China	Patent rates revealing motivations for patenting itself, or as indicators of underlying technological change.	Patents may be used as a proxy for the underlying realities of technological change, rather than just as a crude measure of "inventions"; this deals with problems of differing motivations for patent application.
Griliches, Z., Pakes, A. and Hall, B.H.	Patents used as data for inventive study; their value as useful data in indicating inventive activity	1986	US	Indicators of innovative ability within firms and the substitutability of R&D by patent data.	Patents can be used in tandem with, or should it be lacking, as a substitute for, R&D information; can be used to measure not only particular instances of innovation, but levels of innovation ability within organisations.
Levin, R.C., Klevorick, A.K., Nelson, R.R. and Winter, S.G.	The returns from industrial research and development	1987	N/A	The appropriability quality of patents and the incentive for firms to carry out R&D.	The authors find a positive correlation, that the ability of patents to provide an appropriability mechanism provides a marked incentive for firms to carry out R&D.
Rivette, K.G. and Kline, D.	Patent landscaping and clustering to determine new opportunities within firms	2000	US/general	Patent data in determining acquisition values.	The use by firms of patent registration information (in this case USPTO) to understand acquisition targets' technological capability; also to help in price setting for IP, which had not normally entered accounts.
Schmookler, J.	The connection of invention and rates of invention to economic growth	1952	US/general	Patents use as activity indicators	Patents as an index of inventive "activity", meaning an index of input, instead of inventive output; a narrow definition that excluded development, and being the search for *new* knowledge specifically.

Appendix 3: Mindmap of solar photovoltaic technologies



The main technological areas in the field
2nd generation: Low cost, low efficiency: these are technologies with proven practical lower conversion efficiencies and (potentially) lower costs per watt than crystalline Si
Thin films: applied to substrate, for non-silicon varieties no silicon wafer (wafer=semiconductor) substrate required
Organic solar cells: a thin film material
Polymer OPV
Polymer solar cell
Made by solution processing blends of two conjugated polymers or a conjugated polymer with a molecular sensitizer
PPV - Poly(p-phenylene vinylene)
Polyfluorenes
Polythiophenes
Hybrid OPV
polymer-nanocrystal blended active layers
combined organic and inorganic materials
Excitonic solar cell
excitonic structures
also applicable to Dye-sensitized solar cells
Dye-sensitized solar cell
Gratzel cell
uses a sensitiser dye and nano particles of Titanium dioxide(TiO2)
Grätzel cell
Core innovation areas
Improving efficiency: theoretical efficiency is equivalent to conventional semiconductor devices
OPV systems being leveraged by developments in organic electronics industry based on displays (organic-LEDs) and transistors
inherently inexpensive - costs comparable with other plastics processing
very high optical absorption coefficients - i.e thin films work well
compatible with plastic substrates
versatile - potential to tailor properties such as molecular weight, bandgap, wetting properties, structural properties (rigidity, conjugation length and molecule-molecule interactions) and doping
device degradation issues
chemical decomposition
changes in morphology
loss of interfacial adhesion
interdifusion of components
to be overcome by careful design and improved encapsulation/encapsulants slowing diffusion of oxygen and water
Molecular beam epitaxy for organic material deposition in manufacture
stabilized amorphous Si


otovoltaics (PV): cells,
dules and arrays
Amorphous silicon
single or triple junction devices
a-Si or a-Si:H
Core innovation area: suffers from UV degradation (Stabler-Wronski effect)
Primative crystal structure - phase during crystal growth that evolves into nanocrystalline
Thin film silicon materials
Protocrystalline silicon
Nanocrystalline solar cell
Micromorphous silicon (amorphous-nanocrystalline combination)
Core innovation area: Surface modified for very low reflectivity done by Reactive Ion Etching (RIE)
Black silicon
Core innovation area: Physical Vapor Deposition
Sputtering
Pulsed laser deposition
Evaporative deposiiton
Core innovation area: Improving efficiency; cheaper processing techniques can lead to inherent defects in materials which reduces efficiency; scale-up manufacturing methods including faster machine printing; cost reductions
Gallium arsenide (GaAs)
Germanium
Indium gallium arsenide
Indium gallium phosphide
High temperature all-silicon Tandem cell
embeds Si quantum dots in a matrix of silicon oxide, nitride or carbide, demonstrating an increased optical bandgap
transport of carriers determined by dot density (the closer the better)
Quantum dot solar cells
bandgap of each cell determined by dot size
Hot-carrier cells
Multiple exciton devices: produce multiple electron-hole pairs per photon, including through impact ionisation
Core innovation areas
Proposal to stack one/two quantum dot cells onto thin-film Si bottom cell
Multijunction/tandem solar cells: can incorporate thin film
3rd generation: Low cost, high
Combine layers of thin film silicon types: specifically amorphous and



efficiency: these are uses and adaptations of thin film technologies, and/or the use of abundant, nontoxic and durable materials. Now also applied to all advanced photovoltaic technology
nanocrystalline silicon to exploit both visible and IR light
Cost reductions via placing GaAs top cells on cheaper (non-GaAs) substrates via transfer printing; or using removable GaAs substrates that can be used to make more top cells
Core innovation areas
Capture a larger fraction of solar specrum whilst minimising thermalization losses
Improving efficiency: best efficiency to date is 40%; theoretical efficiencies of ~60% of incoming energy; Depends on no. of junctions/integration of new absorber materials with more optimal bandgaps: stable low-bandgap materials required; layers must be compatible
Possible toxicity guarantees
Building Integrated Photovoltaics (BIPV)
PVs for integration/replace conventional construction materials
Core innovation area: Translucent PV: technologies to make thin film types translucent, such as tin oxide coatings
Intermediate-band devices
Use an impurity level in the bandgap of the semiconductor to split the gap and absorb more solar radiation
Core innovation areas
Use of quantum dot methods
Insertion of transition metals
Thin film: use of the concept in low cost hosts
4th generation: CPV (Concentrated Solar Photovoltaic); employing a range of materials from other generations for concentration
Fresnel reactors
Dish-engine systems
Parabolic trough systems
Power tower systems
Luminescent solar concentrators

Appendix 4: Patent search terms

Search Terms

title:("")	**abstract:("")**
Silicon processing and ingot manufacturing	
czochralski/czochralsky	czochralski/czochralsky
Siemens	Siemens
bed reactor	bed reactor
Fluidized	Fluidized
silicon manufacture/manufacturing	silicon manufacture/manufacturing
silicon process	silicon process
solar grade	solar grade
Purify	Purify
high purity	high purity
Purification	Purification
Smelt	Smelt
Ribbon	
Waste	Waste
Crucible	Crucible
Sand	Sand
Raw	Raw
zinc chloride	zinc chloride
Silicide	Silicide
Ingot	Ingot
Seed	Seed
	Quartz
	Casting
	Bridgman
Doping	Doping
ingot manufacture	ingot manufacture
ingot manufacturing	ingot manufacturing
	Refining
	Mortar
ingot fabrication	ingot fabrication
Wafer manufacturing	
	Wafer
wafer manufacturing	wafer manufacturing
Cutting	Cutting
Kerf	Kerf
Polishing	Polishing
Slicing	Slicing

Wire	Wire
saw	Saw
Wash	Wash
wafer cleaning	wafer cleaning
Sawdust	Sawdust
Recover	Recover
Arsenic	Arsenic
Slice	
Chip	
Tapetum	
Antimony	Antimony
Cells	
Cell	
Sputter	Sputter
cell fabrication	cell fabrication
diamond linear	diamond linear
slice adhesion	
Ribbon	
	chemical vapour
	chemical vapor
Texture	Texture
Printing	Printing
Coat	
	Triple
	Boat
	Tin
	Etch
	cell manufacture
Laser	Laser
Boron	Boron
Phosphorus	Phosphorus
Scrape	Scrape
Cushion	
Tool	
Aerosol	aerosol
Battery	
Ion	
Modules	
	junction box
coupling device	
Welding	
Assembly	
Module	
Illuminator	

Inverter	
Converter	
Cover	
light on the solar cell	
Folding	
Frameless	
Frame	frame
Wiring	
MPP	
MPPT	
tracking/tracker	
EVA	EVA
hot mark	
Vent	vent
	panel
	Encapsulation
Systems	
Tank	
battery fixing device	
Antenna	
detector for laser	
Shaft	shaft
Array	
Mount	
	horizontal bracket
Storage	
MPP	MPP
MPPT	MPPT
Column	column
maximum power	
Pole	
Balancer	balancer
Network	
Cable	
Weather	
Surge	surge
Motor	
Cleaning	
BIPV	BIPV
Cooling	
Lens	
Thin film and next generation PV	
	thin film
	thin-film

Gallium	Gallium
Indium	Indium
	gold
	sulphur
	sulfur
	zinc
	tellurium
	cobalt
	titanium
	Zirconium
	hafnium
	niobium
	Vanadium
	nickel
	Molybdenum
	Manganese
	bismuth
	Beryllium
	antimony
	Berrylium
	thallium
	PECVD
	InxGal
	TF-Si
	DSC
	InAs
	CIS
	CdTe
	a-Si
	tantalum
Selenide	selenide
Cadmium	Cadmium
Germanium	Germanium
Dye	dye
	Amorphous
Excitonic	excitonic
	tandem
Organic	
Dot	
Quantum	quantum
	Microcrystalline
	Nanocrystalline
	molecular beam epitaxy
Rubidium	Rubidium
	chemical vapour
	nanocrystal

	chemical vapor
	black silicon
CIGS	CIGS
Concentrating PV	
Concentrator	
Station	
Fresnel	
Chimney	chimney
Heliostat	heliostat
	tower
Stirling	stirling
Dish	dish
Parabolic	parabolic
Trough	trough
Collector	
Condensation	
optical superposition	
light-focusing	
Mirror	
Cassegrain	Cassegrain

Appendix 5: *Total Patent* Boolean searches

(silicon! W/3 process! AND solar AND photovoltaic) OR (silicon! W/3 process! AND solar AND PV)

(silicon! W/3 manufactur! AND solar AND photovoltaic) OR (silicon! W/3 manufactur! AND solar AND PV)

(manufactur! PRE/3 silicon! AND solar AND photovoltaic) OR (manufactur! PRE/3 silicon! AND solar AND PV)

(silicon! W/3 purif! AND solar) OR (silicon! W/3 purif! AND photovoltaic) (purif! PRE/3 silicon! AND solar) OR (purif! PRE/3 silicon! photovoltaic)

(silicon! W/3 ingot! AND solar AND photovoltaic) OR (silicon! W/3 ingot! AND solar AND PV) (ingot! PRE/3 silicon! AND solar AND PV) OR (ingot! PRE/3 silicon! AND solar AND photovoltaic)

(silicon! W/3 czochralski AND solar AND photovoltaic) OR (silicon! W/3 czochralski AND solar AND PV)

(czochralski PRE/3 silicon! AND solar AND photovoltaic) OR (czochralski PRE/3 silicon! AND solar AND PV) (solar AND PV W/3 wafer) OR (solar AND photovoltaic! W/3 wafer)

(wafer PRE/3 solar AND PV) OR (wafer PRE/3 solar AND photovoltaic!)

(multi! AND wafer AND solar) OR (multi! AND wafer AND photovoltaic!)

(poly! AND wafer AND solar) OR (poly! AND wafer AND photovoltaic!)

(mono! AND wafer AND solar) OR (mono! AND wafer AND photovoltaic!)

(silicon W/3 doping AND solar AND photovoltaic) OR (silicon W/3 doping AND solar AND PV)

(doping PRE/3 silicon AND solar AND photovoltaic) OR (doping PRE/3 silicon AND solar AND PV)

(solar AND PV w/3 cell) OR (solar AND photovoltaic! W/3 cell)

(silicon W/3 cell AND solar) OR (silicon W/3 cell AND photovoltaic!)

(solar AND PV W/3 module) OR (solar AND photovoltaic! W/3 module)

(module PRE/3 solar AND PV) OR (solar AND photovoltaic! PRE/3 solar)

(solar AND PV AND module AND process!) OR (solar AND photovoltaic! AND module AND process!)

(solar AND PV W/3 array) OR (solar AND photovoltaic! W/3 array)

(array PRE/3 solar AND PV) OR (array PRE/3 solar AND photovoltaic!)

(solar AND PV AND mount!) OR (solar AND photovoltaic! AND mount!)

(solar AND PV AND track!) OR (solar AND photovoltaic! AND track!)

(solar AND PV AND MPP!) OR (solar AND photovoltaic! AND MPP!)

(solar AND PV AND maximum!) OR (solar AND photovoltaic! AND maximum!)

(solar AND PV W/5 inverter) OR (solar AND photovoltaic! W/5 inverter)

(solar AND PV AND junction W/3 box) OR (solar AND photovoltaic! AND junction W/3 box)

(solar AND PV W/3 wiring) OR (solar AND photovoltaic! W/3 wiring)

(solar AND PV PRE/3 wiring) OR (solar AND photovoltaic! PRE/3 wiring)

(solar AND PV AND surge W/3 protect!) OR (solar AND photovoltaic! AND surge W/3 protect!)

(solar and PV W/3 concentrat!) OR (solar AND photovoltaic! W/3 concentrat!)

(solar AND PV PRE/3 concentrat!) OR (solar AND photovoltaic! PRE/3 concentrat!)

(solar AND PV AND thin W/3 film) OR (solar AND photovoltaic! AND thin W/3 film)

(solar AND PV AND cadmium W/3 telluride) OR (solar AND photovoltaic! AND cadmium W/3 telluride)

(solar AND PV AND amorphous) OR (solar AND photovoltaic! AND amorphous)

(solar AND PV AND copper W/3 indium W/3 gallium W/3 selenide) OR (solar AND photovoltaic! AND copper W/3 indium W/3 gallium W/3 selenide)

(organic W/3 solar AND PV) OR (organic W/3 photovoltaic! AND solar)

(solar AND PV AND dye!) OR (solar AND photovoltaic! AND dye!)

(solar AND PV AND quantum W/3 dot) OR (solar AND photovoltaic! AND quantum W/3 dot)

(solar AND PV AND polymer!) OR (solar AND photovoltaic! AND polymer!)

(solar AND PV AND hybrid!) OR (solar AND photovoltaic! AND hybrid!)

(solar AND PV AND excitonic!) OR (solar AND photovoltaic! AND excitonic!)

(solar AND PV AND triple junction!) OR (solar AND photovoltaic! AND triple junction!)

(solar AND PV AND protocrystalline!) OR (solar AND photovoltaic! AND protocrystalline!)

(solar AND PV AND germanium!) OR (solar AND photovoltaic! AND germanium!)

(solar AND PV AND arsenide!) OR (solar AND photovoltaic! AND arsenide!)

(solar AND PV AND phosphide!) OR (solar AND photovoltaic! AND phosphide!)

(solar AND PV AND molecular!) OR (solar AND photovoltaic! AND molecular!)

(solar AND PV AND etching!) OR (solar AND photovoltaic! AND etching!)

(solar AND PV AND saw!) OR (solar AND photovoltaic! AND saw!)

(solar AND PV AND depos!) OR (solar AND photovoltaic! AND depos!)

Appendix 6: Chinese patent Kind Codes

China (CN)

- A8 CORRECTED FIRST PAGE OF PATENT APPLICATION [FROM 07-04-2010 ONWARDS]
- A9 CORRECTED FULL SPECIFICATION OF PATENT APPLICATION [FROM 07-04-2010 ONWARDS]
- B EXAMINED APPLICATION [FROM 01-04-1985 - 31-12-1992] or GRANTED PATENT FOR INVENTION
- B8 CORRECTED FIRST PAGE OF GRANTED PATENT [FROM 07-04-2010 ONWARDS]
- B9 CORRECTED FULL SPECIFICATION OF GRANTED PATENT [FROM 07-04-2010 ONWARDS]

- C1 FIRST RE-ISSUE AFTER PARTIAL INVALIDATION OF GRANTED PATENT [FROM 07-04-2010 ONWARDS]
- C2 SECOND RE-ISSUE AFTER PARTIAL INVALIDATION OF GRANTED PATENT [FROM 07-04-2010 ONWARDS]
- C3 THIRD RE-ISSUE AFTER PARTIAL INVALIDATION OF GRANTED PATENT [FROM 07-04-2010 ONWARDS]
- C4 FOURTH RE-ISSUE AFTER PARTIAL INVALIDATION OF GRANTED PATENT [FROM 07-04-2010 ONWARDS]
- C5 FIFTH RE-ISSUE AFTER PARTIAL INVALIDATION OF GRANTED PATENT [FROM 07-04-2010 ONWARDS]
- C6 SIXTH RE-ISSUE AFTER PARTIAL INVALIDATION OF GRANTED PATENT [FROM 07-04-2010 ONWARDS]
- C7 SEVENTH RE-ISSUE AFTER PARTIAL INVALIDATION OF GRANTED PATENT [FROM 07-04-2010 ONWARDS]
- K1 NON-OFFICIAL TRANSLATION OF CN -A DOCUMENT, NOT ISSUED BY PATENT OFFICE
- K2 NON-OFFICIAL TRANSLATION OF CN -B DOCUMENT, NOT ISSUED BY PATENT OFFICE
- K3 NON-OFFICIAL TRANSLATION OF CN -C DOCUMENT, NOT ISSUED BY PATENT OFFICE
- K4 NON-OFFICIAL TRANSLATION OF CN -U DOCUMENT, NOT ISSUED BY PATENT OFFICE
- K5 NON-OFFICIAL TRANSLATION OF CN -Y DOCUMENT, NOT ISSUED BY PATENT OFFICE
- K6 NON-OFFICIAL TRANSLATION OF CN -S DOCUMENT, NOT ISSUED BY PATENT OFFICE
- S DESIGN APPLICATION [FROM 01-04-1985 - 28-08-2007] or REGISTERED DESIGN
- S1 FIRST RE-ISSUE AFTER PARTIAL INVALIDATION OF INDUSTRIAL DESIGN [FROM 07-04-2010 ONWARDS]
- S2 SECOND RE-ISSUE AFTER PARTIAL INVALIDATION OF INDUSTRIAL DESIGN [FROM 07-04-2010 ONWARDS]
- S3 THIRD RE-ISSUE AFTER PARTIAL INVALIDATION OF INDUSTRIAL DESIGN [FROM 07-04-2010 ONWARDS]
- S4 FOURTH RE-ISSUE AFTER PARTIAL INVALIDATION OF INDUSTRIAL DESIGN [FROM 07-04-2010 ONWARDS]
- S5 FIFTH RE-ISSUE AFTER PARTIAL INVALIDATION OF INDUSTRIAL DESIGN [FROM 07-04-2010 ONWARDS]
- S6 SIXTH RE-ISSUE AFTER PARTIAL INVALIDATION OF INDUSTRIAL DESIGN [FROM 07-04-2010 ONWARDS]
- S7 SEVENTH RE-ISSUE AFTER PARTIAL INVALIDATION OF INDUSTRIAL DESIGN [FROM 07-04-2010 ONWARDS]

S9 CORRECTED FULL SPECIFICATION OF INDUSTRIAL DESIGN [FROM 07-04-2010 ONWARDS]

U8 CORRECTED FIRST PAGE OF UTILITY MODEL [FROM 07-04-2010 ONWARDS]
U9 CORRECTED FULL SPECIFICATION OF UTILITY MODEL [FROM 07-04-2010 ONWARDS]

Y1 FIRST RE-ISSUE AFTER PARTIAL INVALIDATION OF UTILITY MODEL [FROM 07-04-2010 ONWARDS]
Y2 SECOND RE-ISSUE AFTER PARTIAL INVALIDATION OF UTILITY MODEL [FROM 07-04-2010 ONWARDS]
Y3 THIRD RE-ISSUE AFTER PARTIAL INVALIDATION OF UTILITY MODEL [FROM 07-04-2010 ONWARDS]
Y4 FOURTH RE-ISSUE AFTER PARTIAL INVALIDATION OF UTILITY MODEL [FROM 07-04-2010 ONWARDS]
Y5 FIFTH RE-ISSUE AFTER PARTIAL INVALIDATION OF UTILITY MODEL [FROM 07-04-2010 ONWARDS]
Y6 SIXTH RE-ISSUE AFTER PARTIAL INVALIDATION OF UTILITY MODEL [FROM 07-04-2010 ONWARDS]
Y7 SEVENTH RE-ISSUE AFTER PARTIAL INVALIDATION OF UTILITY MODEL [FROM 07-04-2010 ONWARDS]

Appendix 7: International Patent Classification (IPC) code examples

10.0.0.60:4200/lists/ipc_grid/76?ipc_type=ipc_subclass

☐	E05B	SECTION E FIXED CONSTRUCTIONS >> LOCKS >> LOCKS >> >>	2
☐	E05F	SECTION E FIXED CONSTRUCTIONS >> LOCKS >> DEVICES FOR MOVING WINGS INTO OPEN OR CLOSED POSITION >> >>	5
☑	E06B	SECTION E FIXED CONSTRUCTIONS >> DOORS, WINDOWS, SHUTTERS, OR ROLLER BLINDS, IN GENERAL >> FIXED OR MOVABLE CLOSURES FOR OPENINGS IN BUILDINGS, VEHICLES, FENCES, OR LIKE ENCLOSURES, IN GENERAL, e.g. DOORS, WINDOWS, BLINDS, GATES >> >>	72
☐	E21B	SECTION E FIXED CONSTRUCTIONS >> EARTH OR ROCK DRILLING >> EARTH OR ROCK DRILLING >> >>	8
☑	E21D	SECTION E FIXED CONSTRUCTIONS >> EARTH OR ROCK DRILLING >> SHAFTS >> >>	1
☐	F01B	SECTION F MECHANICAL ENGINEERING >> MACHINES OR ENGINES IN GENERAL >> MACHINES OR ENGINES, IN GENERAL OR OF POSITIVE-DISPLACEMENT TYPE, e.g. STEAM ENGINES >> >>	1
☐	F01D	SECTION F MECHANICAL ENGINEERING >> MACHINES OR ENGINES IN GENERAL >> NON-POSITIVE-DISPLACEMENT MACHINES OR ENGINES, e.g. STEAM TURBINES >> >>	4
☐	F01K	SECTION F MECHANICAL ENGINEERING >> MACHINES OR ENGINES IN GENERAL >> STEAM ENGINE PLANTS >> >>	1
☐	F02B	SECTION F MECHANICAL ENGINEERING >> COMBUSTION ENGINES >> INTERNAL-COMBUSTION PISTON ENGINES >> >>	13
☐	F02C	SECTION F MECHANICAL ENGINEERING >> COMBUSTION ENGINES >> GAS-TURBINE PLANTS >> >>	1
☐	F02G	SECTION F MECHANICAL ENGINEERING >> COMBUSTION ENGINES >> HOT-GAS OR COMBUSTION-PRODUCT POSITIVE-DISPLACEMENT ENGINE PLANTS >> >>	2
☐	F02M	SECTION F MECHANICAL ENGINEERING >> COMBUSTION ENGINES >> SUPPLYING COMBUSTION ENGINES IN GENERAL WITH COMBUSTIBLE MIXTURES OR CONSTITUENTS THEREOF >> >>	1
☐	F02P	SECTION F MECHANICAL ENGINEERING >> COMBUSTION ENGINES >> IGNITION, OTHER THAN COMPRESSION IGNITION, FOR INTERNAL-COMBUSTION ENGINES >> >>	1
☐	F03B	SECTION F MECHANICAL ENGINEERING >> MACHINES OR ENGINES FOR LIQUIDS >> MACHINES OR ENGINES FOR LIQUIDS >> >>	10
☐	F03D	SECTION F MECHANICAL ENGINEERING >> MACHINES OR ENGINES FOR LIQUIDS >> WIND MOTORS >> >>	157
☐	F03G	SECTION F MECHANICAL ENGINEERING >> MACHINES OR ENGINES FOR LIQUIDS >> SPRING, WEIGHT, INERTIA, OR LIKE MOTORS >> >>	21
☐	F04B	SECTION F MECHANICAL ENGINEERING >> POSITIVE-DISPLACEMENT MACHINES FOR LIQUIDS >> POSITIVE-DISPLACEMENT MACHINES FOR LIQUIDS >> >>	3
☐	F04D	SECTION F MECHANICAL ENGINEERING >> POSITIVE-DISPLACEMENT MACHINES FOR LIQUIDS >> NON-POSITIVE-DISPLACEMENT PUMPS >> >>	5
☐	F16B	SECTION F MECHANICAL ENGINEERING >> ENGINEERING ELEMENTS OR UNITS >> DEVICES FOR FASTENING OR SECURING CONSTRUCTIONAL ELEMENTS OR MACHINE PARTS TOGETHER, e.g. NAILS, BOLTS, CIRCLIPS, CLAMPS, CLIPS OR WEDGES >> >>	1
☐	F16C	SECTION F MECHANICAL ENGINEERING >> ENGINEERING ELEMENTS OR UNITS >> SHAFTS >> >>	3
☐	F16F	SECTION F MECHANICAL ENGINEERING >> ENGINEERING ELEMENTS OR UNITS >> SPRINGS >> >>	2
☐	F16H	SECTION F MECHANICAL ENGINEERING >> ENGINEERING ELEMENTS OR UNITS >> GEARING >> >>	1
☐	F16K	SECTION F MECHANICAL ENGINEERING >> ENGINEERING ELEMENTS OR UNITS >> VALVES >> >>	7
☐	F16L	SECTION F MECHANICAL ENGINEERING >> ENGINEERING ELEMENTS OR UNITS >> PIPES >> >>	7
☐	F16M	SECTION F MECHANICAL ENGINEERING >> ENGINEERING ELEMENTS OR UNITS >> FRAMES, CASINGS, OR BEDS, OF ENGINES OR OTHER MACHINES OR APPARATUS, NOT SPECIFIC TO AN ENGINE, MACHINE, OR APPARATUS PROVIDED FOR ELSEWHERE >> >>	6
☐	F16S	SECTION F MECHANICAL ENGINEERING >> ENGINEERING ELEMENTS OR UNITS >> CONSTRUCTIONAL ELEMENTS IN GENERAL >> >>	2

Source: Cambridge IP

Appendix 8: Complete information provided in a patent

A registered patent provides the following information to the reader:

a) Title – to what the patent refers
b) Publishing date – The date a granted patent enters the public domain and becomes prior art. A patent can be published twice, as it is automatically published 18 months after the earliest given priority date and again after the patent is granted.
c) Inventor(s) – Names the inventor of the patent, the person(s) who contributes to the claims of the patent. In the US the patent must be filed under the name of the inventor, while inventorship is not classified as a patentability criterion under European patent law
d) Applicant(s) – The person/entity which makes the application for the invention and will become the assignee and own the property right to the patent. In the US this is often the inventor.

e) Classification codes – Categorises the patents into a specific area of technology according to one of various hierarchical classification systems. The classification codes have levels of increasing detail. The most common classification systems are the International Patent Classification (IPC, which we use), European Classification (ECLA), the United States Patent Classification (USPC), and the Derwent classification (used in the private DWPI patent database owned by Thompson Reuters).
f) Application number – Reference number given to the patent application.
g) Priority number – The priority number is the number of the application in respect of which priority is claimed, i.e. it is the same as the application number of the claimed priority document.
h) Also published as – Gives the other publication/application numbers assigned to the patent, usually as a result of the patent being granted in other territories. This can be useful when the patent published in one instance doesn't give the claims, or gives the claims in a foreign language as it may be published with the full claims in English under a different publication number.
i) Cited documents – Gives the reference numbers of the documents cited by the patent as prior art.
j) The computerised display of a patent also gives the following information:
k) Description – Gives a detailed explanation of the patent and the background behind it. Doesn't define the scope of the patent in any legal sense
l) Claims – Defines the scope of the protection granted by the patent in technical terms. This is the crucial part of the patent for application and potential future litigation
m) Mosaics – Any figures, technical drawings, or other images that accompany the patent.
n) Original Document – A scan of the original patent with its accompanying documents, when it was first published.
o) INPADOC legal status – Gives information as to whether the patent has been granted, expired, etc.
p) Patent families – Patents are grouped into patent families. Members of a family are either the same patent published in a different country or patents that refer to the same invention, such as utility patents, patents that cover one part of a larger invention, etc.
q) Prior art – The previous knowledge in a field that patented inventions have built on, including previous patents and information in the public domain. A new patent must declare its prior art and distinguish itself from it.
r) Priority right – Allows the owner of a patent to apply for a patent in a different country and claim the same "priority date" as the original patent application. This means that the new patent will be valid from the same date as the previously filed patent. It allows the subsequent patent to claim the same prior art as the earlier patent and thus avoids having to take into account any prior art that have been published in the intervening time.
s) Open for Public Inspection (OPI) – the part in a patents file which members of the public can inspect from the date of publication of the application.
t) Citations – References to other patents. Backward citations are references to previous patents (prior art), forward citations are subsequent patents that reference the given patent.

Appendix 9: Agglomeration rating compilation

City	Total firms in city	Total firms in our sample within 100 miles
Shanghai	15	35
Changzhou	9	42
Beijing	9	17
Suzhou	8	56
Ningbo	8	21
Hangzhou	6	45
Wuhan	5	6
Jiangyin	5	56
Nantong	4	55
Tianjin	4	17
Shenzhen	4	9
Nanjing	3	42
Wuxi	3	61
Taizhou	3	41
Baoding	2	18
Jinan	2	4
Changsha	2	5
Xinyu	2	5
Zhenjiang	2	42
Hohhot	2	2
Quanzhou	2	3
Jiaxing	2	66
Dongguan	2	9
Shaoxing	2	32
Dongying	2	4
Xian	2	3
Hefei	1	6
Chaoyang	1	1
Mudanjiang	1	1
Gaobeidian	1	17
Shantou	1	1
Wuyishan	1	2
Yinchuan	1	1
Foshan	1	9
Baoji	1	3
Nanan	1	3
Leshan	1	2
Rugao	1	38
Nanyang	1	1
Guangzhou	1	9
Yantai	1	3
Zhuji	1	22

Chengdu	1	2
Langfang	1	17
Urumqi	1	1
Taiyuan	1	2
Shijiazhuang	1	4
Luoyang	1	3
Huangshi	1	6
Huzhou	1	64
Xuzhou	1	3
Jiangyan	1	45
Xiangtan	1	5
Jinshan	1	48
Suqian	1	3
Weihai	1	3
Wuhu	1	18
Yingtan	1	2
Qinyang	1	3
Chizhou	1	3
Yangzhou	1	41
Zhuhai	1	9
Pinghu	1	65
Zhengzhou	1	3
Dalian	1	3
Linyi	1	3

Appendix 10: Coding of variables for SPSS

Variable	**Code**	**Coding instructions**
ID for each firm	ID	Number
TRINA SOLAR LTD		1
CANADIAN SOLAR INC		2
YINGLI		3
NINGBO ULICA		4
CEEG		5
SHANGHAI CHAORI SOLAR		6
NINGBO XINYOU PHOTOVOLTAIC INDUSTRY CO., LTD.		7
CHINALAND SOLAR ENERGY CO., LTD.		8
LIAONING SUNRISE SOLAR ENERGY TECHNOLOGY CO., LTD.		9
WUHAN RIXIN TECHNOLOGY		10
MUDANJIANG XUYANG SOLAR TECHNOLOGY CO., LTD.		11
LINUO SOLAR POWER CO., LTD.		12
EOPLLY NEW ENERGY TECHNOLOGY CO LTD		13
JIFU NEW ENERGY TECH SHANGHAI		14
CETC SOLAR		15
JETION SOLAR CHINA CO LTD		16
TIANJIN JINNENG SOLAR CELL CO., LTD.		17
LDK SOLAR		18
CECEP SOLAR ENERGY TECHNOLOGY		19
ASTRONERGY SOLAR		20
SUNTECH		21
CHINA SUNERGY		22
LIGHTWAY GREEN NEW ENERGY CO.,LTD.		23
GUANGDONG GOLDEN GLASS TECHNOLOGIES LTD		24
INNER MONGOLIA SHENZHOU SILICON SCIENCE AND TECHNOLOGY CO LTD		25
GCL		26
CHANGZHOU HUAMEI PHOTOVOLTAIC		27
WUYISHAN XINTAI PHOTOELECTRIC CO., LTD.		28
GOLDEN SUN FUJIAN SOLAR		29
QUANZHOU INTECH SOLAR TECHNOLOGY CO., LTD.		30
WUHAN LINGYUN PHOTOELECTRONIC SYSTEM CO., LTD.		31
NINGXIA YINXING ENERGY CO., LTD.		32
NINGBO CHUANGYUAN PHOTOVOLTAIC TECHNOLOGY CO		33
BEIJING KINGLONG NEW ENERGY TECHNOLOGY CO., LTD.		34
SHANGHAI SOLAR ENERGY		35
HUNAN RED SOLAR NEW ENERGY SCIENCE AND TECHNOLOGY CO LTD		36
SHENZHEN TRONY SOLAR CORP		37
JA SOLAR		38

SHANDONG HUAYI	131
DONGGUAN HUAYUAN	132
ZHEJIANG FORTUNE	133
HENAN ARGUS	134
UPSOLAR TECHNOLOGY (SHANGHAI)	135
HANGZHOU WEISHENG	136
SHANGHAI SINO SOLAR	137
SUZHOU JIEBO	138
ZIXU SOLAR	139
JIANGSU SHUNFENG PHOTOVOLTAIC	140
DALIAN MINE ENERGY	141
SHANGHAI LIANFU	142
LINYI JUHUANG	143
XIAN HUANGHE	144
HANGZHOU SOLAR	145
ZHEJIANG ERA SOLAR	146
SHANGHAI TIANQI NEW ENERGY	147
HANGZHOU VERSOL SOLAR	148
SUZHOU OMNIK	149
INNER MONGOLIA RIYUE	150

The shareholding-related variables were coded as follows:

Variable:	**Code**:	**Value**:
Percentage of firm private domestic	PrivDomPercent	[Number]
Percentage of firm foreign	FPercent	[Number]
Percentage of firm central state held	StateCentralPercent	[Number]
Percentage of firm provincial state held	StateProvPercent	[Number]
Percentage of firm municipal state held	StateMuniPercent	[Number]
Percentage of firm super-municipally state held	StateSuperMuniPercent	[Number]

As such, the shareholding-related variables were coded for each year along the same pattern, for example: PrivDomPercent2006, etc.

The variables for outcome of shareholding for each firm were coded as follows:

Outcome:	**Code**:	**Value**:

Private	POE	1
Central state fully owned	Central SOE	2
Central state majority owned	Central MASOE	3
Central state minority owned	Central MISOE	4
Provincial state fully owned	Prov SOE	5
Provincial state majority owned	Prov MASOE	6
Provincial state minority owned	Prov MISOE	7
Municipal state fully owned	Muni SOE	8
Municipal state majority owned	Muni MASOE	9
Municipal state minority owned	Muni MISOE	10
Super-municipal state owned	Super Muni SOE	11
Super-muni state majority owned	Super Muni MASOE	12
Super-muni state minority owned	Super Muni MISOE	13

As above, the outcome variables were coded for each year along the same pattern: e.g. Outcome2006, etc.

The R&D-related variables were coded as follows:

Variable:	**Code**:	**Value**:
R&D staff number	RDStaff	[Number]
Total staff	TtalStaff	[Number]
R&D staff as percentage of total staff	RDStaffofTtalStaff	[Number]

These variables were then coded for each year along the same pattern: RDStaff2006 etc.

The patent-related variables were coded as follows:

Variable:	**Code**:	**Value**:
Total patents for the firm	PatentTtal	[Number]
Inventive patents for the firm	PatentInvent	[Number]

Non-inventive patents for the firm	PatentNonInvent	[Number]
Forward citations of patents for the firm	PatentCite	[Number]
Patent family registrations per firm (domestic)	PatentFam	[Number]
Patent family registrations outside China (non-US)	PatentFamF	[Number]
Patent family registrations outside China (US)	PatentFamUS	[Number]

As above, the patent-related codes were coded for each year along the same pattern, for example: PatentTtal2006, etc.

The other variables were coded as follows:

Variable:	**Code:**	**Value:**
Location by province	LocationProvIncome	[Number]
Current age of firm	AgFirm	[Number]
Subsidiary	Subsid	[Yes (1) or No (2)]
Listed	Listed	[Yes (1) or No (2)]

Among these variables, only Listed needed to be coded for each year, as Listed2006, etc.

Appendix 11: Factor Analysis full output

Correlation Matrix

Correlation Matrix

		Inventive patents for the firm average 2009-2012	Non-inventive patents for the firm average 2009-2012	Patent citations for the firm average 2009-2012	Patent family entries average 2009-2012	Foreign patent family entries average 2009-2012	US patent family entries average 2009-2012
Correlation	Inventive patents for the firm average 2009-2012	1.000	.733	.627	.856	.497	.316
	Non-inventive patents for the firm average 2009-2012	.733	1.000	.596	.506	.127	.054
	Patent citations for the firm average 2009-2012	.627	.596	1.000	.567	.427	.348
	Patent family entries average 2009-2012	.856	.506	.567	1.000	.707	.436
	Foreign patent family entries average 2009-2012	.497	.127	.427	.707	1.000	.840
	US patent family entries average 2009-2012	.316	.054	.348	.436	.840	1.000

KMO and Bartlett's Sphericity Tests

KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.672
Bartlett's Test of Sphericity	Approx. Chi-Square	762.805
	Df	15
	Sig.	.000

Principal Components Analysis

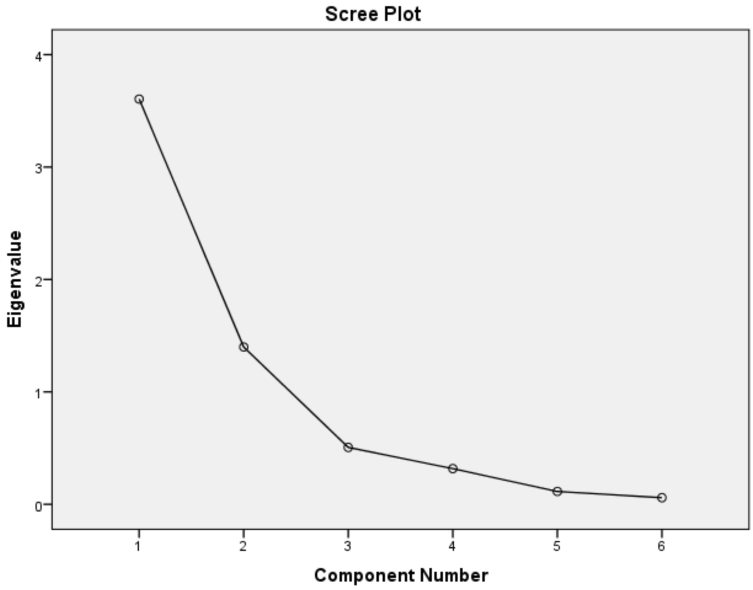
Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings[a]
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total
1	3.605	60.086	60.086	3.605	60.086	60.086	3.146
2	1.399	23.319	83.405	1.399	23.319	83.405	2.522
3	.506	8.434	91.839				
4	.317	5.285	97.124				
5	.114	1.896	99.020				
6	.059	.980	100.000				

Extraction Method: Principal Component Analysis.

a. When components are correlated, sums of squared loadings cannot be added to obtain a total variance.

Screeplot



Component Correlation Matrix

Component Correlation Matrix		
Component	1	2
1	1.000	.315
2	.315	1.000
Extraction Method: Principal Component Analysis. Rotation Method: Oblimin with Kaiser Normalization.		

Oblimin Rotation: Pattern Matrix

Pattern Matrix[a]		
	Component	
	1	2
Non-inventive patents for the firm average 2009-2012	.969	
Inventive patents for the firm average 2009-2012	.886	
Patent citations for the firm average 2009-2012	.745	
Patent family entries average 2009-2012	.675	.420
US patent family entries average 2009-2012		.949
Foreign patent family entries average 2009-2012		.926

Extraction Method: Principal Component Analysis. Rotation Method: Oblimin with Kaiser Normalization.[a]
a. Rotation converged in 6 iterations.

Oblimin Rotation: Structure Matrix

Structure Matrix

	Component	
	1	2
Inventive patents for the firm average 2009-2012	.930	.418
Non-inventive patents for the firm average 2009-2012	.876	
Patent family entries average 2009-2012	.808	.633
Patent citations for the firm average 2009-2012	.792	.384
Foreign patent family entries average 2009-2012	.419	.966
US patent family entries average 2009-2012		.930

Extraction Method: Principal Component Analysis.
Rotation Method: Oblimin with Kaiser Normalization.

Appendix 12: Reverse causation test 1

Descriptive Statistics (N= 20)

	Mean	Std. Deviation
Firm staff (2006-9)	3730.48	3459.442
Factor 1 when staff numbers (2006-2009)	6.397	11.843

Correlations (N= 20)

		Firm staff (2006-9)	Factor 1 when staff numbers (2006-2009)
Pearson Correlation	Firm staff (2006-9)	1.000	
	Factor 1 when staff numbers (2006-2009)	.061	1.000
Sig. (1-tailed)	Firm staff (2006-9)	.	.399
	Factor 1 when staff numbers (2006-2009)	.399	.

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	Factor 1 when staff numbers (2006-2009)[b]	.	Enter

a. Dependent Variable: Firm staff (2006-9)

b. All requested variables entered.

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.061[a]	.004	-.052	3547.566

a. Predictors: (Constant), Factor 1 when staff numbers (2006-2009)

b. Dependent Variable: Firm staff (2006-9)

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	852958.199	1	852958.199	.068	.798[b]

	Residual	226534041.037	18	12585224.502	
	Total	227386999.237	19		

a. Dependent Variable: Firm staff (2006-9)

b. Predictors: (Constant), Factor 1 when staff numbers (2006-2009)

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	3616.045	906.905		3.987	.001
	Factor 1 when staff numbers (2006-2009)	17.890	68.719	.061	.260	.798

a. Dependent Variable: Firm staff (2006-9)

Collinearity Diagnostics[a]

Model	Dimension	Eigenvalue	Condition Index	Variance Proportions	
				(Constant)	Factor 1 when staff numbers (2006-2009)
1	1	1.485	1.000	.26	.26
	2	.515	1.697	.74	.74

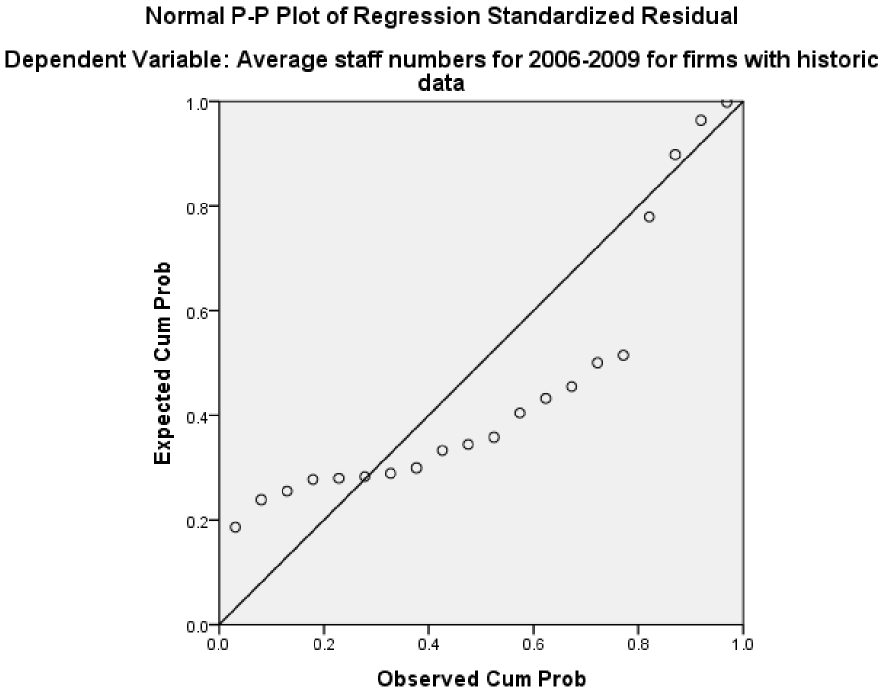
a. Dependent Variable: Firm staff (2006-9)

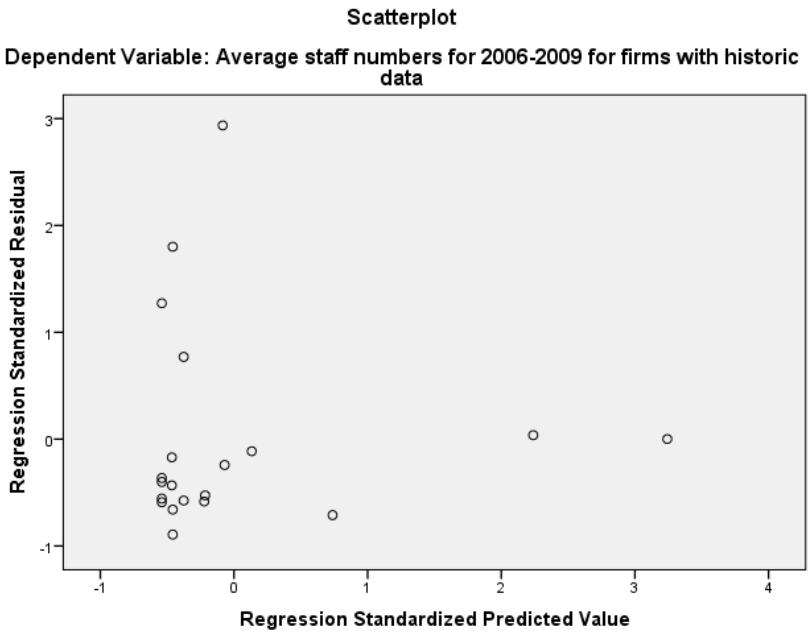
Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	3616.05	4417.41	3730.48	211.879	20
Std. Predicted Value	-.540	3.242	.000	1.000	20
Standard Error of Predicted Value	795.315	2755.310	1018.95	481.505	20
Adjusted Predicted Value	3160.04	4410.95	3734.49	293.765	20
Residual	-3167.881	10417.37	.000	3452.947	20
Std. Residual	-.893	2.936	.000	.973	20
Stud. Residual	-.922	3.013	-.001	1.002	20
Deleted Residual	-3373.867	10969.96	-4.008	3660.266	20
Stud. Deleted Residual	-.917	4.160	.071	1.208	20
Mahal. Distance	.005	10.511	.950	2.498	20

Cook's Distance	.000	.241	.029	.056	20
Centered Leverage Value	.000	.553	.050	.131	20

a. Dependent Variable: Firm staff (2006-9)





Appendix 13: Reverse Causation test 2

Descriptive Statistics (N= 20)		
	Mean	Std. Deviation
Firm staff (2006-9)	3730.5	3459.442
Factor 2 when staff numbers (2006-2009)	1.3271	4.488

Correlations (N= 20)			
		Firm staff (2006-9)	Factor 2 when staff numbers (2006-2009)
Pearson Correlation	Firm staff (2006-9)	1.000	
	Factor 2 when staff numbers (2006-2009)	-.027	1.000
Sig. (1-tailed)	Firm staff (2006-9)	.	.455
	Factor 2 when staff numbers (2006-2009)	.455	.

Variables Entered/Removed[a]			
Model	Variables Entered	Variables Removed	Method
1	Factor 2 when staff numbers (2006-2009)[b]	.	Enter

a. Dependent Variable: Firm staff (2006-9)
b. All requested variables entered.

Model Summary[b]				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.027[a]	.001	-.055	3552.923

a. Predictors: (Constant), Factor 2 when staff numbers (2006-2009)
b. Dependent Variable: Firm staff (2006-9)

ANOVA[a]						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	168285.294	1	168285.294	.013	.909[b]
	Residual	227218713.9	18	12623261.89		
	Total	227386999.2	19			

a. Dependent Variable: Firm staff (2006-9)

b. Predictors: (Constant), Factor 2 when staff numbers (2006-2009)

Coefficients[a]						
Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.
		B	Std. Error	Beta		
1	(Constant)	3758.306	830.210		4.527	.000
	Factor 2 when staff numbers (2006-2009)	-20.969	181.613	-.027	-.115	.909

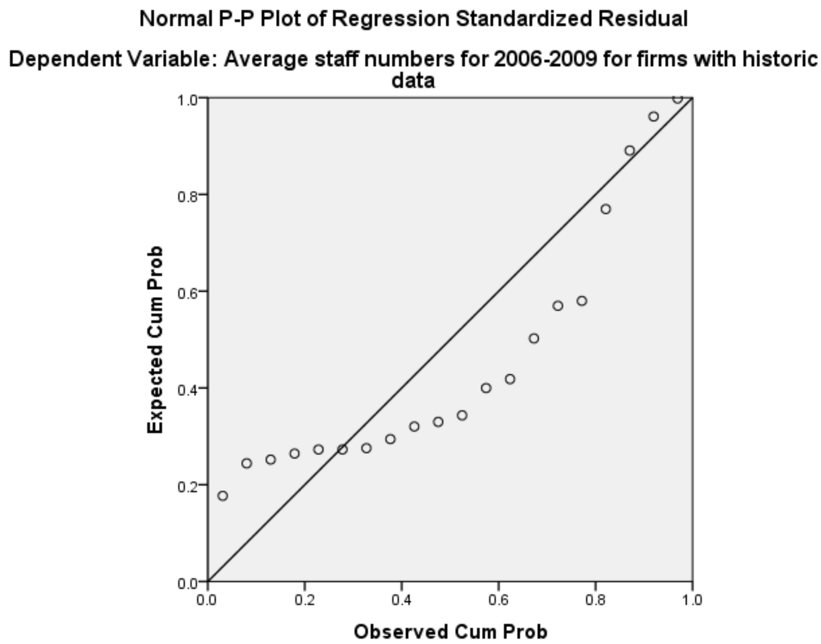
a. Dependent Variable: Firm staff (2006-9)

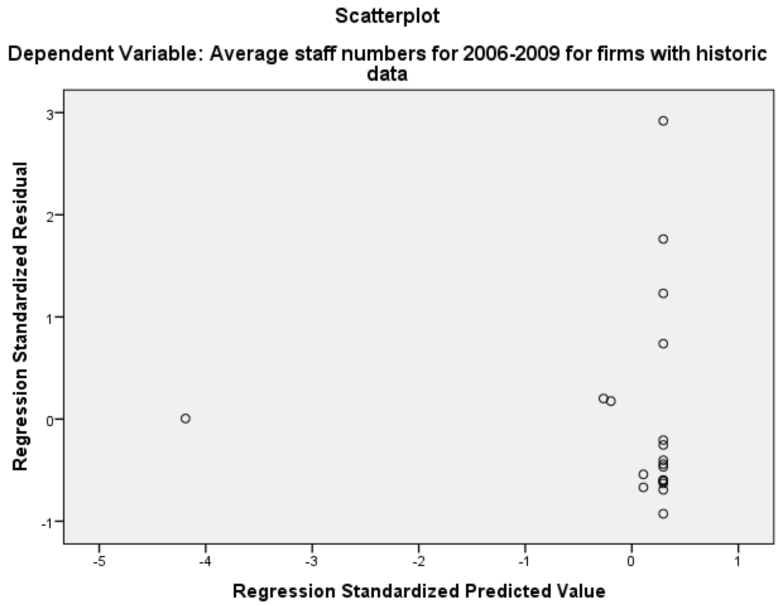
Collinearity Diagnostics[a]					
Model	Dimension	Eigenvalue	Condition Index	Variance Proportions	
				(Constant)	Factor 2 when staff numbers (2006-2009)
1	1	1.290	1.000	.35	.35
	2	.710	1.348	.65	.65

a. Dependent Variable: Firm staff (2006-9)

Residuals Statistics[a]					
	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	3336.15	3758.31	3730.5	94.112	20
Std. Predicted Value	-4.190	.296	.000	1.000	20
Standard Error of Predicted Value	799.367	3506.408	959.61	599.539	20
Adjusted Predicted Value	2546.20	3948.48	3690.2	335.180	20

Residual	-3292.806	10371.693	.000	3458.161	20
Std. Residual	-.927	2.919	.000	.973	20
Stud. Residual	-.953	3.002	.002	1.001	20
Deleted Residual	-3482.982	10970.710	40.265	3661.727	20
Stud. Deleted Residual	-.951	4.129	.071	1.201	20
Mahal. Distance	.012	17.556	.950	3.909	20
Cook's Distance	.001	.260	.029	.059	20
Centered Leverage Value	.001	.924	.050	.206	20
a. Dependent Variable: Firm staff (2006-9)					





Appendix 14: Reverse Causation test 3

```
REGRESSION
  /DESCRIPTIVES MEAN STDDEV CORR SIG N
  /MISSING PAIRWISE
  /STATISTICS COEFF OUTS BCOV R ANOVA COLLIN TOL ZPP
  /CRITERIA=PIN(.05) POUT(.10)
  /NOORIGIN
  /DEPENDENT ForShareholding20082009
  /METHOD=ENTER Factor12Combined20032005
  /SCATTERPLOT=(*ZRESID ,*ZPRED)
  /RESIDUALS NORMPROB(ZRESID)
  /CASEWISE PLOT(ZRESID) OUTLIERS(3).
```

The full coefficient results were: unstandardised B: -2.467; unstandardised standard error: 6.163; standardised coefficient beta: -.038; t: -.400; significance: .690.

Regression

Descriptive Statistics

	Mean	Std. Deviation	N
Foreign percentage (2008-9)	10.075	21.246	112
Factor 1&2 combined (2003-5)	.047	.328	150

Correlations

		Foreign percentage (2008-9)	Factor 1&2 combined (2003-5)
Pearson Correlation	Foreign percentage (2008-9)	1.000	
	Factor 1&2 combined (2003-5)	-.038	1.000
Sig. (1-tailed)	Foreign percentage (2008-9)	.	.345
	Factor 1&2 combined (2003-5)	.345	.
N	Foreign percentage (2008-9)	112	112
	Factor 1&2 combined (2003-5)	112	150

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	Factor 1&2 combined (2003-5)[b]	.	Enter

a. Dependent Variable: Foreign percentage (2008-9)

b. All requested variables entered.

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.038[a]	.001	-.008	21.327

a. Predictors: (Constant), Factor 1&2 combined (2003-5)

b. Dependent Variable: Foreign percentage (2008-9)

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	72.864	1	72.864	.160	.690[b]
	Residual	50032.346	110	454.840		
	Total	50105.210	111			

a. Dependent Variable: Foreign percentage (2008-9)

b. Predictors: (Constant), Factor 1&2 combined (2003-5)

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	10.189	2.035		5.006	.000
	Factor 1&2 combined (2003-5)	-2.467	6.163	-.038	-.400	.690

a. Dependent Variable: Foreign percentage (2008-9)

Coefficient Correlations[a]

Model			Factor 1&2 combined (2003-5)
1	Correlations	Factor 1&2 combined (2003-5)	1.000
	Covariances	Factor 1&2 combined (2003-5)	37.980

a. Dependent Variable: Foreign percentage (2008-9)

Collinearity Diagnostics[a]

Model	Dimension	Eigenvalue	Condition Index	Variance Proportions	
				(Constant)	Factor 1&2 combined (2003-5)
1	1	1.141	1.000	.43	.43
	2	.859	1.152	.57	.57

a. Dependent Variable: Foreign percentage (2008-9)

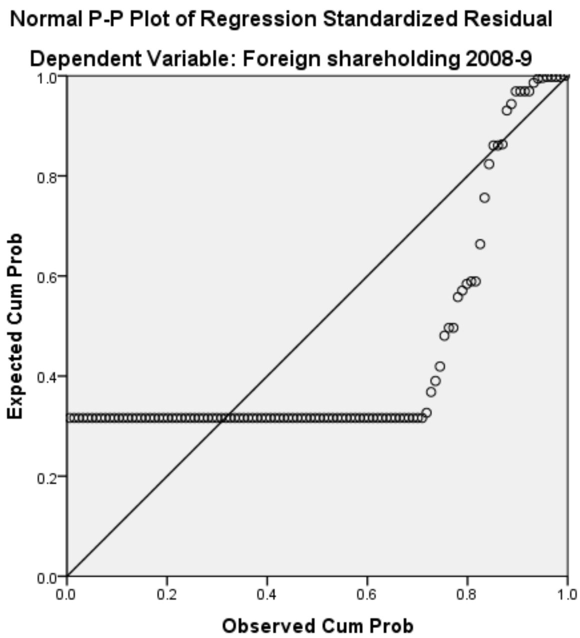
Casewise Diagnostics[a]				
Case Number	Std. Residual	Foreign percentage (2008-9)	Predicted Value	Residual
72	4.211	100.000	10.189	89.811

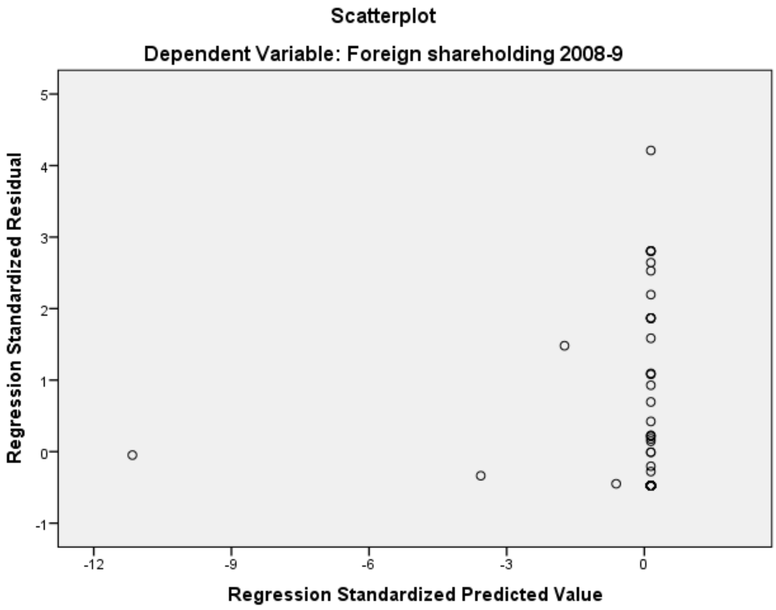
a. Dependent Variable: Foreign percentage (2008-9)

Residuals Statistics[a]					
	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	1.034	10.189	10.075	.810	150
Residual	-10.189	89.811	.0129	21.231	112
Std. Predicted Value	-11.158	.142	.000	1.000	150
Std. Residual	-.478	4.211	.001	.995	112

a. Dependent Variable: Foreign percentage (2008-9)

Charts





Appendix 15: Reverse Causation test 4

```
REGRESSION
  /DESCRIPTIVES MEAN STDDEV CORR SIG N
  /MISSING PAIRWISE
  /STATISTICS COEFF OUTS BCOV R ANOVA COLLIN TOL ZPP
  /CRITERIA=PIN(.05) POUT(.10)
  /NOORIGIN
  /DEPENDENT StateProportion20082009
  /METHOD=ENTER Factor12Combined20032005
  /SCATTERPLOT=(*ZRESID ,*ZPRED)
  /RESIDUALS NORMPROB(ZRESID)
  /CASEWISE PLOT(ZRESID) OUTLIERS(3).
```

The full coefficient results were: unstandardised B: -.169; unstandardised standard error: .317; standardised coefficient beta: -.050; t: -.533; significance: .595.

Regression

Descriptive Statistics

	Mean	Std. Deviation	N
State proportion (2008-9)	2.84	1.098	113
Factor 1&2 combined (2003-5)	.047	.328	150

Correlations

		State proportion (2008-9)	Factor 1&2 combined (2003-5)
Pearson Correlation	State proportion (2008-9)	1.000	
	Factor 1&2 combined (2003-5)	-.050	1.000
Sig. (1-tailed)	State proportion (2008-9)	.	.298
	Factor 1&2 combined (2003-5)	.298	.
N	State proportion (2008-9)	113	113
	Factor 1&2 combined (2003-5)	113	150

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	Factor 1&2 combined (2003-5)[b]	.	Enter

a. Dependent Variable: State proportion (2008-9)

b. All requested variables entered.

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.050[a]	.003	-.006	1.102

a. Predictors: (Constant), Factor 1&2 combined (2003-5)

b. Dependent Variable: State proportion (2008-9)

ANOVA[a]						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.344	1	.344	.284	.595[b]
	Residual	134.788	111	1.214		
	Total	135.133	112			

a. Dependent Variable: State proportion (2008-9)

b. Predictors: (Constant), Factor 1&2 combined (2003-5)

Coefficients[a]						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	2.849	.105		27.205	.000
	Factor 1&2 combined (2003-5)	-.169	.317	-.050	-.533	.595

a. Dependent Variable: State proportion (2008-9)

Coefficient Correlations[a]			
Model			Factor 1&2 combined (2003-5)
1	Correlations	Factor 1&2 combined (2003-5)	1.000
	Covariances	Factor 1&2 combined (2003-5)	.100

a. Dependent Variable: State proportion (2008-9)

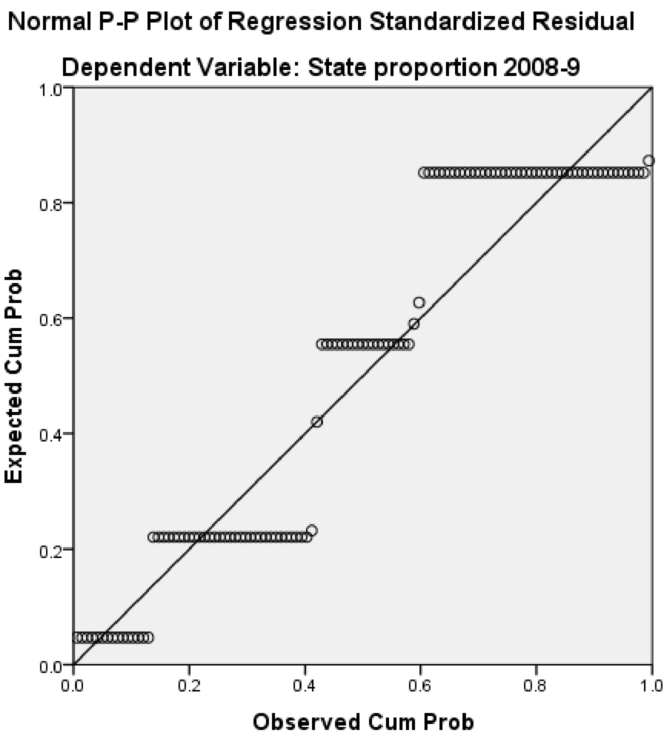
Collinearity Diagnostics[a]					
Model	Dimension	Eigenvalue	Condition Index	Variance Proportions	
				(Constant)	Factor 1&2 combined (2003-5)
1	1	1.141	1.000	.43	.43
	2	.859	1.152	.57	.57

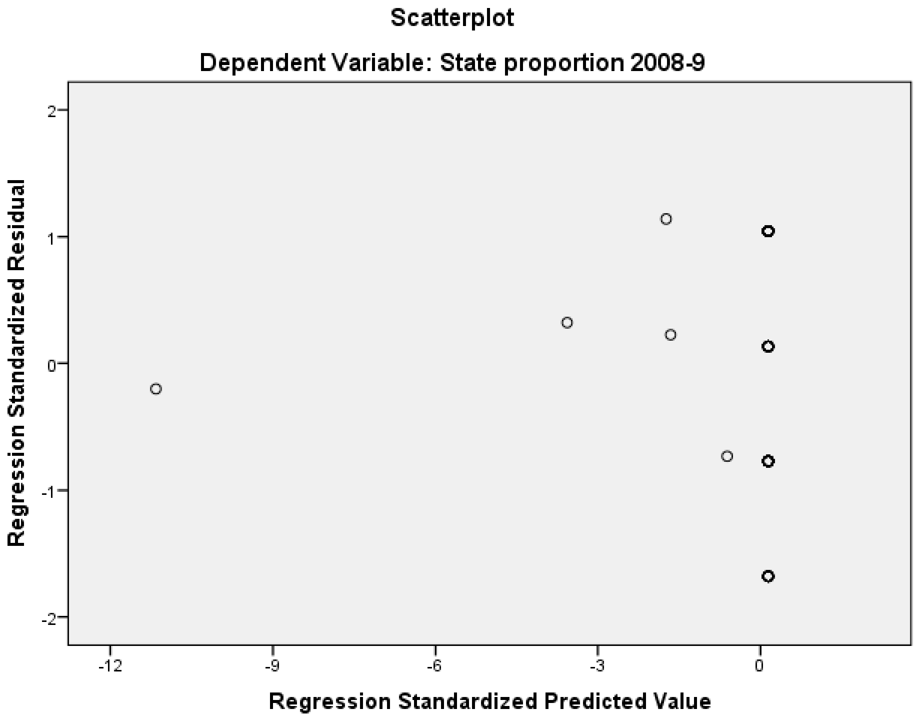
a. Dependent Variable: State proportion (2008-9)

Residuals Statistics[a]					
	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	2.22	2.85	2.84	.055	150
Residual	-1.849	1.256	.002	1.097	113
Std. Predicted Value	-11.158	.142	.000	1.000	150
Std. Residual	-1.678	1.140	.002	.996	113

a. Dependent Variable: State proportion (2008-9)

Charts





Appendix 16: Reverse Causation test 5

```
REGRESSION
  /DESCRIPTIVES MEAN STDDEV CORR SIG N
  /MISSING PAIRWISE
  /STATISTICS COEFF OUTS BCOV R ANOVA COLLIN TOL ZPP
  /CRITERIA=PIN(.05) POUT(.10)
  /NOORIGIN
  /DEPENDENT StateLevel20082009
  /METHOD=ENTER Factor12Combined20032005
  /SCATTERPLOT=(*ZRESID ,*ZPRED)
  /RESIDUALS NORMPROB(ZRESID)
  /CASEWISE PLOT(ZRESID) OUTLIERS(3).
```

The full coefficient results were: unstandardised B: .209; unstandardised standard error: .416; standardised coefficient beta: .061; t: .502; significance: .617.

Regression

Descriptive Statistics			
	Mean	Std. Deviation	N
Level of state (2008-9)	2.16	1.120	69
Factor 1&2 combined (2003-5)	.0465	.328	150

Correlations			
		Level of state (2008-9)	Factor 1&2 combined (2003-5)
Pearson Correlation	Level of state (2008-9)	1.000	
	Factor 1&2 combined (2003-5)	.061	1.000
Sig. (1-tailed)	Level of state (2008-9)	.	.309
	Factor 1&2 combined (2003-5)	.309	.
N	Level of state (2008-9)	69	69
	Factor 1&2 combined (2003-5)	69	150

Variables Entered/Removed[a]			
Model	Variables Entered	Variables Removed	Method
1	Factor 1&2 combined (2003-5)[b]	.	Enter

a. Dependent Variable: Level of state (2008-9)
b. All requested variables entered.

Model Summary[b]				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.061[a]	.004	-.011	1.126

a. Predictors: (Constant), Factor 1&2 combined (2003-5)
b. Dependent Variable: Level of state (2008-9)

ANOVA[a]						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.319	1	.319	.252	.617[b]
	Residual	84.927	67	1.268		
	Total	85.246	68			

a. Dependent Variable: Level of state (2008-9)

b. Predictors: (Constant), Factor 1&2 combined (2003-5)

Coefficients[a]						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	2.150	.137		15.702	.000
	Factor 1&2 combined (2003-5)	.209	.416	.061	.502	.617

a. Dependent Variable: Level of state (2008-9)

Coefficient Correlations[a]			
Model			Factor 1&2 combined (2003-5)
1	Correlations	Factor 1&2 combined (2003-5)	1.000
	Covariances	Factor 1&2 combined (2003-5)	.173

a. Dependent Variable: Level of state (2008-9)

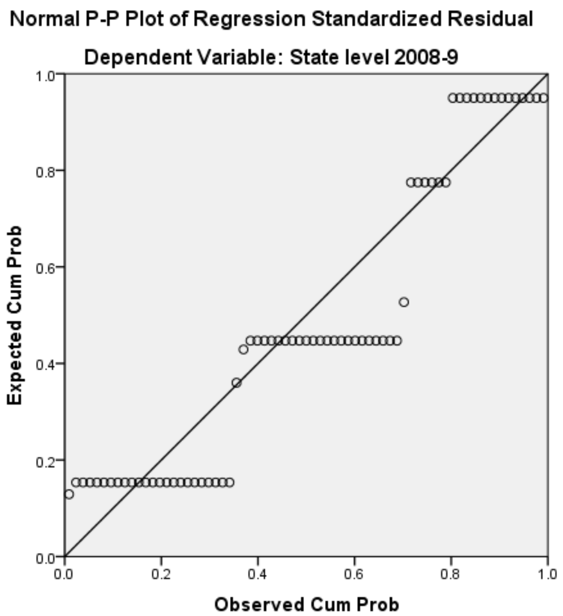
Collinearity Diagnostics[a]					
Model	Dimension	Eigenvalue	Condition Index	Variance Proportions	
				(Constant)	Factor 1&2 combined (2003-5)
1	1	1.141	1.000	.43	.43
	2	.859	1.153	.57	.57

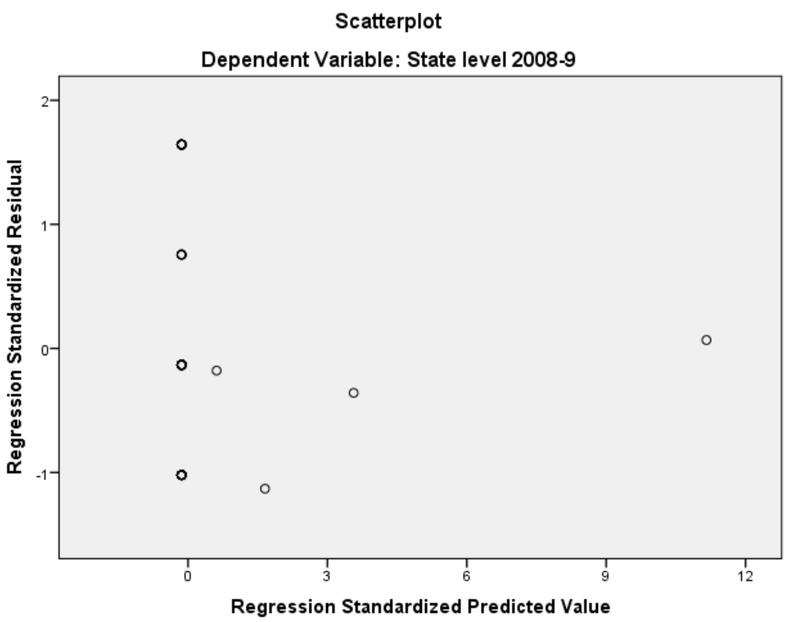
a. Dependent Variable: Level of state (2008-9)

Residuals Statistics[a]	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	2.15	2.92	2.16	.069	150
Residual	-1.273	1.850	-.008	1.118	69
Std. Predicted Value	-.142	11.158	.000	1.000	150
Std. Residual	-1.131	1.643	-.007	.993	69

a. Dependent Variable: Level of state (2008-9)

Charts




Scatterplot
Dependent Variable: State level 2008-9
Regression Standardized Residual
Regression Standardized Predicted Value
2
1
0
-1
0
3
6
9
12

Appendix 17: Hypothesis 6b full correlations

Correlations

		Annual average output of both factors for each firm 2008-2012	Firm staff or firm PV arm staff (current)	SOEs	MASOEs	MISOEs	POEs	Firm HQ province GDP per capita	Age of the firm	Firm agglomeration rating
Pearson Correlation	Annual average output of both factors for each firm 2008-2012	1.000								
	Firm staff or firm PV arm staff (current)	.438	1.000							
	SOEs	-.076	.143	1.000						
	MASOEs	-.144	-.173	-.258	1.000					
	MISOEs	.194	.197	-.157	-.289	1.000				
	POEs	.042	-.079	-.306	-.572	-.352	1.000			
	Firm HQ province GDP per capita	-.010	-.103	-.083	-.050	.020	.082	1.000		
	Age of the firm	.106	.230	.387	-.053	-.069	-.155	-.179	1.000	
	Firm agglomeration rating	.109	.082	-.159	-.160	-.010	.266	.533	-.156	1.000
Sig. (1-tailed)	Annual average output of both factors for each firm 2008-2012	.	.000	.178	.041	.009	.303	.452	.105	.093

	Firm staff or firm PV arm staff (current)	.000	.	.041	.018	.008	.168	.105	.003	.159
	SOEs	.178	.041	.	.001	.027	.000	.155	.000	.026
	MASOEs	.041	.018	.001	.	.000	.000	.272	.270	.026
	MISOEs	.009	.008	.027	.000	.	.000	.403	.210	.454
	POEs	.303	.168	.000	.000	.000	.	.159	.034	.001
	Firm HQ province GDP per capita	.452	.105	.155	.272	.403	.159	.	.017	.000
	Age of the firm	.105	.003	.000	.270	.210	.034	.017	.	.033
	Firm agglomeration rating	.093	.159	.026	.026	.454	.001	.000	.033	.
N	Annual average output of both factors for each firm 2008-2012	150	150	150	148	150	150	150	140	150
	Firm staff or firm PV arm staff (current)	150	150	150	148	150	150	150	140	150
	SOEs	150	150	150	148	150	150	150	140	150
	MASOEs	148	148	148	148	148	148	148	138	148
	MISOEs	150	150	150	148	150	150	150	140	150
	POEs	150	150	150	148	150	150	150	140	150
	Firm HQ province GDP per capita	150	150	150	148	150	150	150	140	150
	Age of the firm	140	140	140	138	140	140	140	140	140
	Firm agglomeration rating	150	150	150	148	150	150	150	140	150

Appendix 18: *ANOVA testing for Hypothesis 8b core technologies*.

Descriptives

Percent factors tech type C

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
1	28	67.93	32.224	6.090	55.43	80.42	0	100
2	30	86.30	27.171	4.961	76.15	96.45	0	100
3	12	76.75	34.014	9.819	55.14	98.36	0	100
4	19	81.16	30.325	6.957	66.54	95.77	0	100
Total	89	78.13	30.866	3.272	71.63	84.64	0	100

NB: the means above, as with all the related figures, refer to percentages.

Test of Homogeneity of Variances

Percent factors tech type C

Levene Statistic	df1	df2	Sig.
1.229	3	85	.304

ANOVA

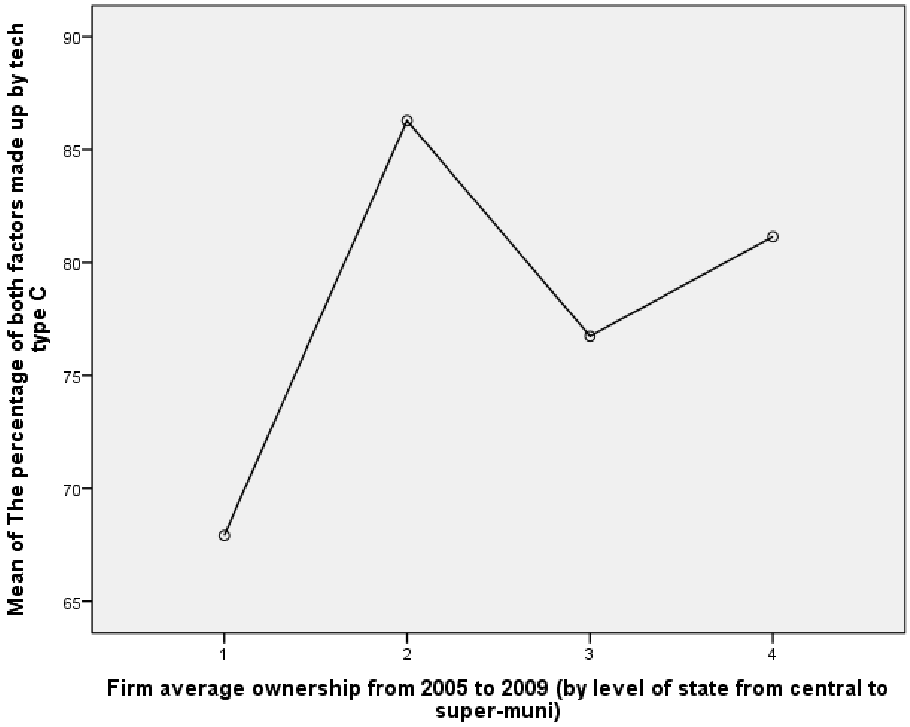
Percent factors tech type C

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	5113.449	3	1704.483	1.840	.146
Within Groups	78724.933	85	926.176		
Total	83838.382	88			

Robust Test of Equality of Means				
Percent factors tech type C				
	Statistic[a]	df1	df2	Sig.
Welch	1.805	3	35.974	.164
Brown-Forsythe	1.748	3	58.151	.167
a. Asymptotically F distributed.				

Contrast Coefficients				
Contrast	Firm average ownership from 2005 to 2009 (by level of state from central to super-muni)			
	1	2	3	4
1	-3	1	1	1

Contrast Tests							
		Contrast	Value of Contrast	Std. Error	t	df	Sig. (2-tailed)
Percent factors tech type C	Assume equal variances	1	40.42	21.319	1.896	85	.061
	Does not assume equal variances	1	40.42	22.432	1.802	49.434	.078



Appendix 19: *ANOVA testing for Hypothesis 8c related technologies.*

Descriptives

Percent factors tech type R

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean Lower Bound	95% Confidence Interval for Mean Upper Bound	Minimum	Maximum
1	28	17.75	27.151	5.131	7.22	28.28	0	100
2	30	7.73	21.310	3.891	-.22	15.69	0	100
3	31	9.55	22.705	4.078	1.22	17.88	0	100
Total	89	11.52	23.879	2.531	6.49	16.55	0	100

Test of Homogeneity of Variances

Percent factors tech type R

Levene Statistic	df1	df2	Sig.
2.409	2	86	.096

ANOVA

Percent factors tech type R

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	1637.431	2	818.715	1.451	.240
Within Groups	48538.794	86	564.405		
Total	50176.225	88			

Robust Tests of Equality of Means

Percent factors tech type R

	Statistic[a]	df1	df2	Sig.
Welch	1.260	2	56.040	.292
Brown-Forsythe	1.434	2	79.840	.245

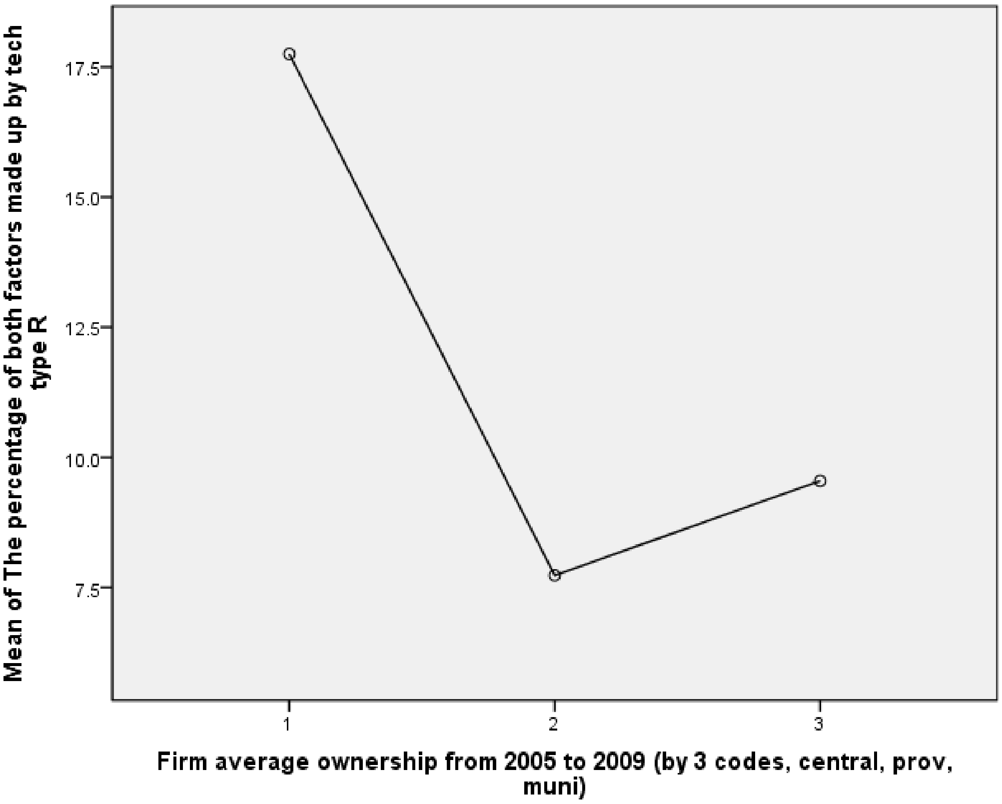
a. Asymptotically F distributed.

Contrast Coefficients

Contrast	Firm average ownership from 2005 to 2009 (by 3 codes, central, prov, muni)		
	1	2	3
1	2	-1	-1

Contrast Tests

		Contrast	Value of Contrast	Std. Error	t	df	Sig. (2-tailed)
Percent factors tech type R	Assume equal variances	1	18.22	10.847	1.680	86	.097
	Does not assume equal variances	1	18.22	11.708	1.556	43.916	.127


Mean of The percentage of both factors made up by tech type R
17.5
15.0
12.5
10.0
7.5
1
2
3
Firm average ownership from 2005 to 2009 (by 3 codes, central, prov, muni)