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Optimal Control, the UK Economy and the International Oil Market

by

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to my parents

Abstract

This thesis analyses the macroeconomic effects of UK oil production on the UK economy. We argue that the literature dealing with this problem to date has disregarded any interaction of the UK economy with other economic agents in the world economy. Instead we extend the ‘narrow’ conventional analytical framework by incorporating the interactions of the UK economy and the international oil market. The analysis is conducted with two macroeconomic models — one featuring the UK economy, the other relating to the international oil market. The models are combined and solved as an interdependent system. The implicit contention that there is an interaction between the two independent models is tested and established. This provides new results as far as the macroeconomic effects are concerned, and it also opens the door for the application of game theoretic concepts to the analysis. Within this generalised framework, optimal economic policies are designed both for the UK and for OPEC — the dominant force in the international oil market — first in isolation by disregarding any interaction with others and then by considering two multi-player games, of which one is a non-cooperative Nash game and the other a cooperative Pareto game.

The theoretical underpinning of the UK macroeconomic model is an extension of the Dornbusch (1976) model of exchange rate determination. We argue that the Dornbusch model lacks a feedback mechanism from trade flows onto the rest of the model. Our model incorporates such a mechanism and provides different, less recessionary results.

The model of the international oil market is adapted from Baldwin and Prosser (1987). OPEC is assumed to equilibrate demand and supply by adjusting its oil production. The oil price depends on the capacity utilisation of OPEC’s oil production.

The estimation of both models follows the methodology of Hendry and Richards (1982, 1983), and Engle and Granger (1987). This stresses misspecification testing; and allows the data to determine short run fluctuations, and economic theory to determine the long run.

Acknowledgements

Having been through confinement to a small office with just some books and a computer for a number of years, I now know how easy it is to be very self-centred and to forget that producing a PhD thesis is hard and perhaps impossible to achieve without the help of many others. In order to appreciate the help I have received, imagine a ship: you have the captain who decides where to go, and you have those who keep the vessel in good working order. The ship wouldn't reach its destination if anybody was missing — everyone is equally important.

Starring in the role of the captain was my supervisor, Dr Elias Karakitsos. I am grateful to him for a series of vital meetings, in which he clarified my research task and ensured with great patience that I was not losing direction. Of those who kept my thesis and me in good working order, my greatest debt undoubtedly is to Robin Becker, whose simulation program I have used. Throughout my research I have tried many econometric software packages but not come across any that would match his in complexity, clarity and ease of use. As if that wasn't enough already, Robin also provided many pointers out of situations where I had got stuck.

I am also grateful to Dr Berç Rustem for his friendly and encouraging advice, to Dr Richard Prosser for many useful discussions about the international oil market and other matters, and to Dr Sailesh Tanna for reading parts of my thesis and again for many useful discussions. John Nicholles has earned my gratitude by proof-reading most of the chapters, and Dr Norman Murray simply by being patient.

If so far you have the impression that doing a PhD thesis is learning just about one area and nothing else, I have misled you. Helping me to relax from economics and to re-open my narrowed horizon were a number of dear friends. First among equals in this respect came Mohan Krishnamoorthy and Yazid Sharaiha, without whom I might have finished my degree sooner but learned less. These two were closely followed by Andy Beck, Merza Hassan, Nathan Joseph, Dulce Lopes, Niki Niktari, Ibrahim Osman, Paek Gwan Ho, Dimitri Paraskevopoulos, and my two Chinese friends Yang Guang and Yu Jiping.

Errata

Page 80, in footnote 17; replace

. . . listed in Table 4.3 on page 30.

with

. . . listed in Table 4.3 on page 88.

Page 84, in footnote 26; replace

See page 30.

with

See page 88.

Page 113, first paragraph; insert new sentence (in bold) as follows:

. . . The increased competition caused the oil price to decline and, in turn, lowered the oil companies' profits. **In February 1959 for example, the "posted price" of Arabian Light is below 2 \$ per barrel.** But since the tax revenues accruing to the oil producing countries were based on these profits, . . .

Page 113, first sentence, third paragraph; insert new sub-clause (in bold) as follows:

For these reasons, **and after a renewed reduction of the "posted price" of Arabian Light in the summer of 1960 to 1.86 \$ per barrel,** the producing countries combined forces in OPEC . . .

Page 115, replace first sentence of Section 5.3

Because OPEC caused the two price explosions in the 1970s [. . .] concerned with the explanation of OPEC pricing behaviour.

with:

We have seen that since the late 1960s OPEC was able to increase steadily its market power and thereby its ability to set oil prices. This is reflected in the two price explosions in the 1970s, which catapulted the oil market from the relative calmness of the late 1960s into the limelight for world

attention. Most modelling studies of the international oil market, therefore, are basically concerned with the explanation of OPEC pricing behaviour.

Page 134; replace Section 5.4.2.1 with:

5.4.2.1 Specification of supply side

The specification of the supply side considers both geological as well as economic factors, whereby the incorporation of geological factors is based on Hubbert's work.²⁷ As mentioned above, Hubbert postulates that the life time cumulative production profile can be approximated by a logistic curve. Production, however, is preceded by discovery and the methodological steps of producing a geological production profile would therefore involve first to estimate a logistic curve for cumulative discoveries, to lag this by a fixed time interval in order to obtain the corresponding logistic curve for cumulative geological supply, and then to differentiate this function to derive annual production figures. However, as Baldwin and Prosser (1987, p.26/7) point out, data problems make this avenue difficult to take. As a simplification, the logistic curve for cumulative geological supply can be estimated directly using readily available supply data. Consider

$$CGS_t = \frac{URS}{1 + A \cdot e^{-\frac{t}{a}}}, \quad (5.1)$$

where CGS_t is the cumulative geological supply at time t , URS is the ultimate recoverable supply of oil, and A and a are constants. The above cumulative geological supply curve can be estimated in its logarithmic form

$$\ln\left(\frac{URS}{CGS_t} - 1\right) = \beta_0 + \beta_1 t + \epsilon_t, \quad (5.2)$$

where $\beta_0 = \ln A$, $\beta_1 = -\frac{1}{a}$, and ϵ_t is the error term. Since URS is unknown, this equation has to be estimated iteratively by substituting different values for URS such that the residual sum of squares of the

²⁷see the discussion in Section 5.3.2, and Renshaw and Renshaw (1980) as a reference.

equation is minimised. Working backwards, the geological annual production curve can be determined by

$$GS_t = \frac{dCGS_t}{dt} = CGS_t - CGS_{t-1}, \quad (5.3)$$

where GS_t is the geologically determined supply at time t . Similarly to equation (5.2) and as a check for consistency, the cumulative discovery curve can be estimated by

$$\ln\left(\frac{URS}{CD_t} - 1\right) = \gamma_0 + \gamma_1 t + u_t, \quad (5.4)$$

where CD is cumulative discoveries and the other terms are as above. And lastly, the proven reserves can be determined using the following identity

$$R_t = CD_t - \sum S_t, \quad (5.5)$$

where $\sum S_t$ stands for the summation of each S value over the whole time period. The equation that was estimated for each of the supply blocks was of the form

$$S_t = F(GS_{t-i}, S_{t-j}, P_{t-i}), \quad (5.6)$$

where $0 \leq i \leq 3$, and $1 \leq j \leq 3$; P is the oil price. That is, actual supply was postulated to be a function, F , of the geological supply trend, lagged values of actual supply, and the oil price.

Page 135, fourth line from bottom; replace

... the CS^u that minimises the RSS ...

with:

... the URS that minimises the RSS ...

Page 136, first line; replace

... geological supply trends — as outlined above — which in turn ...

with:

... geological supply trends — based on equation (5.2) — which in turn ...

Page 136, first line of Table 5.4; replace

$$\ln \frac{CSNA^u}{CSNA} = 1.052 - 0.070 * TIME$$

(311.85) (303.41)

with:

$$\ln \left(\frac{URSN A}{CSNA} - 1 \right) = 1.052 - 0.070 * TIME$$

(311.85) (303.41)

Page 136, first line of Table 5.5; replace

$$\ln \frac{CSONOUK^u}{CSONOUK} = 3.154 - 0.085 * TIME$$

(183.19) (71.99)

with:

$$\ln \left(\frac{URSONOUK}{CSONOUK} - 1 \right) = 3.154 - 0.085 * TIME$$

(183.19) (71.99)

Page 214, insert the following after bottom line:

An alternative extension to the nature of the games analysed here would be to incorporate the other non-OPEC oil producing countries as players into the games played. This would shed a more realistic light on the working of the international oil market as differences in national oil policies could be considered. An example may be the different approach to oil extraction that is taken in the UK and in Norway.

Finally, further interesting results might be obtained by relaxing the present assumption of a fixed proportion of UK oil that is exported.

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Chapter 1

Introduction and Overview

In 1975 UK oil exploitation was 1 million tonnes, by 1985 it had reached 128 million tonnes. With oil consumption averaging about 85 million tonnes each year, this transformed the UK economy from an oil importer into a substantial net oil exporter. Combined with the two main oil price increases in the 1970s, the British economy was suddenly benefiting from an income source as unexpected 'as 'manna from heaven'. Soon after exploitation had begun, a lively public debate started about what to do with the growing income source.¹ Economic advice for the government as the owner of the resource and hence the prime beneficiary was based on several areas of research.

The first concerns the macroeconomic implications of the oil discovery and exploitation. Of interest here are the effects on some of the main macroeconomic variables — GDP and the exchange rate — and more particularly on the evolution of the trading and service sectors of the economy. Economic theories dealing with these issues are often categorised as belonging to the 'Dutch Disease' literature, because after discovering and exploiting large natural gas resources the Netherlands saw its service sector grow at the expense of its traditionally stronger manufacturing sector. Much of the Dutch Disease literature is concerned with this seeming paradox, according to which it is impossible for a resource owner to exploit the resource without harming his manufacturing (trading) sector. The economic analysis is generally conducted in a comparative static framework, evaluating the gains and losses between two steady states — before and after the resource discovery or exploitation.

The second area of research from which advice was drawn is concerned with resource exploitation in an intertemporal framework. Comparative static analysis usually aims at answering questions of a general nature; in the case of the Dutch Disease phenomena, whether the manufacturing sector of a resource

¹see for example the debate of Bank of England (1980) versus Forsyth and Kay (1980).

exploiting economy inevitably must decline. It is, however, not endowed with the means to answer specific questions about when and how much of the resource should be exploited. This is left to the theory of exhaustible resources to which Hotelling (1931) first drew attention.² The theory of exhaustible resources addresses the question of how a resource owner can maximise his wealth over the lifetime of the resource. The study of this problem, however, is fraught with difficulties and therefore seldom used in short term policy making for two main reasons.

First, since the main part of the time horizon under investigation usually lies in the future, assumptions about the forecasts of many variables have to be made. These cover the ultimately recoverable size of the resource, its likely price path, as well as the evolution of many macroeconomic time series. This, of course, increases the uncertainty of the theory's predictions and hence renders it less practicable as a decision making instrument for policy makers.

A second difficulty is posed by the analytical tools that are used in the theories of exhaustible resources. Although the analytic solution to a linear, quadratic optimisation problem is simple to understand, that of a complex, more realistic — and hence nonlinear — optimisation problem requires numerical techniques and can be a formidable task for a large model. In order to keep problems analytically tractable, most theories of exhaustible resources therefore consider relatively simple problems. These may be elegant but also open to criticism from practitioners who are more interested in results of practical relevance.

A further weakness of traditional theories of exhaustible resources is the assumption of a single resource owner. While this may be an appropriate assumption for a resource whose supply is dominated by a single owner³ (or a few dominant owners), the discovery of oil in many countries and the emergence of OPEC — the Organisation of Petroleum Exporting Countries — as a major player in the oil market have pointed to the market form as an important determinant of resource exhaustion.⁴ This has led to an expansion of research into the area of game theory, where the interaction of several oil suppliers with the international demand for oil can be studied.

²see Dasgupta and Heal (1979) for extensive coverage of many aspects of resource allocation.

³The example of diamonds springs to mind, where the South African De Beers company dominates the international supply of diamonds.

⁴see Stiglitz and Dasgupta (1982).

The major contribution of this thesis is with the study of the macroeconomic effects of North Sea oil on the UK economy by extending the analytical framework to incorporate the interactions between the UK economy and the international oil market. Two independent macroeconometric models — of the UK economy and of the international oil market — are developed and combined in a game theoretic framework in order to aid in the analysis of those issues. Within this framework, optimal economic policies are designed for the UK economy and for the dominant force in the international oil market, OPEC. So far, studies applying optimal control techniques to this area have disregarded the interrelationship between the UK and the international oil market and instead viewed the latter as an external force beyond the influence of the oil policies of the UK.

This thesis consists of eight chapters. In the next chapter we review the literature of the three related research areas — optimal resource extraction, Dutch Disease problems and applications of game theory to macroeconomic policy making in an international setting. The chapter concludes by pointing out deficiencies in the literature, and as such provides the justification for the present study. One of the gaps in the literature on Dutch Disease problems has given the impetus for Chapter 3, where a theoretical model of exchange rates, asset accumulation and oil extraction is presented. The main experimental vehicle of this study is a combined econometric model that consists of two sub-models — one covering the UK economy and the other describing the international oil market. The estimation and specification of these models is the subject of Chapters 4 and 5 at large. Chapter 4 also includes a survey of the estimation methodology and techniques that are prevalent in the literature. Chapter 5, in addition, conducts a survey of modelling attempts of the international oil market. The dynamic solution of the interrelated model, an assessment of its historical tracking record and its simulation properties are all presented in Chapter 6. The chapter also contains some important results, which confirm the *raison d'être* of this study, namely the inclusion of the international oil market in an analysis of the effects of North Sea oil on the UK economy. In Chapter 7, we present four optimisation exercises in a game theoretic context in order to explore the gains and losses that the UK and OPEC incur as participants in an interdependent economic system. Chapter 8 concludes this thesis with a summary of the presented work and suggestions for future research.

Chapter 2

Literature Survey and Formulation of Problem

2.1 INTRODUCTION

This chapter is concerned with a survey of the three areas of literature that are related to the task of this study — the analysis of the impacts of oil on the UK economy within a much wider framework than has hitherto been used.

The next section surveys the Dutch Disease literature, a body of research that analyses macroeconomic the effects of discovery and exploitation of a natural resource, such as oil, within a comparative static framework. In Section 3, there is a review of research that has changed the analysis from a static mode into a dynamic one and is mainly concerned with the analysis of optimal depletion policies. Section 4, the last review section, deals with applications of game theory. The various strands of the literature are summarised in Section 5 and formulated in such a way as to justify this study.

2.2 MACROECONOMIC IMPACTS OF RESOURCE DISCOVERIES

The term Dutch Disease was coined because the discovery of natural gas in the Netherlands led to a shrinking Dutch manufacturing sector, essentially through an appreciation of the Dutch exchange rate. Because of this example the theoretical literature's central problem is whether a resource discovery necessarily implies a contraction of exporting and import-competing industries. Of secondary interest is the question whether, and if so to what extent, government policies are required to reinforce or weaken the resulting change in the economy.

2.2.1 Theory

In dealing with the first of these two aspects the Dutch Disease literature generally divides the overall effects of a resource discovery, or those of a booming sector in general, into two sub-effects: a spending effect and a resource movement effect. The spending effect captures the following chain of events. As a result of the resource discovery the wealth of the economy rises, which will push up the demand for consumer goods. The next element in the chain of events depends crucially on the assumption that is usually made in the analysis of Dutch Disease problems, namely the assumption that the producing country is small in relation to the rest of the world. If this assumption is made the price of the country's manufacturing goods, which it also exports, is determined by world markets and therefore beyond any influence of the producing country. This given, a higher level of domestic demand will lead to a large increase in the price of services relative to the price of manufactures. This is because demand for manufactures can be satisfied by increased imports, the price of domestic manufactured goods will therefore only be pushed up if domestic and foreign manufactures are imperfect substitutes; in this case, the country's terms of trade improve, as foreign prices of manufactures remain constant. Higher demand for domestic services, however, can only be compensated for by a large increase in the price of domestic services, which is equivalent to an appreciation of the real exchange rate.

The second sub-effect, the resource movement effect, describes how the increased consumer demand level will ultimately lead to a changed supply pattern of the economy. Higher demand will first influence the demand for various production factors. To satisfy the high demand in the service sector, factor production rewards will be increased there, which means that production factors will be moved out of the manufacturing sector and moved into the service sector as well as into the booming sector. The new overall level of supply in the economy will then be composed of an increased output level of the service and booming sector and a decline in output of the manufacturing sector, a characteristic that is commonly termed as de-industrialisation. The resource movement effect is of course critically dependent upon the mobility of the production factors, labour and capital, as well as upon the capital and labour intensity of the industrial sector that caused the boom.

It is clear from this general overview that the movements of the real exchange rate play a crucial role in the transmission of the effects that are caused by a resource discovery. Not surprisingly, therefore, have modellers of resource discoveries in relation to Dutch Disease phenomena borrowed from the literature of exchange rate determination. The main source has been the asset market approach to exchange rate determination. This theory originally developed by Fleming (1962) and Mundell (1963) allows assets to be traded internationally. Although their stock size does not enter the theory, assets are represented by their rates of return, i.e. by the respective interest rates. The assumption of perfect substitutability of domestic and foreign assets means that their expected returns are equal. This, combined with the naive assumption of static expectations produces the result that the actual rates of return are equal, i.e. that the domestic interest rate equals the foreign rate. When, however, the simple static expectations scheme is substituted by some other, more sophisticated scheme, domestic and foreign interest rates are no longer equal; instead, there exists the potential for capital gains. Dornbusch (1976) in his further development of the asset market approach incorporated this idea and introduced some other, new features. Specifically, he firstly assumed that exchange rate expectations are formed rationally. Secondly, he endogenised the domestic price level. Thirdly, he assumed a slower adjustment process for asset markets than for goods markets. This third assumptions leads to the well-known result that the exchange rate may overshoot its long term stationary value when the economy adjusts slowly from the previous equilibrium price level to its new equilibrium price level.

As mentioned above, modellers of resource discoveries have readily adopted the assets approach to exchange rate determination in general, and Dornbusch's model in particular. An early and influential paper was that by Eastwood and Venables (1982) whose model assumptions closely follow Dornbusch's, namely perfect international capital mobility, rational exchange rate expectations, and sluggish adjustment of domestic goods prices. In addition, nominal money supply is assumed to be fixed. Their answer to the above mentioned central question of Dutch Disease economics — whether a resource discovery will necessarily lead to a recession in the manufacturing sector — is quite optimistic. For they argue that if the spending spree that follows a resource discovery is allowed to adjust immediately no recession will occur. Even for the more realistic case where there is some time lag between the announcement of the discovery and the start of exploitation and hence

spending, Eastwood and Venables' model predicts that the ensuing recession will be short-lived and be followed by a boom period as soon as spending has adjusted.

These findings have been criticised subsequently as incomplete. Neary and van Wijnbergen (1984), for example, admonish a missing wealth effect on asset markets in Eastwood and Venables' model. In their own model, which is an amended version of Eastwood and Venables' model, this effect is incorporated into the equation of demand for real money balances. In comparison to the Eastwood and Venables model, the amended model predicts a greater appreciation of the nominal exchange rate and a lower domestic price level, which for some parameter values may even be lower than that during the period before the resource discovery. The economic predictions are therefore more pessimistic than those made by Eastwood and Venables. For example, the boom that followed a mild recession in the Eastwood and Venables model in the case of a spending lag does not occur in Neary and van Wijnbergen's model. Instead, the recession that results in both models is here deeper and longer. The economic reason for this is that the increase in wealth pushes up the demand for real money balances. Since, however, nominal money supply is not allowed to expand, this has a dampening effect on the general economic activity, which may even be greater than the expansionary spending effect that follows a resource discovery.

Buiter and Purvis (1983) also show the Eastwood and Venables outcome as too optimistic. Although based on similar assumptions as Eastwood and Venables, the Buiter and Purvis model reaches more recessionary conclusions. The core of their model is again derived from the exchange rate model of Dornbusch (1976); it assumes perfect foresight in asset market behaviour, but domestic prices adjust sluggishly. Another important assumption is that of an exogenous nominal money supply growth. But whereas Eastwood and Venables reach fairly optimistic results for the economic development, Buiter and Purvis show that even when steady-state non-oil output is fixed there are temporary negative effects on manufacturing output in the wake of a resource discovery. Essentially this derives from the 'Dornbusch' outcome that the exchange rate overshoots its long term value to keep the equilibrium in the assets markets.

Although these results seem to imply a general agreement among researchers that some Dutch Disease effects will have to be borne by the economy,

Bean (1986) points out that the models derived from Dornbusch (1976) depend crucially on two assumptions: on a non-accommodating monetary policy, and on sluggish adjustment of nominal domestic prices. With regard to what type of monetary policy should be incorporated into the model, Bean argues that only since 1979 when, in the wake of the the UK government's Medium Term Financial Strategy, target growth rates for £M3 were announced for a three-year period ahead, does the assumption of a non-accommodating monetary policy seem justified. Furthermore, even though the Government has reiterated its wish to fight inflation, the importance of announcing target growth rates of money supply has ceded in recent years. This was largely because of the inherent difficulty in controlling the actual money supply growth. Bean also points to a number of studies that cannot find any evidence of nominal inertia in the medium term, even though its existence in the short term is not doubted.

Another criticism against Dornbusch's model has been levelled by Kawai (1985). The basis of the asset approach to exchange rate determination is of course that demand and supply conditions in the asset markets determine the exchange rate, but what Dornbusch fails to consider is a feedback of a possible imbalance in the current account on the state of the asset markets. Without this extra loop, a country would be able to run current account deficits for ever, and would not be penalised for it by a resulting fall in the exchange rate. In Kawai's model this extra feedback mechanism is added to the other well-known features of Dornbusch's model. Since part of the analysis is aimed at short run monetary-fiscal policy effects on real output, Kawai has also added a government budget constraint to his model as another piece of realism. His findings are that instantaneous exchange rate overshooting is not a necessary consequence of most policy measures, but occurs only under special circumstances. For example, when the exchange rate declines in the long run, overshooting only occurs as a response to a monetary expansion if the interest rate declines too. Moreover, a fiscal expansion may or may not lead to exchange rate overshooting. However, even though instantaneous overshooting may not occur, Kawai finds that the exchange rate may still overshoot its long run value during its dynamic adjustment process.

Kawai's basic idea of closing the loop of influence between exchange rate and current account has been taken up by Karakitsos (1989). He extends Kawai's model in four ways: by adding one more type of asset (foreign currency), by allowing for imperfect asset substitutability, by assuming that

trade flows adjust slowly to changes in relative prices, and by incorporating an endogenous capital effect onto investment, which makes the model non-neutral in the long run. The model is solved numerically because its complexity makes an analytical solution impossible. Karakitsos shows that the real exchange rate dynamics are much more complex than in simple Dornbusch-type models. Instead of causing the usual monotonic exchange rate adjustment, a monetary contraction in Karakitsos's model leads to a cyclical behaviour of the exchange rate path, where appreciation and depreciation alternate. These cycles always occur, but the degree of asset substitutability and the speed of adjustment in the goods markets influence their shape. For example, when wages in the labour market respond sluggishly, impact overshooting increases as the degree of asset substitutability rises. Since trade flows are realistically assumed to adjust only after some time, they do not influence the initial exchange rate adjustment path — and hence do not cause any overshooting or undershooting — but influence greatly the subsequent adjustment path of the real exchange rate.

2.2.2 Policy responses to Dutch Disease phenomena

It was mentioned in the introduction to Dutch Disease phenomena that a second aspect of the literature is the question whether government policies are required to modify the negative macroeconomic impacts of a resource discovery — a contraction of the manufacturing sector and some unemployment in the sector. Enders and Herberg (1983) discuss the policy demands that are likely to be brought up.

A bond financed demand policy to counter the contraction of the manufacturing sector is found to be ineffective, essentially because the decline of the manufacturing sector was not caused by a lack of demand — indeed demand for its products has risen consequent upon the spending effect. The culprit was rather the sector's inability to raise its price simultaneously with the price rise in the service sector; it was this real exchange rate appreciation that caused a relative decline in the sector's profitability and the subsequent demise of part of the sector.

A second policy that is often proposed is a general nominal wage freeze. The economics of this proposal seem sensible, as profitability and hence production and employment in the manufacturing sector remain unchanged.

Also, inflation caused by rising prices will be less. The criticism against this policy, however, will come from both the employers and the unions. The employers will press for change, so that they will be able to attract more workers into the service sector. The unions will want to abandon the wage freeze in order that their members can benefit from the abnormally high profits that are earned in the service sector as long as wage costs stay low. Apart from the political pressure against such a policy, the government has to consider that this policy will prevent the country from making an adjustment in the production profile, as labour and capital resources will not leave the manufacturing sector to be employed in the service sector. Any decision will doubtless depend on the time span during which the country is expected to extract the natural resource.

A third policy measure is a devaluation of the currency. This is intended to reduce the country's imports and boost its exports. Even though a devaluation will have positive short term effects, its real long term effects are nil. In the short term a devaluation will cause various price and income effects, which will result in different growth rates across the economy because of the time lags these multiplier effects need to work through the system. The most important of these effects will be the improvement of the manufacturing sector's profitability relative to the service sector; this will lift its employment and production levels. In the long run, however, adjustments to the devaluation will have come to a standstill and therefore the manufacturing sector's profitability will fall back to the situation before the devaluation. All further effects will be purely nominal wage and price increases which, unpleasant in themselves, will also fail to achieve the desired goal of preventing the decline of the manufacturing sector.

The fourth policy aimed at moderating the negative effects of a resource discovery on the manufacturing sector is a subsidy that is financed out of lump-sum taxes. This policy will have positive effects on the manufacturing sector in the short term, in the longer term the relative gains to the manufacturing sector will be less but overall the sector will still be better off than without a subsidy. However, these beneficial effects to the 'loosing' manufacturing sector have to be weighed up against the negative impacts of this subsidy. Among these are demand-pull type inflationary pressures, caused by increased earnings and hence spending in the manufacturing sector. But there are also longer term problems with subsidies in general. Politically, it is difficult to abandon subsidies once a certain group in society has grown accustomed to it. That

means that in the long run the country has to pay for an inherently inefficient allocation of resources, because the new, optimal allocation of resources that was caused by the resource discovery will not be attained.

Yet another policy request that is often made by groups that are put under economic pressure by unforeseen developments is the imposition of import tariffs. The economic effects of this policy are similar to the previous policy; hence the general criticism against this will again come from the academic corner. The argument being that the imposition of tariffs in one country will cause other countries to reply in kind. Eventually, this will lead to an inefficient allocation of world resources, as the world economies will not take advantage of the international specialisation of labour and capital resources.

Two more policy proposals that are seldom put forward, but that are deemed to have few negative side effects are an improvement of labour mobility and a policy of investing part of the resource revenues abroad. The first of these policies, an improvement of labour mobility, is a way letting the economy achieve the new, optimal resource allocation by accepting an output reduction of the manufacturing sector and an expansion of the service sector. The faster the economy moves towards the new allocation, the less overall strain there will be and the greater the total benefit from the resource discovery will be. Similarly, a policy of investing part of the resource revenues abroad reduces the demand-pull effects of larger earnings that are due to the resource discovery and thus allows the economy to adjust more slowly and therefore for some of its sectors less painfully. At the same time, this policy allows the economy to reap the benefits of the resource discovery once the resource has been completely depleted. It therefore converts a temporary income stream arising from the sale of the resource into a more permanent one from which future generations will be able to benefit.

2.2.3 Empirical papers

After having discussed the theoretical background of resource extraction we now move to a discussion of empirical papers in the area. The group of empirical papers can be categorised into whether the analysis is based on 'guesstimates' or whether it is based on an econometric model. Important contributions which

fall into the first of these groups are Forsyth and Kay (1980), Bruno and Sachs (1982), and Motamen (1983).

A first group of papers is concerned with whether the UK economy has benefited from North Sea oil and if so, by how much. One of the earliest and also most influential papers on the effects of North Sea oil on the UK economy is that by Forsyth and Kay (1980). Forsyth and Kay conduct their analysis in terms of constant 1980 prices and compare two states of the UK economy: the pre-oil situation in 1970, when all oil had to be imported, with the post-oil situation when the UK had become a substantial net oil exporter. They conclude that the potential benefits of North Sea oil are large, but also that the benefits accrue to the economy in a highly unbalanced form, since the economy has to undergo a structural change in order to reap the benefits of oil. Since oil wealth is assumed to be valued in US dollars, it has to be 'converted' into pound sterling in order to be spent on domestic goods and services.¹ Forsyth and Kay assume that domestic demand rises by the same margin as overall domestic production. This implies that the current account balance of the pre-oil state is preserved in the post-oil state. According to a further assumption the extra demand generated by the oil wealth is spread equally across the various sectors of the economy. Taken together with the previous assumption of long term current account balance, this implies that the expansion of the export orientated primary (oil producing) sector has to lead to the contraction of another part of the export orientated sector of the economy — the manufacturing sector. These classical Dutch Disease phenomena are brought about by a substantial appreciation of the real exchange rate.

Though liked by supporters of the government as a justification of the then ongoing recession, Forsyth and Kay's paper has been criticised as irrelevant to the UK example. In Bank of England (1980)² the Governor's Ashridge Lecture considered from various angles the basic question whether the UK had benefited from North Sea oil. He maintained that an *absolute* comparison of the situation in 1980 with that in 1970 left the economy worse off, since more resources had to be put up acquiring oil in 1980 than in 1970. The only way the country had gained was *relative* to other countries, since in

¹This, of course is a stylised account of the actual processes. In reality, most of the oil income accrues to the government in the form of taxes on oil revenues and profits of the oil companies that operate in the North Sea. Consumers therefore benefit in an indirect way from higher oil wealth; for example, through tax cuts, higher government spending, and spin-off effects these economic policies might have.

²see also papers by Forsyth and Kay (1981) and Bank of England (1982).

the wake of quadrupled oil prices other countries had to produce more exports in order to pay for their oil imports. This necessary expansion of their trading sectors represented a substantial structural adjustment, which the UK was spared. Nonetheless, the paper regards this as unfortunate, since in the time after oil has run out, the UK industrial base would not only not have expanded but might even have declined because of a high exchange rate.

A reconciliation of these two fundamentally opposite assessments of UK North Sea oil can be found in Allsopp and Rhys (1989). It is argued that the argument of Bank of England (1980, 1982) is correct, and that the claims of Forsyth and Kay (1980, 1981) are false, since a logically coherent argument had been applied to the wrong country. Several conceptual errors are detected in Forsyth and Kay (1980). For example, the comparison of the non-oil situation in 1970 with the post-oil situation assumes in both instances an oil price of \$35 per barrel and consumption of 1 billion barrels per year. This is shown to be misleading, since in 1970 oil was imported at \$2–\$3 per barrel (\$12 in 1976), at a much lower cost than the assumed \$35. In addition, the figure of 1 billion barrels is assumed to be wholly used as net exports, whereas in fact, 60% of it are shown to be directly consumed domestically; and thus only 400 million barrels can be regarded as net exports. Allsopp and Rhys argue further that the value of UK oil wealth in Forsyth and Kay is evaluated incorrectly. Whereas Forsyth and Kay use the international oil price as a measure of value, Allsopp and Rhys claim that for domestically produced and consumed oil the proper measure of value ought to be the production costs of the resource; for net exports it should be the world oil price less domestic production costs. Taken together, these points illustrate that Forsyth and Kay severely overestimated the potential benefits of North Sea oil to the UK economy.

Bruno and Sachs (1982) criticise modelling attempts of Dutch Disease phenomena because, in many instances, the analysis is kept static. They argue, however, that a proper analysis of Dutch Disease phenomena calls for a dynamic analysis because “the effects of wealth on the traded and non-traded goods sectors are inherently dynamic” (p. 845). The model they present is therefore dynamic in nature and is solved as an intertemporal optimisation problem, where economic agents are presumed to have perfect foresight. Their model specifically features short-run capital immobility, but long-run capital mobility. Furthermore, it is assumed that capital accumulation is possible in the aggregate, and capital is taken to be internationally mobile. The rationale of these specific assumptions lies in the slow adjustment process that static

models fail to consider. As Bruno and Sachs argue, the shift from a 'pre-oil' state to a 'post-oil' state does not happen instantaneously but gradually. As discussed further above (in Section 2.2.1.), this is because capital profitability in the trading and non-trading sectors will differ consequent upon the spending effect and will also differ from the rate of return that can be obtained on world markets. However, in the long run these rates must converge, which implies that international capital will flow into the booming sector to take advantage of the higher profit rates that can be achieved there. The reason for assuming aggregate capital accumulation is that agents become aware that oil is a non-renewable resource and agents will therefore invest abroad the proceeds of oil revenue with the aim of transforming a current income stream into a future one. Bruno and Sachs's model thus focuses on intertemporal capital movements and their effects on the economy, but it does not contain any monetary assets. Hence, monetary policy and exchange rate management are not studied. Turning to the findings of Bruno and Sachs's study, one cannot detect fundamentally different results from other studies. The common Dutch Disease effects on the trading and non-trading sectors appear. A novel aspect, however, is that farsighted consumers save much of the oil revenues in anticipation of an 'oil-free' state of affairs.

Similar results have been obtained by Motamen (1983), who uses Optimal Control theory to analyse optimal depletion and investment strategies for the life time of the UK oil resource, assumed to cover the time period 1976–2000. The structure of the macroeconomic model is recursive, that is no feedback loops are implemented. Nonetheless, the model is kept in check during the optimisation exercises by the somewhat arbitrary imposition of a balance of payments constraint according to which “there is an upper limit to the maximum surplus the country can enjoy”.³ This constraint can be taken as representing a variety of economic mechanisms that would stop the economy from overheating, from arbitrarily running down non-oil exports, and which balance over time oil depletion and investment profiles. The macroeconomic model itself is a 'one-variable' model that is essentially driven by the exogenous price of oil. This influences the real exchange rate, which in turn has Dutch Disease-like impacts on non-oil exports. The model serves to confirm common sense according to which it is profitable to accelerate oil depletion when the oil price is high and to invest abroad a proportion of the proceeds, which can be transformed into an additional income stream when the oil has run out.

³Motamen (1983), p. 16.

The above discussed empirical models have one feature in common: the parameter values of their models are based on the respective authors' guesses. This allows a model to be constructed very quickly, but it limits severely the model's credibility in representing economic reality. The models that we now discuss have overcome this weakness, in the sense that their parameter values have mostly been estimated econometrically. This lends more credibility to the authors' claims of an accurate representation of the UK economy, and also allows their models to be used for forecasting, simulation, and policy design purposes.

Bond and Knöbl (1982) present a model that has been designed specifically to deal with the effects that North Sea oil has on the UK economy. In particular, the model is used to assess the medium term effects of an oil price rise, a change in monetary policy, and a different fiscal policy. The time horizon of the simulation analysis is medium term, covering the period 1980–1989.

There are four markets in the model: a product market, a financial assets market, a foreign exchange market, and a labour market. The financial and real sectors are linked via the interest rate, the exchange rate, and the inflation rate. Oil production is exogenous. The influence of oil — in terms of its production and its price — is channelled through the exchange rate into the real side of the economy, the manufacturing sector in particular. Here the possibility of Dutch Disease phenomena is modelled insofar as the investment function for manufactures is adversely affected by an appreciation of the real exchange rate. That is, as oil production and prices raise the exchange rate, investment for manufactures slows down and results in a structural shift away from the manufacturing sector. The exchange rate is further affected by financial policies, directly through the rate of interest, and it is therefore possible for the modellers to distinguish between long lasting oil effects on the exchange rate and more short term financial effects on the exchange rate. Three different simulations have been carried out: a sustained 10 per cent rise in the real price of oil, a temporary monetary shock represented by a 1 per cent drop in the growth rate of central bank money, and a fiscal shock generated by a 1 per cent reduction in government expenditure. The simulation results show that more than half of the 45 per cent appreciation of the real exchange rate between 1977 and 1981 may be due to the existence of North Sea oil and the rise in the real oil price. The sizable remainder, however, is thought to have been influenced by the tight monetary conditions that were imposed by

the Government, thus also contradicting the claims of Forsyth and Kay (1980) that the exchange rate appreciation is solely due to the effects of North Sea oil on the economy. It is furthermore shown that *ceteris paribus* the rise in the real oil price resulted in a lower inflation rate. This is explained by the strong appreciation of sterling which outweighs the direct effect of higher oil prices.

The empirical studies we have considered so far have all dealt with relatively small models, which were especially designed to analyse the effects of North Sea oil. We now turn to a discussion of papers that analyse the impact of oil on the UK within large macro-economic models, such as the National Institute (NIESR) model. Atkinson *et al.* (1983) analyse the effects of oil on the economy within the National Institute model. As they argue, the main channel of influence on the economy is via the real exchange rate. For this reason, the analysis is divided into two groups. In one, only the direct effects of oil on the exchange rate are studied. This is done in a partial equilibrium context, isolated from the rest of the Institute's model. In the other, the indirect effects of oil are analysed within the context of the whole of the NIESR model. In the then current version of the NIESR model, the real exchange rate depended on three different factors — one non-oil factor and two oil related factors. The non-oil factor is the real differential between domestic and foreign short-term interest rates, and for the two oil related factors the current balance and the value of the UK's oil reserves are considered. The current balance itself is influenced by the trade balance in oil as well as by imports of capital equipment for North Sea operations. From the outcome of their first simulation experiment, which looks at the isolated oil impact on the exchange rate, the authors estimate that by 1982 some 35 per cent of the appreciation of sterling was due to oil. In their second simulation exercise Atkinson *et al.* consider how the economy would have fared had there been no oil. They compare this with the actual evolution of the UK economy. For their counterfactual economy they assume that economic policy would have been the same as it has been, furthermore they do not constrain the current balance to be the same with and without oil. This assumption has been made by Forsyth and Kay (1980) but Atkinson *et al.* argue that the imposition of a balanced current balance is idealistic and true at best in the very long run. A third assumption is that the overseas environment would also have been the same. The wisdom of this assumption, however, is questioned by the authors themselves as they admit that there certainly had been some influence of UK oil output on OPEC's oil output and therefore on the level of international oil prices. The authors

nevertheless justify their assumption by the absence of a working model of the international oil market. The results of their simulation exercise show that the economy has been unambiguously better off with oil. In the counter-factual case, the exchange rate is much lower — a consequence of the missing positive oil effects. The lower exchange rate fuelled higher inflation rates which in turn eroded consumer purchasing power and hence caused lower consumption levels. Overall, and not surprisingly, total output was down. An unexpected result, however, was that non-oil output, and manufacturing output especially, were reduced as a consequence of a more depressed domestic consumer demand outweighing higher non-oil exports and lower non-oil imports.

Even though this last result could have been due to the hypothetical assumptions that were made for the counter-factual simulation run, it nevertheless arouses some suspicion about the validity of their approach. Indeed, Bean (1986, p. 25) considers these findings as “rather implausible”.

All but one of the other large, national macroeconometric models, HMT, LBS, CUBS,⁴ feature a similar North Sea sector to the NIESR model. The exception is the Liverpool model, LPL, which does not have an oil sector. This is despite it being an annual model and thus well suited for a longer term analysis of North Sea oil effects on the economy. Minford (1977), however, argues that the exploration of North Sea oil would only have transient effects on the current balance and hence would not necessarily cause an appreciation of the exchange rate. The HMT and the LBS model are both quarterly models. Their main use is therefore short-term forecasting, which makes them unsuitable for a proper analysis of the dynamic, long-term adjustment of the economy to the discovery and production of North Sea oil. The CUBS model is an annual model, but its treatment of the North Sea sector is similar to that of the other, quarterly models.

Summing up the various strands of empirical models we can establish the following: Oil production is exogenous in all models. Another variable that is considered exogenous throughout is the dollar oil price. Variation in the sterling oil price is only caused by changes in the dollar/sterling exchange rate. These two universally made assumptions lead Wallis *et al.* (1985) to the observation that macroeconometric models regard the North Sea sector as a pool of foreign currency that can be tapped as fast as exogenously given oil

⁴The acronyms stand for Her Majesty's Treasury model, the London Business School model, the City University Business School model, and the model by the Liverpool University Research Group in Macroeconomics.

production is allowed to proceed. Employment in the North Sea sector is considered to be negligible — the figures have never exceeded 25000, which constitutes approximately 1 per cent of the working population. Direct influences on consumption thus remain negligible too. The installation of capital equipment, though massive in relation to the labour demands of the sector, is again considered as exogenous. Overall, therefore, the models concentrate on spending effects, which are caused by an increase in national wealth and filtered through the economy via the exchange rate and tax revenues.

Let us now evaluate the various exogeneity assumptions that are commonly made for macroeconomic models that analyse the effects of North Sea oil on the UK economy. The assumption of an exogenous oil production rate is probably justified because through its North Sea oil taxation scheme and through its power to grant exploration licences the government has ample opportunity to influence, and indeed to determine, oil production. Further justification lies in the time horizons that the various models have chosen. Clearly, for quarterly models with a forecasting horizon of less than a year, oil production is unlikely to change as a result of alterations in oil prices, government taxation or licensing policy. Next, the assumption to regard investment in the North Sea sector as exogenous can be justified, because most of the North Sea operators are multi-national companies, whose capital base is not necessarily owned by and thus beyond the control of UK residents.

The assumption of an exogenous oil price, however, seems doubtful. The dollar oil price has important repercussion on the state of any economy that is as open as the UK economy through its influence on domestic inflation rates via producer prices and oil product prices. Indeed, this influence on the UK economy is increased by the UK's position as a major oil producer, since any change in the international dollar oil price also affects the value of the UK's oil production. This, in turn, has important consequences on its balance of payments and the exchange rate. As the discussion of the empirical models has shown this interrelationship has been recognised by various modellers (*cf.* Atkinson *et al.* (1983)), but it has been omitted from their modelling approaches for want of a properly working model of the international oil market. To overcome this deficiency in the modelling attempts of the effects of North Sea oil on the UK economy we will present a model of the international oil market in Chapter 4. The literature review is continued by

searching for ways of combining the two models — i.e. of the UK economy and the international oil market — within some theoretical framework.

2.3 THEORIES OF SUPPLY OF EXHAUSTIBLE RESOURCES

This section is concerned with the analysis of theories of supply of exhaustible resources. Examples of such resources are oil, metals and precious stones. They are distinct from fish populations or arable land in that they do not regenerate themselves in time — their stock is finite.⁵

Any economic agent — the UK government in our case — is of course interested in depleting a resource he owns in such a way that his (economic) objectives are fulfilled. Of particular interest to him is information about the movement of price and extraction rate of the resource, as both determine his revenues. Hotelling was the first to provide any such information. His paper (1931) is the classical account of optimal depletion of exhaustible resources. In his simple model, resource owners operate in a competitive (i.e. price-taking) market; they produce a simple homogeneous product and have complete knowledge of current and future prices and costs. Let t denote time, R_t the stock of the resource at time t , p_t the resource price at t , and q_t the extraction rate at time t . The resource stock can be determined at any time by

$$R_t = q_t + R_{t-1}. \quad (2.1)$$

Furthermore, associated with q_t are extraction costs $E(q_t)$. The objective of the resource owner, who is organised as a firm, is kept simple. He is assumed to maximise his profits⁶. In order to achieve this, he has to choose his extraction rate over time such that the following holds true

⁵For that reason, theories of supply or depletion of renewable resources differ from those surveyed here. Chapter 5 of Dasgupta and Heal (1979) provides an exhaustive discussion of depletion theories of renewable resources.

⁶see Williamson (1964) for a discussion of several other objectives of firms and their managers. Among them are *inter alia*: maximisation of managerial power, extension of market share, and maximisation of revenues.

$$\begin{aligned} \max_{q_t} \sum_0^T d^t (p_t q_t - E(q_t)), \\ \text{s.t. } q_t \geq 0 \text{ and } R(T) \leq 0, \end{aligned} \quad (2.2)$$

where $d = 1/(1+r)$ is the discount factor, and r is the discount rate. The constraints specify that extraction must be positive at all times, and that total extraction over time must be less than or just equal to the initial stock of the resource. Equation (2.2) states that the resource owner maximises the sum of his discounted profits, which not only depend on the extraction rate, q_t , but also on T , the terminal time period when the resource is exhausted. The condition for an optimal extraction rate is

$$d^t (p_t - E_q(q_t)) = \lambda, \quad \text{for all } t, \quad (2.3)$$

which implies that discounted profits are constant. Inverting (2.3) yields an optimal extraction path,

$$q_t = f(p_t)$$

with q_t dependent solely on prices. Equation (2.3) is known as the r per cent rule, since in an alternative interpretation it says that undiscounted profits must grow at the discount rate, r . This can also be seen if (2.3) is rearranged and solved for $\Delta p_t/p_t$ as

$$\Delta p_t/p_t = r + \Delta E_q^t/p_t - r E_q^t/p_t, \quad (2.4)$$

where $\Delta p_t = p_{t+1} - p_t$ is the change in price and $\Delta E_q^t = E_q^{t+1} - E_q^t$ is the change in marginal extraction cost. If marginal extraction costs are assumed to be constant, and as p_t gets larger, the growth rate of price approaches the discount rate. Equation (2.4) can be interpreted from an asset holding point of view, where the resource owner decides between keeping the resource in the ground or extracting it. If he decides to keep it in the ground the capital gain involved, $\Delta p_t/p_t$, would have to be as great as the alternative capital gain, r , which he would realise if he kept any other asset.

The r percent rule implies two features. The first is that the only way a resource can yield a return to its owner is by appreciating in value. More specifically, the rate by which the resource appreciates in value must equal the

rate of return that any other asset can yield. The second implied feature is that under competitive market conditions the spot price of the resource will always rise, unless r_t was zero.

The attractiveness of the r per cent rule lies in its simplicity and its ability to predict price and extraction profiles. None the less, not many researchers have investigated whether this elegant and simple theory holds in practice. But among the ones who have tested the relationship implied by equation (2.4), Barnett and Morse (1963) stand out because of their comprehensive study on a number of resources produced in the USA over the period 1870 – 1957. The data they analysed had the following two characteristics: the average extraction costs fell over the whole time period; and the resource prices too fell relative to an index of output prices. Taken on their own, these features would contradict the r percent rule, but Barnett and Morse were not interested in testing the r percent rule. Instead they regarded it as true and used it to prove whether or not the studied resources were becoming more scarce. Given this premise they conclude that the hypothesis of increasing scarcity is false, for if it had been true resource prices would have risen. However, Dasgupta and Heal (1979, ch.15) propose that Barnett and Morse's conclusion is not the only possible one, nor is it the most persuasive one that would follow from an analysis of their data. First of all, they argue that from a logical point of view it is futile to analyse scarcity, because the stock of fossil resources on earth is finite and these resources, therefore, are scarce by circumstance. Dasgupta and Heal prefer to analyse the data with a view to whether resources were under-priced and thus over-consumed for some part of the time period studied. This can be done by comparing the actual price path of the resources with the competitive price path. Even though it is impossible to compute the competitive price path of the resources, Dasgupta and Heal argue that it "would have taken exceedingly high and sustained rates of cost reducing technical progress in extractive industries to generate a competitive price path that was declining over so long a period" (*op. cit.* p.466). Regarding this as improbable, they therefore suggest that the competitive price path would have risen for at least the later part of the time period, which — confirming their hypothesis of underpriced and overconsumed resources — contradicts Barnett and Morse's findings. Without a more thorough quantitative analysis however, even Dasgupta and Heal's cannot be regarded as the ultimate truth. As they concede, the overall quantitative effect of new, random discoveries of resource deposits — which first will lead to sudden drops

in price at the dates of discoveries and then to surges in price — may change from resource to resource.

In a subsequent study, Heal and Barrow (1980) use an econometric model of several metal prices to test the r percent rule. Their model relates the rate of change of a commodity price to two other factors: the rate of return on other assets, and the rate of growth of output. The estimation results confirm a significant relationship between these factors, but the relationship is found to differ in a subtle though important point from the one Hotelling suggested for a set of efficient intertemporal markets. Whereas Hotelling stipulated that the rate of change of a resource price depend on the level of the interest rate, the rate of price change is here found to depend on the interest rate's rate of change. The intuitive economic reason for this difference is the way in which expectations are formed in the model.

2.3.1 Theoretic extensions to Hotelling

The inability of the r percent rule to predict resource price movements has caused many authors to extend Hotelling's theory. The criticism levelled against Hotelling's theory is that its underlying assumptions are unrealistically restrictive. Levhari and Liviatan (1977) point out two shortcomings. The first concerns Hotelling's assumption that the output of the well or mine is reduced to zero at the terminal point, T . The other refers to Hotelling's assumption that at the terminal point the resource is completely exhausted. It may, however, well be that at T output is positive. Moreover, the assumption of complete exhaustion ignores that many resources become uneconomic to exploit beyond some point, because extraction costs may have risen. To see this, our model of optimal extraction in equation (2.2) will be modified by incorporating an extraction cost term that now depends on that amount that is left in the ground as well as on the simple extraction rate. Specifically, it is assumed $E_R^t > 0$, which implies that extraction costs rise as the resource level declines. We then have

$$\begin{aligned} \max_{q_t} \quad & \sum_0^T d^t [p_t q_t - E(q_t, R_t)], \\ \text{s.t.} \quad & q_t \geq 0 \end{aligned} \tag{2.5}$$

where, apart from assuming a different cost function term, it is also assumed that the resource constraint is not binding anymore, that is the resource is not expected to be exhausted completely. Solving (2.5) similarly to equation (2.3) (see Chapter 2 of Bohi and Toman, 1984) we obtain the equilibrium condition for optimal extraction

$$d^t [p_t - E_q(q_t, R_t)] = \sum_{s=t+1}^T d^s [-E_q(q_s, R_s)]. \quad (2.6)$$

This condition implies that discounted marginal profit equals the discounted sum of future marginal extraction cost. The RHS of equation (2.6) is known as the ‘user cost’ of resource extraction. Similarly to above, (2.6) can be interpreted as an equilibrium condition for optimal asset holding decisions. We can solve equation (2.6) for $\Delta p_t/p_t$ and obtain

$$\Delta p_t/p_t = r + \Delta E_q^t/p_t - r E_q^t/p_t - E_R^{t+1}/p_t, \quad (2.7)$$

Comparing (2.7) and (2.4) we note that the last term in (2.7) did not appear in equation (2.4). Consequently, the price growth rate rises more slowly when the more realistic assumption of incomplete exhaustion is held.

Nevertheless, not even the extensions to Hotelling’s simple model that have been considered here seem to have had much success in applied work. Recall that Heal and Barrow (1980) found the change of the interest rate term to have a significant impact, but this term still lacks in the theoretical models. Rather than blaming details of the derived theories, the criticism against the theories becomes more substantial when directed at the assumptions that underlie the theories.

The assumption of no uncertainty, for example, seems particularly unrealistic. Given that oil has been exploited in Texas, USA, for about 100 years, how is it possible to assume full knowledge of price movements and size of the resource? The theory may certainly be more realistically applicable to the depletion of a small-sized resource, where depletion is estimated to exhaust the stock of the resource within 5 or even 10 years. For such a time span, it may be conceivable to predict with a fair degree of accuracy the movement of prices, for example. But when applied to the extraction of a large resource whose owner is a national government, the theory becomes less credible as a guide for the government to control optimally the depletion of the resource. To see this, it may be sufficient to consider that discoveries of new oil fields

exceeded production of oil for most of the time since large scale oil exploitation started at the end of the last century.

The next fundamental assumption that can be criticised concerns the ownership of the 'firm' that exploits the resource, and the objectives of this firm. The theory assumes that a single firm produces a single homogeneous good,⁷ oil in our case. The firm's objective is assumed to maximise profits. In reality, however, most oil resources today are owned — directly or indirectly — by national governments. The important consequence of this is that a government may not necessarily aim to maximise the profits obtained from exploiting the resource. Other considerations may play a role, and these should enter the objective function of the maximisation problem. First and foremost of these are macroeconomic considerations. At a basic level, economic policies of national governments are usually aimed at increasing GDP growth while reducing inflation. There is no reason why a national resource, such as oil or gas, should not be used to further these aims. A second consideration of national governments as the owner of a resource is the pursuit of political aims. It can be argued that the oil production in 1990 of Kuwait and other states in excess of their allocated OPEC quotas was done for primarily political rather than economic reasons. A direct consequence of over supply in any market is a drop in prices, which in the case of oil has important, dampening effects on inflation all around the world and notably in industrialised countries, where oil is used in large quantities. It is therefore arguable that whether or not Kuwait was able to keep its revenues constant is of secondary economic interest. Of greater, political importance to Kuwait may have been the loss in revenues that those countries suffered which produced at agreed OPEC quotas. This loss may have pleased other countries — most probably the USA — with whom which it is in Kuwait's national interest to have good relations. A third consideration of a resource owning government concerns the time span for which policy decisions of resource depletion are made. Since future values of prices are unknown and predictions unreliable, and since the exact size of the resource may not be known, governments may pursue depletion policies that serve their short term aims rather than long term considerations. An example of this was Nigeria, which when under enormous cash flow problems continuously exceeded quotas that were agreed upon by OPEC. It is safe to assume that for a short Nigeria was

⁷The assumption of a homogeneous good itself is questionable in the case of oil, as there are various types of crude oil and hence prices.

able to increase its oil revenues, but a damaging long term consequence of its excess production was a loss of OPEC power and therefore a long term oil price level below its cartel level.

The third fundamental assumption which seems irrelevant to oil studies is that of the market form. Recall that Hotelling's theory and its derivatives assume a competitive market form, with no single resource owner able to influence the market. Clearly, the open cooperation of many oil exploiting countries under the umbrella of OPEC agreements, and the tacit collaboration of others with OPEC has invalidated the assumption of competitive, price-taking oil producers. For it was because of the two OPEC agreements that the oil price quadrupled during the 1970s.

2.4 GAME THEORY

The previous section has shown that Hotelling's theory of exhaustible resources can be criticised as being unrealistic and incomplete in scope. Later, in Chapter 7, we will argue that macroeconomic implications are an important factor to be considered in the objective function.⁸ Here, however, we are concerned with another extension of the 'simple' theory of exhaustible resources into the realm of Game Theory. It is claimed by many contributors to this body of research that the basic assumption of the conventional theory of exhaustible resources — the existence of only *one* extractive agent (firm, government, etc.) — no longer holds.⁹ The continuing large production rates in North America, the more recent expansion of oil production in the North Sea and in other countries, and the firm establishment of OPEC as the dominant force in the world oil market constitute a body of producers that is as diverse in aims as it is in size and development. This diversity in economic policies combined with the influence of oil on the world economy and of oil producers on the world oil market warrant an analysis of economic policies in a game

⁸This is certainly true for developed economies where the oil sector — though important — is not the only export-orientated sector in the economy. Examples may be US or the UK economies. However, the importance of macroeconomic implications may be less relevant for countries that depend on oil as the only foreign exchange earning commodity, e.g. most OPEC countries in the Middle East. For these economies, the prime objective is to maximise profits from the resource.

⁹see below.

theoretic context. Before discussing individual contributions, we briefly summarise some basic game theoretic concepts.

Game theory¹⁰ is a solution concept of alternative decisions made under uncertainty. Uncertainty in a game theoretic context means that the players do not know which strategy the other players in the game will choose, even though every possible strategy and its outcome is known to all players. Various ways of classifying game theory are possible. Intriligator (1971) lists four alternatives. Game theory can be classified according to the number of players. It can also be classified according to the number of strategies that are available to the players — usually a finite number of strategies are considered, but an infinite number of strategies is also admissible. A third classification is that according to the nature of the payoff function — here one differentiates between zero-sum games and non zero-sum games. In zero-sum games, the loss of one player is the other's gain, whereas in non zero-sum games the size of gains and losses may be different. Players can often improve their outcome by agreeing upon a joint course of action before starting the game. The degree of this preplay negotiation constitutes another, the fourth, characterisation of games. If the rules of the game allow collusive actions of the players, the game is termed a cooperative game. As the name implies, in non-cooperative games no agreement to cooperate is possible. It is useful to classify the outcomes of games according to whether the outcome of any at all, some or all of the players can be improved upon by choosing a different strategy. Dasgupta and Heal (1979, Chapter 2) summarise various equilibrium concepts, of which those of Pareto efficiency and Nash equilibrium are commonly used.¹¹

The classification of games according to the nature of strategies available to the players leads on to the consideration of the specific market form in which the games are played. Shubik (1980) provides a survey of applications of game theory to classical oligopoly theory by relating various market structures to game theory. When applying market structures to the world oil market, many studies choose to represent the market as a cartel (meaning OPEC) which faces a competitive fringe. Salant (1976) analyses the pricing and production behaviour of the cartel and the competitive fringe under the assumption that both players take part in a Nash-Cournot non-cooperative game, that is each

¹⁰Game theory was first developed by Morgenstern and von Neumann, see von Neumann and Morgenstern (1944).

¹¹The two concepts can be defined as follows. If cooperation is impossible to achieve, the game's solution will be a Nash equilibrium. The outcome of a game is Pareto efficient, if cooperation of all players will not improve every player's situation.

player maximises his own profit while taking as given the sales path of the other player. He further assumes that the cartel owns more oil than any single member of the competitive fringe, which makes the cartel a dominant firm. The paper's results, which do not depend on whether marginal production costs are constant or upward sloping, show that the existence of the cartel raises the sum of the discounted profits of the competitive fringe by a greater percentage than those of the cartel itself. The equilibrium price path shows an initial jump, after which the cartel continues to raise the oil price monotonically over time. It is further shown that irrespective of how small the cartel's supplies are in relation to the whole of the competitive fringe, the cartel restricts its sales as long as the competitive fringe's reserves are not exhausted in order to have the market for itself thereafter.

In a similar paper, Gilbert (1978) describes a von Stackelberg model of pricing behaviour by a dominant firm, which again faces a competitive fringe. Under the assumption of a von Stackelberg duopoly, the resulting equilibrium will not generally be a Cournot equilibrium, which means that each player could improve his payoff. Otherwise, however, the results resemble those of Salant's paper. The cartel again waits for the exhaustion of the competitive fringe's reserves in order to monopolise the market thereafter. If a capacity constraint is assumed for the fringe below which its marginal production costs would be constant, but above which costs would rise, a different price path would result. In this case, the cartel can maximise profits by choosing the strategy of limit-pricing. That is, as long as the fringe produces at capacity the price remains constant. If, however, the fringe increases its production, the price will fall over time. Either price path would only last until some date before the fringe's reserves are exhausted. Then the capacity level would no longer be a binding constraint and the price would rise monotonically until the complete exhaustion of the fringe's reserves.

In Stiglitz and Dasgupta (1982) various types of monopolistic competition are studied in an intertemporal framework. The specific question asked is how the 'market' would exploit an exhaustible resource with no extraction costs, when there is a substitute – sometimes referred to as a backstop technology – with infinitely elastic supply. It is shown that the resource is completely exhausted before the new technology is introduced, when the prevailing market form is either a competitive market, a pure monopoly, or a resource cartel that faces competitive producers. That is, the market behaves rationally by exhausting the cheaper resource before introducing the

more expensive substitute. In other cases, however, the market behaves irrationally in the sense that the expensive backstop technology is used before the cheap resource is exhausted. Further results confirm that when a monopolist owns the resource, he will exploit it excessively slowly. This result is also extended to other forms of imperfect competition. It is shown that there is no linear transgression from the perfectly competitive market form to the pure monopoly via various non-competitive market forms. For instance, in two models of limited competition, the market is even more conservationist than in a pure monopoly and innovation occurs even earlier than in pure competition.

As we can see from these results and from the ones discussed above, game theory yields no compelling mechanistic solutions to oligopoly theory. Scherer (1980, p. 164), however, states that it helps to identify general structural characteristics of situations involving conflict mixed with incentives for cooperation.

2.5 CONCLUSIONS

We have surveyed three areas of the literature that are related to the problem of this thesis: the calculation of optimal policies for two players in an interdependent system.

The first part of the survey concerned the analysis of macroeconomic impacts caused by discovery and exploitation of a non-renewable resource on an open economy. Theories of this kind are categorised under the Dutch Disease literature, after the well-documented adverse effects of natural gas discoveries on the Dutch manufacturing sector in the 1970s. Many of the earlier papers analysing Dutch Disease problems use the framework of Dornbusch (1976). Damaging effects on the trading (manufacturing) sector within this model type are essentially caused by an appreciation of the real exchange rate. This comes about because the goods market adjusts more sluggishly to a resource discovery than the assets market, for which perfect foresight and hence instantaneous adjustment is assumed. However, Dornbusch-type models have been shown to lack an important feedback mechanism, which links the current account with the rest of the model, and the exchange rate in particular. Kawai (1985) and

Karakitsos (1989) have added this feature to a Dornbusch type model and found much more sophisticated exchange rate reactions to changes in monetary or fiscal policies than are possible in simple Dornbusch type models. An application of this feedback mechanism to models analysing Dutch Disease phenomena is, however, still lacking in the literature. This gap will be filled in Chapter 3, where a theoretical model in the spirit of Kawai and Karakitsos, but amended to the situation of a resource discovery, will be presented.

The second part of the literature survey dealt with theories that extended the comparative statics analysis of the Dutch Disease literature into a dynamic framework and considered questions of optimal depletion profiles over time. The classical supply theory in this area of research is Hotelling (1931), which states that in the case of optimal depletion the percentage change of the resource price will equal the going interest rate — the r percent rule. However, Hotelling's theory has been criticised on empirical as well as theoretical grounds. There is no empirical confirmation of the r percent rule. Of the two major empirical studies, Barnett and Morse (1963) find resource prices falling relative to an index of output prices. The other study, Heal and Barrow (1980), is only able to relate the rate of change of commodity prices to the *rate of change* of the interest rate (*inter alia*), and not as stipulated by Hotelling to the interest rate. The unsuitability of the r percent rule has been blamed on unrealistically restrictive assumptions that underlie Hotelling's theory. But even when amended to allow, for example, exploitation to stop once it becomes uneconomic to continue, Hotelling-type supply theories seem unable to provide realistic predictions of resource prices and quantities — at least in our case of oil.

It has been argued in this chapter that this may partly be due to further unrealistic assumptions or to the failure to extend the objectives of the resource owner who is assumed to operate as a price-taking firm in a competitive market. For example, it is well known that theories assume perfect foresight mainly for mathematical tractability rather than for its realism. Moreover, the assumption of a single price-taking firm as the owner of a resource was shown to be unrealistic in the case of oil. Most oil resources are owned by national governments, and it was argued that for these, considerations other than pure profit maximisation may play a role. In our case of the UK as a developed economy, macroeconomic considerations should surely enter the objective function of the policy maker (resource owner).

A further assumption that was shown to be unrealistic concerned the market form within which oil exploitation takes place. It is generally accepted that the international oil market is composed of a dominating cartel, OPEC, and a competitively operating fringe of small and medium sized producers — the UK among them. It is argued that this has two important consequences for our analysis. The first is that the assumption of a competitive market form alone is not applicable to the case of the international oil market. The second is that more than one player operates in the international oil market. Any analysis of the effects of oil on a significant oil producer — the UK in our study — should therefore consider the interaction of this single player with the other player, OPEC.

For this reason, the third section of this literature survey dealt briefly with aspects that game theory might provide for the analysis of this study. Game theory will be introduced as an analytical tool in Chapter 7.

Chapter 3

A Theoretical Model of Exchange Rates, Asset Accumulation and Oil Extraction

3.1 INTRODUCTION

In this chapter, we present a model that is intended to serve as the theoretical backbone of the empirical analysis to follow in later chapters. The analysis is comparative static in spirit, similar to that of most studies of macroeconomic effects of resource discoveries, which we surveyed in the previous chapter. There, we argued that the popular Dornbusch-type models lacked one important link between the current account and the asset market. Kawai (1985) and Karakitsos (1989) recognised that this missing link allowed an economy to run indefinite current account imbalances without ever experiencing counterbalancing effects in the asset market, and the exchange rate in particular.

The model presented in the next section includes this link and allows therefore a more realistic analysis of the effects of oil discovery and exploitation on the economy. Short run and long run comparative static analyses of various changes in exogenous variables are presented in Sections 3 and 4. Conclusions of the analysis follow in Section 5.

3.2 THE MODEL

The model we are proposing largely follows the tradition of Dornbusch (1976), but it also takes into account the improvements of Dornbusch-type models that have been pointed out by Kawai (1985) and Karakitsos (1989). Briefly, our model is an open economy model where domestic and foreign goods and assets

can be traded internationally. Domestic oil production as an exogenous variable enters the domestic net export function. The accumulation of net exports has a feedback effect on the movement of the exchange rate and aggregate demand, and it is through these channels that UK oil production acts as a provider of wealth to the economy.

There are three types of assets in the economy: domestic money, M , domestic currency denominated bonds, B , and foreign currency denominated bonds, F . Domestic bonds yield an interest of r , the yield on foreign bonds is denoted by r^* . Both types of assets are assumed to be perfect substitutes. The model considers two markets: a goods market and an assets market. Domestic residents are allowed to trade over the whole range of assets, the economic actions of foreign residents, instead, are assumed to be exogenous. It is furthermore possible for domestic residents to import goods at an exogenously given price of P^* .

The model is divided into two parts: a static part and a dynamic part, corresponding to a short and a long term equilibrium view of the economy. A short term equilibrium is achieved when the dynamic part of the model is taken as predetermined and the static part is solved, the long term equilibrium position has been reached when the dynamic variables have stopped moving and all other variables have converged to their respective stationary values. In moving from one equilibrium point to another, we follow the Dornbusch tradition by assuming a different adjustment speed for the different markets. Specifically, it is assumed that prices in the goods market are 'sticky' so that its re-adjustment is comparatively slow, whereas assets markets are assumed to clear instantaneously through the necessary movements in the spot rate of the exchange rate, e .

The model equations (3.1) – (3.13) are listed in Table 3.1, and the corresponding economic variables are defined in Table 3.2. We now discuss the meaning of the various model equations. The goods market is described by equations (3.1) – (3.6). Equation (3.1) states that aggregate demand in the economy is the sum of private consumption, investment, government expenditure, and net exports (which are the difference between total exports and total imports). In equation (3.2) private consumption expenditure is determined by consumers' personal disposable income and by their available stock of real wealth; a rise in either constituent will increase consumption. Consumers' personal disposable is obtained through an identity in equation

Table 3.1: Model equations

$$AD = C + I + G + X, \quad (3.1)$$

$$C = c_{YD}YD + c_V \frac{V}{P}, \quad 0 < c_{YD} < 1, \quad (3.2)$$

$$0 < c_V < 1,$$

$$YD = Y - T, \quad (3.3)$$

$$I = i_Y Y + i_r r, \quad i_Y > 0, \quad i_r < 0, \quad (3.4)$$

$$X = x_{YD}YD + x_V \frac{V}{P} + x_{WT}WT + x_O \frac{OIL}{P_e} + x_C \frac{P_e}{P^*},$$

$$-1 < x_{YD}, x_V \leq 0,$$

$$x_{WT} < 1, \quad x_O > 0,$$

$$x_C < 0, \quad (3.5)$$

$$Y = AD, \quad (3.6)$$

$$V = M + B + \frac{F}{e}, \quad (3.7)$$

$$\frac{\dot{M}}{P} = m_Y Y + m_r r + m_V \frac{V}{P}, \quad m_Y > 0, \quad m_r < 0, \quad (3.8)$$

$$0 < m_V < 1,$$

$$r = r^* - \dot{e}^e, \quad (3.9)$$

$$\dot{e}^e = \theta(\bar{e} - e), \quad \theta \geq 0, \quad (3.10)$$

$$\dot{P} = \alpha(Y - \bar{Y}), \quad \alpha \geq 0, \quad (3.11)$$

$$\frac{\dot{M}}{P} + \frac{\dot{B}}{P} = G - T, \quad (3.12)$$

$$\frac{\dot{F}}{P_e} = x_{YD}YD + x_V \frac{V}{P} + x_{WT}WT + x_O \frac{OIL}{P_e} + x_C \frac{P_e}{P^*}. \quad (3.13)$$

Table 3.2: Variable definitions

AD	aggregate demand
B	nominal stock of domestic bonds
C	real consumers' expenditure
e	exchange rate, defined as the foreign price of a domestic currency unit. An increase in e therefore implies an appreciation of the exchange rate.
$\dot{e}^e$	expected rate of change of exchange rate
$\bar{e}$	long run exchange rate
F	nominal stock of foreign bonds, denominated in foreign currency. If $F > 0$, the domestic economy is a net creditor to the world.
G	real government expenditure
I	real investment expenditure
M	nominal money supply thought of as $M0$, i.e. coins and cash in circulation
OIL	domestic oil production, denominated in foreign currency
P	domestic price level
P^*	foreign price level
r	domestic interest rate
r^*	foreign interest rate
T	total real tax income
V	nominal stock of domestic private wealth
WT	index of world trade activity
X	net real exports, i.e. the difference between total exports and total imports
Y	total real income, equivalent to total supply of goods and services
$\bar{Y}$	long run value of total real income
YD	total real personal disposable income

(3.3) as the difference between total income and total taxation. The second constituent of aggregate demand, investment, is described by equation (3.4) as depending positively on total income and negatively on the nominal domestic interest rate.

Total domestic absorption, which is the sum of consumption and investment and represents domestic demand for foreign and domestic goods, is therefore dependent on the interest rate as well as the two income terms. This influence is also included in Dornbusch (1976), but Kawai (1985) has ignored it for simplicity.

Equation (3.5) shows net exports to be a function of personal disposable income, real private wealth, world trade activity, domestic oil production, and an index expressing the competitiveness of the domestic economy. Personal disposable income and real wealth enter the equation with a negative sign attached to them, because they are constituents of total imports and therefore an increase in either of them would ultimately lower total income. An increase in world trade or in domestic oil production will boost total exports and total income, hence their positive sign. The measure of competitiveness in equation (3.5) is described by the ratio of domestic prices and foreign prices that are converted into the home currency by the exchange rate. Clearly, as domestic prices rise relative to foreign ones, competitiveness is harmed and net exports and total income will fall; this explains the negative sign in front of the competitiveness measure in equation (3.5). Equation (3.6) is an identity and simply states that total income is demand determined.

Consider now the assets market, which is described by equations (3.7) – (3.10). Equation (3.7) is an identity which defines the composition of private wealth. Accordingly, economic agents can hold three types of assets: money, domestic bonds, and foreign denominated bonds. The equilibrium condition for the assets market, equation (3.8), is satisfied when money supply equals money demand. Money demand depends positively on total income and private real wealth, and negatively on the interest rate. Note the inclusion of real private wealth in the money demand equation. Since oil wealth will feed into private wealth, this represents an indirect effect of oil on the demand for money. Neary and van Wijnbergen (1984) have pointed out the importance of this effect within the context of the model by Eastwood and Venables (1982) where it is missing. The inclusion of real private wealth is important for another reason. It is through this channel that changes in wealth accumulation

influence the asset market and cause equilibrating movements in the spot rate of the exchange rate, e .

Equation (3.9) implies uncovered interest rate parity, that is domestic and foreign bonds are perfect substitutes and hence their return is equal. This condition also implies that the two assets can be consolidated into one equation. In the short run, therefore, the return on foreign bonds is equal to the foreign interest rate minus any expected change in the value of the domestic currency. Under rational expectations in the short run, the assumption of an uncovered interest parity implies the somewhat non-intuitive result that an increase in the foreign interest rate leads because of an expected currency appreciation to an increase in the spot rate. This has been justified by Dornbusch (1980) using the distinction between anticipated and unanticipated changes between the domestic and foreign levels of interest.¹

Equation (3.10) clarifies the type of expectation scheme chosen for our model. It is evident that rational expectations do not enter the model in the short run; rather, two types of expectations exist in the foreign exchange market, depending on the time horizon considered. In the short run, expectations are formed regressively, whereby the current rate is adjusted the faster the more it deviates from its long run value; in the long run, however, expectations are formed rationally, so that only then are economic agents assumed able to compute the exact value of the exchange rate. The regressive expectations scheme in the short run implies that the spot rate will fall, given a fixed level of the long run exchange rate and an increase in the foreign interest rate. This fall in the short term makes the currency a more attractive buy in the long term and therefore justifies an expected appreciation when demand for it increases.

The following three equations describe the dynamic part of the economic system. Equation (3.11) simply states that domestic prices are sticky and that they adapt according to excess demand in the goods market, whereby $\bar{Y}$ represents the exogenous natural unemployment level of output. $\bar{Y}$ is assumed to depend on capital accumulation, the growth of the economy, and other factors whose feedback influence is, however, omitted here for simplicity; in this we follow most other analytical studies in the field, but Karakitsos (1989) has included a capacity effect on investment and therefore on potential output in his simulation model. The adjustment parameter α allows for two extreme

¹see Begg (1982) for a summary of the argument.

cases: for $\alpha = 0$ the model reverts to a Keynesian model with fixed prices and flexible income, whereas for $\alpha \rightarrow \infty$ the model takes on monetarist characteristics with flexible prices and fixed income. Equation (3.11) first appeared in Dornbusch (1976) and can be justified in a number of ways, for example as a representation of a Phillips curve or as a representation of Okun's law. The government budget constraint, equation (3.12), shows that the government's issuing of bonds and money finances its excess expenditure, namely the difference between its expenditure, G , and its total tax income, T . The last equation of the economic system, equation (3.13), is what the government budget constraint is to government finances: it is the economy's budget constraint. It states that a current account² deficit — the RHS of (3.13) — must be financed by the sale of an appropriate part of the economy's foreign assets — the LHS of (3.13). Alternatively put, (3.13) also implies that successive current account surpluses swell the economy's holding of foreign assets which — by being part of private wealth — feed into the asset market as well as into the goods market. It is this equation that distinguishes this model from Dornbusch-type models, which lack a feedback mechanism from movements of the current account to the rest of the model, and the asset market and exchange rate in particular.

3.3 SOLVING THE MODEL — THE SHORT RUN

In this section, the above model will be solved. It is assumed throughout that the budget is balanced; this allows us to ignore equation (3.12) during the ensuing analysis. In the way the model is solved, we distinguish between two types of solution: a short run solution and a long run solution. The short run solution differs from the long run solution in that the dynamic variables are thought of as constant. Hence, equations (3.1)–(3.10), the static part of the model, are solved given constant values of those variables that are determined in equations (3.11) and (3.13); and consequently, we consider F and P as state variables. Before we solve the model and analyse its short run properties, however, we rewrite it more succinctly into a familiar IS–LM model. Successive substitution yields the following two equations

²More precisely, it should be the real current account, as interest payments on the net foreign asset position are ignored here for simplicity.

$$\begin{aligned}
& -\kappa Y + i_r \theta e + x_O \frac{OIL}{P e} + x_C \frac{P e}{P^*} - c'_{YD} T + c'_V \frac{V}{P} + i_r (r^* - \theta \bar{e}) \\
& + G + x_{WT} WT = 0,
\end{aligned} \tag{3.14}$$

$$m_Y Y + m_r \theta e + m_V \frac{V}{P} - \frac{M}{P} + m_r (r^* - \theta \bar{e}) = 0, \tag{3.15}$$

where

$$\begin{aligned}
\kappa &= 1 - c'_{YD} - i_r, & 0 < \kappa < 1, \\
c'_{YD} &= c_{YD} + x_{YD}, & 0 < c'_{YD} < 1, \\
c'_V &= c_V + x_V, & 0 < c'_V < 1,
\end{aligned}$$

Equation (3.14) is the IS curve, which represents all loci of equilibrium in the goods market. The LM curve is described by equation (3.15).

To facilitate the following analysis, it is useful to totally differentiate the IS-LM system, which in an e - Y space yields

$$\begin{bmatrix} \kappa & -E_{IS} \\ m_Y & E_{LM} \end{bmatrix} \begin{bmatrix} dY \\ de \end{bmatrix} = \tag{3.16}$$

$$\begin{bmatrix} -c'_{YD} dT + \frac{c'_V}{P} (dB + dM + \frac{dF}{e}) + dG + i_r dr^* - i_r \theta d\bar{e} + x_{WT} dWT + P_{IS} dP + \frac{x_O}{P e} dOIL \\ \frac{1 - m_V}{P} dM - m_r dr^* + m_r \theta d\bar{e} - \frac{m_V}{P} dB - \frac{m_V}{P e} dF + P_{LM} dP \end{bmatrix}$$

where

$$E_{IS} = -\frac{c'_V F}{P e^2} + i_r \theta - \frac{x_O OIL}{P e^2} + \frac{x_C P}{P^*} < 0,$$

$$E_{LM} = m_r \theta - \frac{m_V F}{P e^2} < 0,$$

$$P_{IS} = -\frac{c'_V F}{P^2 e} - \frac{x_O OIL}{P^2 e} + \frac{x_C e}{P^*} - \frac{c'_V (M + B)}{P^2} < 0,$$

$$P_{LM} = \frac{m_V F}{P^2 e} - \frac{(1 - m_V) M}{P^2} + \frac{m_V B}{P^2} < 0.$$

In matrix notation (3.16) can be written as

$$A Y = X, \tag{3.17}$$

where Y is the vector of endogenous variables, A the matrix of coefficients, and X the vector of exogenous variables. E_{IS} represents the influence of the exchange rate on aggregate demand. Its overall influence, which is positive, is composed of three positive sub-effects and one negative sub-effect. The positive effects are caused by the interest rate effect, the oil effect, and an effect of competitiveness; the negative sub-effect is caused by the foreign component of private wealth. Since this last sub-effect is small relative to the other sub-effects, we assume that the three positive effects dominate the negative one, the overall effect is thus positive. E_{LM} represents the influence of the exchange rate on the money market. Its overall effect is unambiguously negative, since both the interest rate effect and the foreign wealth effect are negative. P_{IS} shows the effect of a reduction of the domestic price level on aggregate demand; its overall effect is again unambiguous, and positive. This is because real wealth, real oil revenues, and competitiveness are all bolstered by a fall in the domestic price level. Lastly, P_{LM} reflects the influence of a fall in the domestic price level on the demand for money; its effect — stemming from the change in real private wealth — is positive. This is, because the effect of the money supply dominates the bond and the foreign wealth sub-effects.

The slopes of the IS and LM curves can be computed from equation (3.16) as follows

$$\left. \frac{\partial e}{\partial Y} \right|_{IS} = \frac{\kappa}{E_{IS}} < 0,$$

$$\left. \frac{\partial e}{\partial Y} \right|_{LM} = -\frac{m_Y}{E_{LM}} > 0.$$

As can be seen, the IS curve is negatively sloped and the LM curve has a positive slope. The economic rationale for this is as follows. An increase in Y will lead to excess supply in the goods market; for the equilibrium to be re-established the exchange rate needs to fall in order to boost aggregate demand. Likewise, an increase in Y will lead to excess demand for money and the exchange rate will rise as foreign assets are converted into the domestic currency.

Before analysing the short run comparative statics of this system, it is worthwhile to consider the various shifts of the IS and LM curves that are caused by exogenous variables. Similarly to the derivation of the slopes of IS and LM curve, these shifts can be obtained from equation (3.16) as

$$\left. \frac{\partial e}{\partial T} \right|_{IS} = \frac{c'_{YD}}{E_{IS}} < 0, \quad \left. \frac{\partial e}{\partial G} \right|_{IS} = -\frac{1}{E_{IS}} > 0, \quad \left. \frac{\partial e}{\partial r^*} \right|_{IS} = -\frac{i_r}{E_{IS}} < 0,$$

$$\left. \frac{\partial e}{\partial M} \right|_{IS} = -\frac{c'_V}{P E_{IS}} > 0, \quad \left. \frac{\partial e}{\partial WT} \right|_{IS} = -\frac{x_{WT}}{E_{IS}} > 0, \quad \left. \frac{\partial e}{\partial P} \right|_{IS} = -\frac{P_{IS}}{E_{IS}} < 0,$$

$$\left. \frac{\partial e}{\partial B} \right|_{IS} = -\frac{c'_V}{P E_{IS}} > 0, \quad \left. \frac{\partial e}{\partial F} \right|_{IS} = -\frac{c'_V}{E_{IS} P e} > 0, \quad \left. \frac{\partial e}{\partial OIL} \right|_{IS} = -\frac{x_O}{P e E_{IS}} > 0,$$

$$\left. \frac{\partial e}{\partial M} \right|_{LM} = \frac{1 - m_V}{P E_{LM}} < 0, \quad \left. \frac{\partial e}{\partial r^*} \right|_{LM} = -\frac{m_r}{E_{LM}} < 0, \quad \left. \frac{\partial e}{\partial B} \right|_{LM} = -\frac{m_V}{P E_{LM}} > 0,$$

$$\left. \frac{\partial e}{\partial F} \right|_{LM} = -\frac{m_V}{E_{LM} P e} > 0, \quad \left. \frac{\partial e}{\partial P} \right|_{LM} = \frac{P_{LM}}{E_{LM}} > 0, \quad \left. \frac{\partial e}{\partial \bar{e}} \right|_{LM} = -\frac{m_r \theta}{E_{LM}} > 0.$$

The shifts in the IS-LM curves have the following economic rationale behind them. First, we turn to the goods market. An increase in taxation, T , will diminish personal disposable income, YD , with consequent reductions in consumption, C , net exports, X , and therefore aggregate demand, AD . For the same level of total income, Y , the exchange rate will have to fall to boost exports and to move back into equilibrium; this is equivalent to a shift towards the left of the IS curve. The opposite movement of the exchange rate is necessary when government expenditure, G , has been increased. Here, AD will rise immediately and, since Y will not move, the exchange rate will have to rise to diminish net exports. An increase in the foreign rate of interest, r^* , will lead to an increase in the domestic interest rate, r , and in turn to decreases in

investment, I , and AD . This will force the exchange rate down and the goods market will return to equilibrium.

Increases in B , M , and F will all boost private wealth which will have two opposing effects on AD . On the one hand, higher wealth means higher consumption which will push up AD ; on the other hand higher wealth also implies more imports with a consequent decline in net exports and aggregate demand, AD . Overall, however, AD will rise since the rise in consumption will dominate the fall in net exports. For an unchanging level of total supply, Y , the exchange rate will have to rise in order to reduce net exports and thereby AD . The exchange will also have to rise in response to an increase in world trade, WT , or an increase in the domestic production of oil, OIL . In both cases, net exports and aggregate demand will be pushed up, so that the increase in e will reduce net exports and AD . Finally, an increase in the price level, P , will affect two components of AD : consumption and net exports. Since real wealth is lower, consumption expenditure will be lower too — AD will fall. The effect on net exports is more complex. Lower real wealth means that there will be fewer imports, and AD will rise; but the rise in P will harm competitiveness and reduce real oil earnings, so that AD will fall. The overall effect, of course, will be a decline in AD , but the consequent decline in e will re-establish equilibrium in the goods markets.

We now turn to a brief discussion of shocks to the money markets. An increase in the supply of money, M , will immediately create excess supply of money. This will be partly offset by increase in the demand for money since the higher M has boosted private wealth, V . The remaining excess supply of money, however, will be spent abroad — the exchange will fall and the money markets will return to an equilibrium. For increases in either B or F , the effects are unambiguous. In both cases, private wealth will be raised so that an overall excess demand for money exists. For the same level of income, Y , the exchange rate will rise by absorbing the excess demand for money.

An increase in the level of the foreign interest rate, r^* , will lead to an increase in the domestic interest rate too. This will cause an excess supply of money, as the demand for money has fallen. Money will leave the country, the exchange rate will fall, and the money markets will return to a new equilibrium position. Finally, an increase in the domestic price level, P , will affect both sides of the money markets. Real money balances, $\frac{M}{P}$, will fall and reduce the money supply; the demand side is affected because real wealth, $\frac{V}{P}$, is reduced

which will cause money demand to fall. But demand will fall by less than money supply because wealth is the only one of three factors that falls — the other two stay constant. Overall, therefore, a strong excess demand for money exists. In response, the exchange rate will rise to equilibrate the markets again.

3.3.1 Comparative statics — the short run

In this section we analyse the short run comparative statics of the model system. The analysis is similar to the one conducted above with the difference, however, that now we are interested in the combined change of the IS and LM curves to a shock of an exogenous variable. The induced changes are expected to be similar to those that other Dornbusch-type models obtain, for the simple reason that in the short run our model assumptions are the same as those of the other studies.

3.3.1.1 *A change in the net foreign asset position*

The effects of an increase in the net foreign asset position, F , on total income, Y , and the exchange rate, e , can be computed from equation (3.16) as

$$\frac{\partial Y}{\partial F} = \frac{1}{|A|} \left(\frac{c'_V}{P e} E_{LM} - E_{IS} \frac{m_V}{P e} \right) \gtrless 0,$$

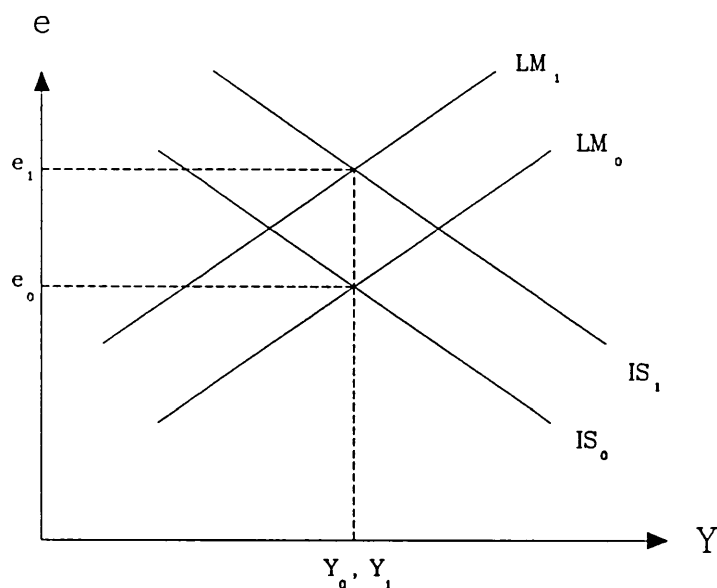
$$\frac{\partial e}{\partial F} = \frac{1}{|A|} \left(-\frac{\kappa m_V}{P e} - \frac{m_Y c'_V}{P e} \right) > 0,$$

where

$$|A| = \kappa E_{LM} + E_{IS} m_Y < 0.$$

The total effect on output is thus unclear, as the shifts of the IS and LM curves cause output to move into opposite directions. As can be seen from Figure 3.1, the exact outcome will depend on the relative size of the shifts. The effect on the exchange rate, however, is clear, as the shifts of both curves push the exchange rate up to reach a new equilibrium. The chain of economic changes can be represented as follows. An increased F will increase V . This will have three further effects: a positive wealth effect on consumption and income; a negative wealth effect on income through a reduction of net exports; and a positive wealth effect on the demand for money. This last effect will lead to an

Figure 3.1: Short run change in F



increase in the domestic interest rate, which, in turn, will lead to an expected depreciation of the exchange rate in the future, but an appreciation of the spot rate, e . This increase in e will close the circle as $\frac{F}{e}$ will fall and therefore lead to a reduction of private wealth.

3.3.1.2 A change in the domestic price level

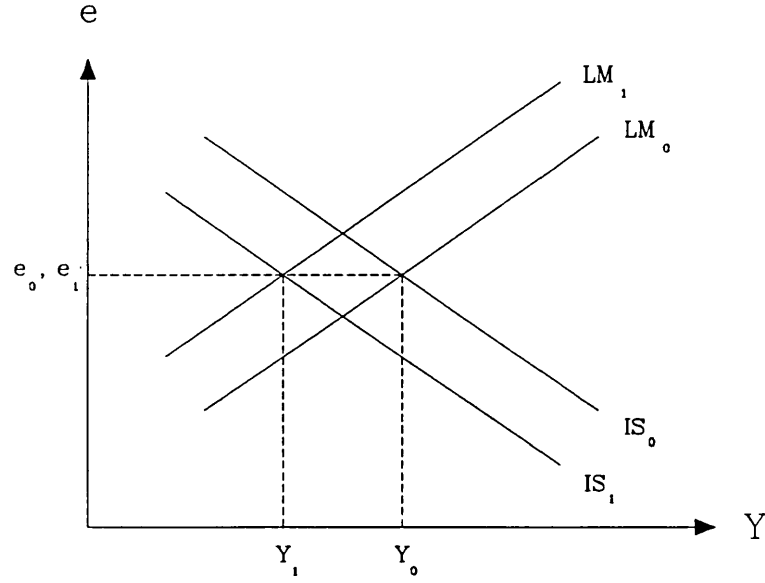
The total effect of an increase in the domestic price level can again be computed from equation (3.16)

$$\frac{\partial Y}{\partial P} = \frac{1}{|A|} (P_{IS} E_{LM} - E_{IS} P_{LM}) < 0,$$

$$\frac{\partial e}{\partial P} = \frac{1}{|A|} (\kappa P_{LM} - P_{IS} m_Y) \gtrless 0.$$

In this case, the total effect on output is certain, but the effect on the exchange rate is unclear; Figure 3.2 shows that the overall effect depends on the relative size of the shifts of the IS and LM curves. The rise in P triggers the following chain of economic changes. The two variables that are immediately affected are real wealth and the real money supply. In the goods market, changes in real wealth will affect consumption more strongly than net exports — aggregate demand will thus fall and the exchange rate will have to rise to equilibrate the market again. In the money market, real wealth will lower the demand for

Figure 3.2: Short run change in P



money; but overall there will be excess demand for money because supply will have been cut by more. Excess demand for money will of course lead to an appreciation of the exchange rate, whose total change is therefore ambiguous.

3.3.1.3 A change in the domestic production of oil

The effects of an increase in the domestic oil production can be obtained from equation (3.16) as

$$\frac{\partial Y}{\partial OIL} = \frac{1}{|A|} \left(\frac{x_O}{P e} E_{LM} \right) > 0,$$

$$\frac{\partial e}{\partial OIL} = \frac{1}{|A|} \left(- \frac{x_O m_Y}{P e} \right) > 0.$$

As is evident from the partial derivatives, the total effect of a boost in oil production will raise both total income and the exchange rate. Using economic intuition, this can be explained as follows. The increase in OIL will boost net exports and, in turn, Y . A higher Y requires a rise in the exchange rate to equilibrate the goods market, but a higher Y also causes excess demand for money. Again, a rise in the exchange rate is necessary to move the money markets back into equilibrium.

This is the standard results of Dornbusch-type models, which has been expected since in the short run our model's assumptions do not differ from those of the other studies.

3.4 SOLVING THE MODEL — THE LONG RUN

In this section we consider the economy when its long run equilibrium has been achieved. The following conditions are then to hold

$$\dot{e} = \theta(\bar{e} - e) = 0 \Rightarrow e = \bar{e},$$

$$\dot{P} = \alpha(Y - \bar{Y}) = 0 \Rightarrow Y = \bar{Y},$$

$$\frac{\dot{F}}{P e} = x_{YD}YD + x_V\frac{V}{P} + x_{WT}WT + x_O\frac{OIL}{P e} + x_C\frac{P e}{P^*} = 0.$$

That is, the spot exchange rate, e , and total income, Y , will have converged to their respective long run values, $\bar{e}$ and $\bar{Y}$. The second condition is important for its economic implication, which is that in the long run total income is invariant to any changes that might affect the economy otherwise; this condition is also known as neutrality. The third condition implies that the economy's net foreign asset position is balanced in the long run — that is the economy is neither a net debtor nor a net creditor to the world.

The model can again be re-written in a more succinct form. We substitute the first two relationships into equations (3.14) and (3.15), we then re-arrange the last relationship and obtain the long run IS, LM, and TB curves

$$\begin{aligned} -\kappa\bar{Y} + x_O\frac{OIL}{P\bar{e}} + x_C\frac{P\bar{e}}{P^*} - c'_{YD}T + c'_V\frac{V}{P} + i_r r^* \\ + G + x_{WT}WT = 0, \end{aligned} \quad (3.18)$$

$$m_Y Y + m_V \frac{V}{P} - \frac{M}{P} + m_r r^* = 0, \quad (3.19)$$

$$x_V \frac{V}{P} + x_O \frac{OIL}{P\bar{e}} + x_C \frac{P\bar{e}}{P^*} + x_{YD}(Y - T) + x_{WT}WT = 0. \quad (3.20)$$

In order to analyse the system's long run properties, we totally differentiate equations (3.18) – (3.20) and obtain

$$\begin{bmatrix} -\frac{c'_V}{P\bar{e}} & -P_{IS} & -E_{LIS} \\ \frac{m_V}{P\bar{e}} & -P_{LM} & E_{LLM} \\ \frac{x_V}{P\bar{e}} & P_{LTB} & E_{LTB} \end{bmatrix} \begin{bmatrix} dF \\ dP \\ d\bar{e} \end{bmatrix} = \begin{bmatrix} -c'_{YD}dT + \frac{c'_V}{P}(dB + dM) + dG + i_r dr^* + x_{WT}dWT - \kappa d\bar{Y} + \frac{x_O}{P\bar{e}}dOIL \\ \frac{1 - m_V}{P}dM - m_r dr^* - \frac{m_V}{P}dB - m_Y d\bar{Y} \\ -x_{YD}(d\bar{Y} - dT) - \frac{x_V}{P}(dB + dM) - x_{WT}dWT - \frac{x_O}{P\bar{e}}dOIL \end{bmatrix} \quad (3.21)$$

where

$$\begin{aligned} E_{LIS} &= -\frac{c'_V F}{P\bar{e}^2} - \frac{x_O OIL}{P\bar{e}^2} - \frac{x_C P}{P^*} < 0, \\ E_{LLM} &= -\frac{m_V F}{P\bar{e}^2} < 0, \\ E_{LTB} &= -\frac{x_V F}{P\bar{e}^2} - \frac{x_O OIL}{P\bar{e}^2} + \frac{x_C P}{P^*} < 0, \\ P_{LTB} &= -\frac{x_V F}{P^2\bar{e}} - \frac{x_O OIL}{P^2\bar{e}} + \frac{x_C \bar{e}}{P^*} - \frac{x_V (M + B)}{P^2} < 0. \end{aligned}$$

The subscripts, LIS, LLM, and LTB, denote the long run IS, LM, and TB curves; and the expression E_{LIS} , for instance, denotes the influence of the exchange rate on the long run IS curve and thus the influence on the long run equilibrium in the goods market. Equation (3.21) can be written in matrix notation as

$$\mathbf{A}^L \mathbf{Y}^L = \mathbf{X}^L. \quad (3.22)$$

E_{LIS} is the effect of an increase in the long run value of the exchange rate on the equilibrium position in the goods market; since E_{LIS} is negative, aggregate demand will fall upon an increase in $\bar{e}$. E_{LLM} measures the impact of an increase of $\bar{e}$ on the long run equilibrium position in the money market; the

negative sign implies that as $\bar{e}$ rises the demand for money will fall. The impact of a rise of $\bar{e}$ on the long run equilibrium of the balance of payments is described by E_{LTB} . It shows that the balance of payments will show a deficit if $\bar{e}$ rises, because the reduction in oil revenues and the deterioration in competitiveness will dominate the improvement in net exports due to lower imports. Lastly, P_{LTB} reflects the negative impact of a rise in the domestic price level on the long run balance of payment equilibrium position. P_{LTB} is negative because two positive, but secondary, wealth effects are dominated by two negative effects that influence AD more directly.

We now continue with a discussion of the slopes of the long run IS, LM and TB curves. The respective slopes can be computed from equation (3.21) as

$$\begin{aligned}\left.\frac{\partial \bar{e}}{\partial P}\right|_{\text{IS}} &= -\frac{P_{\text{IS}}}{E_{\text{LIS}}} < 0, \\ \left.\frac{\partial \bar{e}}{\partial P}\right|_{\text{LLM}} &= \frac{P_{\text{LM}}}{E_{\text{LLM}}} > 0, \\ \left.\frac{\partial \bar{e}}{\partial F}\right|_{\text{LTB}} &= -\frac{x_V}{P \bar{e} E_{\text{LTB}}} < 0.\end{aligned}$$

Because of the neutrality condition, Y is no longer an endogenous variable. Hence, the space within which we analyse the long run properties of the model has been changed to an $\bar{e}$ - P space. Within this space the formulae show that the IS curve is downwards sloped, that the LM curve is upwards sloped, and that the TB curve is also downwards sloped. This can be intuitively justified as follows. In the case of the IS curve, an increase in $\bar{e}$ would lower AD and a lower price level is therefore necessary to re-gain equilibrium in the goods market. For the case of the LM curve, a higher $\bar{e}$ would lower money demand; consequently, a higher price level will cut the supply of money to balance the market again. The LTB curve is depicted within an e - F space, its slope is negative. Bearing in mind that the LTB curve is the locus of all pairs of e and F for which net exports are zero, the slope can be explained as follows. Consider an increase in F , that is an increase in private wealth. This will push up imports; and in order to keep net exports at zero exports will have to rise too, which will come about through a drop in the exchange rate.

We now discuss shifts in long run IS, LM, and TB curves. First, we turn to shocks to the goods market.

$$\left.\frac{\partial \bar{e}}{\partial T}\right|_{\text{IS}} = \frac{c'_{YD}}{E_{\text{LIS}}} < 0, \quad \left.\frac{\partial \bar{e}}{\partial G}\right|_{\text{IS}} = -\frac{1}{E_{\text{LIS}}} > 0, \quad \left.\frac{\partial \bar{e}}{\partial r^*}\right|_{\text{IS}} = -\frac{i_r}{E_{\text{LIS}}} < 0,$$

$$\left. \frac{\partial \bar{e}}{\partial M} \right|_{\text{LIS}} = -\frac{c'_V}{P E_{\text{LIS}}} > 0, \quad \left. \frac{\partial \bar{e}}{\partial WT} \right|_{\text{LIS}} = -\frac{x_{WT}}{E_{\text{LIS}}} > 0, \quad \left. \frac{\partial \bar{e}}{\partial OIL} \right|_{\text{LIS}} = -\frac{x_O}{P \bar{e} E_{\text{LIS}}} > 0,$$

$$\left. \frac{\partial \bar{e}}{\partial B} \right|_{\text{LIS}} = -\frac{c'_V}{P E_{\text{LIS}}} > 0, \quad \left. \frac{\partial \bar{e}}{\partial F} \right|_{\text{LIS}} = -\frac{c'_V}{E_{\text{LIS}} P \bar{e}} > 0.$$

The economic rationale behind these long run shifts is as follows. An increase in taxation is followed by a decline in personal disposable income. That, in turn, will push downwards consumption. However, in order to maintain equilibrium in the goods market, the exchange rate would have to come down in order to boost net exports which will compensate for the loss in consumption. Similar forces work when government expenditure, G , is increased, as aggregate demand, AD , would be pushed up. But again, equilibrium has to be maintained and therefore the exchange rate will have to come down in order to boost net exports. Increases in B , M or F work more slowly through the system as they affect private wealth first and then consumption. Here, C , AD would rise, and so the exchange rate will have to rise in order to reduce net exports.

A rise in the foreign interest rate, r^* , translates into an equal rise of the domestic interest rate, r , because of their equivalence in the long run. This will depress investment, I , and would eventually diminish AD . Consequently, the exchange rate will have to come down to boost net exports. A direct effect on net exports is brought about by increases in world trade, WT , or by an increase in domestic oil production, OIL . Since AD is not allowed to move, the exchange rate will have to rise to reduce net exports in order to steer the goods market back towards its long run equilibrium.

We now turn to a discussion of shocks to the money market. As before, these can be computed from equations (3.21) as follows.

$$\begin{aligned} \left. \frac{\partial \bar{e}}{\partial M} \right|_{\text{LLM}} &= \frac{1 - m_V}{P E_{\text{LLM}}} < 0, & \left. \frac{\partial \bar{e}}{\partial r^*} \right|_{\text{LLM}} &= -\frac{m_r}{E_{\text{LLM}}} < 0, \\ \left. \frac{\partial \bar{e}}{\partial B} \right|_{\text{LLM}} &= -\frac{m_V}{P E_{\text{LLM}}} > 0, & \left. \frac{\partial \bar{e}}{\partial F} \right|_{\text{LLM}} &= -\frac{m_V}{E_{\text{LLM}} P \bar{e}} > 0. \end{aligned}$$

The intuition behind these shifts can be explained in the following manner. A rise in the money supply, M , creates excess supply in the money markets. This excess supply of money will be allocated on foreign assets since the

domestic components of money demand are fixed at their long run values. The consequent outflow of money is accompanied by a decline in the exchange rate, which will redress the imbalance in the money markets. An increase in the foreign interest rate, r^* , will raise the domestic interest, rate, r , by an equal amount. This, in turn, would depress money demand. However, the domestic components of money demand have already converged towards their long run values and the excess money supply will again be allocated abroad thereby causing a reduction in the exchange rate and an eventual return to the long run equilibrium in the money markets. Finally, an increase in B or F will affect private wealth — which will rise — and, in turn, money demand which would be higher too. But for equilibrium to be maintained higher holdings of B or F are converted into holdings of cash which implies an increase in the exchange rate.

Lastly, we turn to a discussion of shifts of the long run TB curve in response to various shocks to the balance of payments.

$$\begin{aligned}\left.\frac{\partial \bar{e}}{\partial M}\right|_{\text{LTB}} &= -\frac{x_V}{P E_{\text{LTB}}} < 0, & \left.\frac{\partial \bar{e}}{\partial B}\right|_{\text{LTB}} &= -\frac{x_V}{P E_{\text{LTB}}} < 0, \\ \left.\frac{\partial \bar{e}}{\partial WT}\right|_{\text{LTB}} &= -\frac{x_{WT}}{E_{\text{LTB}}} > 0, & \left.\frac{\partial \bar{e}}{\partial OIL}\right|_{\text{LTB}} &= -\frac{x_O}{E_{\text{LTB}}} > 0.\end{aligned}$$

These shifts can be explained as follows. An increase in either M or B will cause the LTB curve to shift inwards. This is, because a higher M or B will decrease the foreign net asset position, since the three variables are linked through the wealth identity. An independent increase in either world trade or in domestic oil production will swell the net foreign asset position and therefore push the LTB curve outwards.

3.4.1 Comparative statics — the long run

In this section, we analyse the long term characteristics of the model. The following sub-sections determine from equation (3.21) the policy multipliers that result from changes in the money supply, the production of oil, and the level of foreign interest rates. To determine the policy multipliers it is necessary first to compute the determinant of A^L , the long run coefficients matrix of equation (3.21). This is

$$\begin{aligned}
|A^L| = & -\frac{c'_V}{P\bar{e}} \left\{ -P_{LM} E_{LTB} - E_{LLM} P_{LTB} \right\} \\
& + P_{IS} \left\{ \frac{m_V}{P\bar{e}} E_{LTB} - E_{LLM} \frac{x_V}{P\bar{e}} \right\} \\
& - E_{LIS} \left\{ \frac{m_V}{P\bar{e}} P_{LTB} - P_{LM} \frac{x_V}{P\bar{e}} \right\} \\
& > 0.
\end{aligned}$$

3.4.1.1 *A change in the supply of money*

The effects of an increase in the money supply can be computed from equation (3.21) as

$$\begin{aligned}
\frac{\partial F}{\partial M} = & \frac{1}{|A^L|} \left(\frac{c'_V}{P} \left\{ -P_{LM} E_{LTB} - E_{LLM} P_{LTB} \right\} \right. \\
& + P_{IS} \left\{ \frac{1-m_V}{P} E_{LTB} - E_{LLM} \frac{x_V}{P} \right\} \\
& \left. - E_{LIS} \left\{ \frac{1-m_V}{P} P_{LTB} - P_{LM} \frac{x_V}{P} \right\} \right) < 0,
\end{aligned}$$

$$\begin{aligned}
\frac{\partial P}{\partial M} = & \frac{1}{|A^L|} \left(-\frac{c'_V}{P\bar{e}} \left\{ \frac{1-m_V}{P} E_{LTB} + E_{LLM} \frac{x_V}{P} \right\} \right. \\
& - \frac{c'_V}{P} \left\{ \frac{m_V}{P\bar{e}} E_{LTB} - E_{LLM} \frac{x_V}{P\bar{e}} \right\} \\
& \left. - E_{LIS} \left\{ -\frac{m_V}{P\bar{e}} \frac{x_V}{P} - \frac{1-m_V}{P} \frac{x_V}{P\bar{e}} \right\} \right) > 0,
\end{aligned}$$

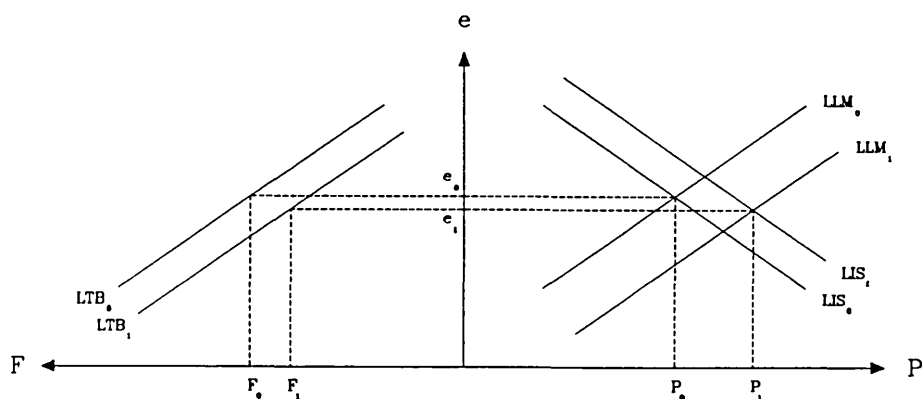
and

$$\begin{aligned}
\frac{\partial \bar{e}}{\partial M} = & \frac{1}{|A^L|} \left(-\frac{c'_V}{P\bar{e}} \left\{ \frac{x_V}{P} P_{LM} - P_{LTB} \frac{1-m_V}{P} \right\} \right. \\
& + P_{IS} \left\{ -\frac{m_V}{P\bar{e}} \frac{x_V}{P} - \frac{1-m_V}{P} \frac{x_V}{P\bar{e}} \right\} \\
& \left. + \frac{c'_V}{P} \left\{ \frac{m_V}{P\bar{e}} P_{LTB} + P_{LM} \frac{x_V}{P\bar{e}} \right\} \right) < 0.
\end{aligned}$$

The economic effects of the long run multipliers can be analysed with the help of Figure 3.3, which shows the shifts of the various curves. As is evident, an increase in the supply of money shifts all three curves but it shifts them to different degrees. This is because the resulting changes in the exchange rate

work in opposite directions. For example, e is pushed down in the money market and as a consequence of the shift of the long run TB curve, but it is also required to rise in the goods market. Since the absolute change in e is small, the change in P has to be the larger to re-equilibrate the markets. Apart from this function, the rise in P also cuts real private wealth and as a consequence F falls, as Figure 3.3 clearly shows.

Figure 3.3: Long run change in M



3.4.1.2 A change in the production of oil

The effects of an increase in domestic oil production on the three endogenous variables F , P , and e can be computed from equation (3.21) as

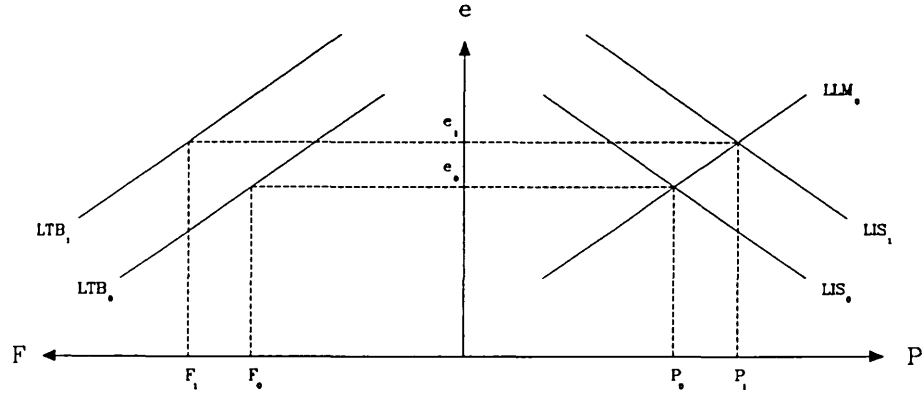
$$\begin{aligned} \frac{\partial F}{\partial OIL} = \frac{1}{|A^L|} & \left(\frac{x_O}{P\bar{e}} \left\{ -P_{LM} E_{LTB} - E_{LLM} P_{LTB} \right\} \right. \\ & + P_{IS} \left\{ E_{LLM} \frac{x_O}{P\bar{e}} \right\} \\ & \left. - E_{LIS} \left\{ -P_{LM} \frac{x_O}{P\bar{e}} \right\} \right) > 0, \end{aligned}$$

$$\frac{\partial P}{\partial OIL} = \frac{1}{|A^L|} \left(-\frac{c'_V}{P\bar{e}} \left\{ E_{LLM} \frac{x_O}{P\bar{e}} \right\} - \frac{x_O}{P\bar{e}} \left\{ \frac{m_V}{P\bar{e}} E_{LTB} - E_{LLM} \frac{x_V}{P\bar{e}} \right\} - E_{LIS} \left\{ -\frac{m_V}{P\bar{e}} \frac{x_O}{P\bar{e}} \right\} \right) > 0,$$

and

$$\frac{\partial \bar{e}}{\partial OIL} = \frac{1}{|A^L|} \left(-\frac{c'_V}{P\bar{e}} \left\{ P_{LM} \frac{x_O}{P\bar{e}} \right\} + P_{IS} \left\{ -\frac{m_V}{P\bar{e}} \frac{x_O}{P\bar{e}} \right\} - \frac{x_O}{P\bar{e}} \left\{ \frac{m_V}{P\bar{e}} P_{LTB} + P_{LM} \frac{x_V}{P\bar{e}} \right\} \right) > 0.$$

Figure 3.4: Long run change in oil production



The effects of an oil production increase are less complex than those of an increase in the money supply, as here only two curves in Figure 3.4 shift: the LIS and the LTB curve. Since *OIL* only affects net exports the resulting changes of the two curves are the same. That is, the increase in *OIL* leads to an increase in net exports, which shifts both curves outwards. To equilibrate

the goods market again, increases in P and e are necessary; this last increase will also neutralise the temporary disequilibrium in the balance of payments.

A comparison of our long term comparative statics results with those of other major studies reveals the following. The paper by Eastwood and Venables (1982) as amended by Neary and van Wijnbergen (1984) shows an overshooting exchange rate, and an overall increase in the real exchange rate, whose contractionary effects may outweigh in some cases the expansionary spending effects that also follow the discovery and exploitation of an oil resource. The case of Buiter and Purvis (1983) is similar. In their examples of an oil discovery, they distinguish between a permanent effect of the discovery on oil production and a temporary effect. The case of a permanent increase — which would be comparable to our case — again yields a similar appreciation of the real exchange rate.

Our own results confirm the standard appreciation of the real exchange rate, but they also show a strong rise in the domestic price level. Within the context of the model this implies that the new steady state level of output is higher than during the ‘pre-oil’ state. A recession has therefore not occurred. This result can be traced back to the strong wealth effect that originates from the current account, which is a direct consequence of our specification that includes a feedback mechanism from the current account to the rest of the model. As oil production proceeds, a current account surplus is likely, and the economy’s stock of foreign denominated bonds therefore increases. This then adds to the overall stock of private wealth and reinforces the expansionary spending effects that follow an increase in oil production.

3.4.1.3 *A change in the level of the foreign interest rate*

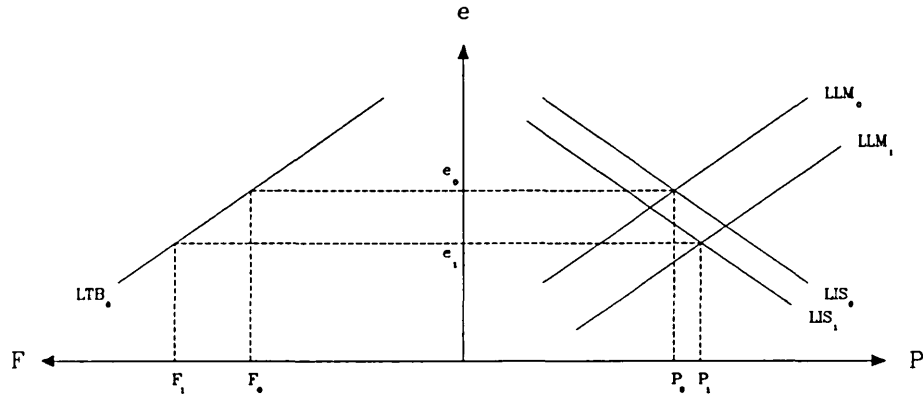
The effects of an increase in foreign interest rate on the three endogenous variables F , P , and e can again be computed from equation (3.21), and this yields

$$\begin{aligned} \frac{\partial F}{\partial r^*} = \frac{1}{|A^L|} & \left(i_r \left\{ -P_{LM} E_{LTB} - E_{LLM} P_{LTB} \right\} \right. \\ & + P_{IS} \left\{ -m_r E_{LTB} \right\} \\ & \left. - E_{LIS} \left\{ -m_r P_{LTB} \right\} \right) > 0, \end{aligned}$$

$$\frac{\partial P}{\partial r^*} = \frac{1}{|A^L|} \left(-\frac{c'_V}{P\bar{e}} \left\{ -m_r E_{LTB} \right\} \right. \\ \left. - i_r \left\{ \frac{m_V}{P\bar{e}} E_{LTB} - E_{LLM} \frac{x_V}{P\bar{e}} \right\} \right. \\ \left. - E_{LIS} \left\{ m_r \frac{x_V}{P\bar{e}} \right\} \right) > 0,$$

$$\frac{\partial \bar{e}}{\partial r^*} = \frac{1}{|A^L|} \left(-\frac{c'_V}{P\bar{e}} \left\{ m_r P_{LTB} \right\} \right. \\ \left. + P_{IS} \left\{ m_r \frac{x_V}{P\bar{e}} \right\} \right. \\ \left. + i_r \left\{ \frac{m_V}{P\bar{e}} P_{LTB} + P_{LM} \frac{x_V}{P\bar{e}} \right\} \right) < 0.$$

Figure 3.5: Long run change in interest rate



As in the previous case, here again there are only two curves that shift consequent upon an increase in the foreign interest rate. But Figure 3.5 shows that they are not the same — the balance of payments is not affected. As for the LIS and LLM curves, both shift downwards; but the shift in the LIS curve is relatively smaller than that of the LLM curve. This is because P has to fall to re-equilibrate the money market, but it also has to rise to balance the goods market again; the composite effect is a small rise in the domestic price level.

This, combined with the original rise in r^* that caused e to fall, means that there is excess demand for money in the money market and a further drop in the exchange rate and a swelling of the net position of foreign assets are required to return to a general equilibrium.

3.4.2 Stability analysis of the long run

In order to see whether the model is stable, the following analysis has been carried out. By stability we mean that the equation system will return to its long run equilibrium values when subjected to any kind of disturbance. This implies that the two differential equations (3.11) and (3.13) have to be stable. For the state-space representation of these equations it is required that they be functions of F and P only. That is, we have to find $Y(F, P)$ and $F \cdot e \cdot P(F, P) = Z(F, P)$; both functions will then be linearised around their long run equilibrium values and can be substituted into equations (3.11) and (3.13) to yield

$$\begin{bmatrix} \dot{P} \\ \dot{F} \end{bmatrix} = \begin{bmatrix} \alpha \frac{\partial Y}{\partial F} & \alpha \frac{\partial Y}{\partial P} \\ \frac{\partial Z}{\partial F} & \frac{\partial Z}{\partial P} \end{bmatrix} \begin{bmatrix} F - \bar{F} \\ P - \bar{P} \end{bmatrix}, \quad (3.27)$$

or in matrix notation

$$\dot{\mathbf{X}} = \mathbf{A} \bar{\mathbf{X}}. \quad (3.28)$$

For this system to be stable, we require that $\text{tr}(\mathbf{A})$ be negative and that $|\mathbf{A}|$ be positive.

$$\begin{aligned} \text{tr}(\mathbf{A}) &= \gamma \frac{\partial Y}{\partial F} + \frac{\partial Z}{\partial P} \\ &= \gamma \frac{\partial Y}{\partial F} + eX + P \left\{ \frac{\partial e}{\partial P} \left(X + e \frac{\partial X}{\partial e} \right) + e \frac{\partial X}{\partial Y} \frac{\partial Y}{\partial P} \right\} < 0, \end{aligned} \quad (3.29)$$

and

$$\begin{aligned}
|A| &= \gamma \frac{\partial Y}{\partial F} \frac{\partial Z}{\partial P} - \gamma \frac{\partial Y}{\partial P} \frac{\partial Z}{\partial F} \\
&= \gamma \frac{\partial Y}{\partial F} \left(eX + P \left\{ \frac{\partial e}{\partial P} \left(X + e \frac{\partial X}{\partial e} \right) + e \frac{\partial X}{\partial Y} \frac{\partial Y}{\partial P} \right\} \right) \\
&\quad - \gamma \frac{\partial Y}{\partial P} \left(P \left\{ \frac{\partial e}{\partial F} \left(X + e \frac{\partial X}{\partial e} \right) + e \frac{\partial X}{\partial Y} \frac{\partial Y}{\partial F} \right\} \right) > 0.
\end{aligned}$$

For either condition to hold true we make the auxiliary assumptions that

$$\frac{\partial Y}{\partial F} > 0, \quad \frac{\partial e}{\partial P} < 0,$$

and

$$\frac{\partial e}{\partial P} \left(X + e \frac{\partial X}{\partial e} \right) > e \frac{\partial X}{\partial Y} \frac{\partial Y}{\partial P}.$$

The economic interpretation of these assumptions is as follows. The first condition implies that the negative influence which an increase in private wealth has on net exports through increased imports outweighs the influence of greater private wealth on the demand for money — the former would reduce aggregate demand while the latter would imply an increase in aggregate demand. Similarly, the second condition implies that the effects on the goods market (a fall in net exports and consumption) again outweigh the effects on the money markets, so that overall the exchange rate will have to fall to re-establish equilibrium. The third condition states that changes in the domestic price level affect net exports more strongly via the exchange rate than via income.

3.5 CONCLUSIONS

In this chapter, we have presented a theoretical model of an open economy with an oil extracting sector. The model will form the basis of an econometric model of the UK economy, which will be developed in the next chapter. Similar to other models concerned with the effects of oil on the economy³, our

³We have compared our results with the outcomes of Neary and van Wijnbergen (1984), and Buiter and Purvis (1983). Further studies with similar characteristics are surveyed in Chapter 2.

model is largely based on Dornbusch (1976). Within his model, the exchange rate can be shown to overshoot its long term steady state value, when the economy is subjected to the discovery of oil reserves, or a monetary contraction. These results are essentially due to the assumptions of sticky prices in the goods market and instantaneous movements of the exchange rate in the assets market.

The Dornbusch model has been used widely⁴ in explaining Dutch disease phenomena of a declining manufacturing sector as a consequence of the discovery and exploitation of a natural resource, such as oil or gas. A weakness of Dornbusch-type models is their lack of a link between the current account and the assets market. An economy would therefore be allowed to run indefinite current account imbalances without ever experiencing correcting effects of a change in the exchange rate. This was recognised *inter alia* by Kawai (1985) and Karakitsos (1989). Incorporating the effects of wealth accumulation on the assets market, our model therefore has different long run characteristics to conventional Dornbusch-type models.

The model's short term results, in contrast, are standard. It was shown that an increase in oil production leads to an appreciation of the nominal exchange rate. In the long run, however, while still displaying a standard appreciation of the nominal exchange rate, the model shows a strong upward movement in the domestic price level. This implies a higher, new steady state level of output, and is in contrast to results commonly obtained. Neary and van Wijnbergen (1984), for example, find a recession a likely consequence of the discovery of an oil resource. This occurs because the contractionary effects of the increase in the real exchange rate outweigh the expansionary effects of increase spending in their model. The unambiguous increase in national income within our model, however, essentially occurs because the spending effect has been reinforced by a larger stock of foreign wealth. This has been shown to be a direct consequence of the inclusion of a feedback mechanism between the current account and the rest of the model. Increases in oil production swell the economy's holding of foreign denominated bonds, which — as part of private wealth — affect the goods market as well as the money market. A recession does not occur because here the expansionary wealth effects outweigh the contractionary effect of a higher real exchange rate. Finally, we have shown that the model is stable, provided that three intuitively appealing conditions hold.

⁴see Chapter 2.

In this chapter, we have not discussed which dynamic paths the exchange rate may take in adjusting from one equilibrium to another — something which other papers on the exchange literature (e.g. Dornbusch (1976) or Kawai (1985)) have commented on. Since Kawai (1985) has shown that the dynamic exchange rate paths may be considerably more complex than those predicted by simple models as in Dornbusch (1976), we leave this as a matter to be investigated in Chapter 6, where our econometric model will undergo various simulation exercises.

Chapter 4

An Econometric Model of the UK Economy

4.1 INTRODUCTION

In the previous chapter we presented a theoretical model of an open economy with an oil producing sector. Within the model, oil influences the economy in two ways — one affecting wealth with consequent spending effects, the other affecting the exchange rate with effects on the price system of the economy. An increase in domestic oil production, for example, raises output on the demand side and thus creates excess demand in the goods market. This imbalance will be passed on to the assets market, as the shift in output will increase the demand for money. Since prices are sticky in the short run but the exchange rates moves instantaneously, the imbalance in the assets market is neutralised by an appreciation of the exchange rate. The disequilibrium in the goods market disappears only in the longer run, once prices have risen to reduce excess demand. An important feature of the model in Chapter 3 is an influence of current account imbalances on the assets market, and the exchange rate in particular. Through this link, the economy is inhibited from running indefinite current account deficits by experiencing counterbalancing movements in the exchange rate.

This chapter is concerned with the specification and estimation of an econometric model relating to the UK economy. The econometric model will embody the theoretical structure described in Chapter 3 — particularly the links just mentioned — but it will reflect the dynamic structure characterised by historical data.¹ The model will be linked with a model of the international oil market (that will be presented in the next chapter) to allow an analysis of the interaction of the UK economy and the international oil market; results of this analysis will be reported in Chapters 6 and 7.

¹The time horizon of the estimation depends on data availability; in most cases, however, estimation covers the period 1963–1985.

The estimation methodology that has been employed is based firmly on probability theory and stresses therefore thorough mis-specification testing of proposed econometric relationships. The methodology also discriminates between concepts such as theoretical and empirical models, and theoretical variables and observed data series. It is therefore suited to explain the fluctuations in many economic variables, which followed the abandonment of the Bretton-Woods system of fixed exchange rates and the two oil price shocks in the 1970s.

The first two sections of the chapter deal with methodological aspects of estimation. This is followed by the presentation of the econometric model and a discussion of the estimation results.

4.2 ECONOMETRIC METHODOLOGY

It is the aim of economic theory to explain real life phenomena, or more formally, it pretends to be an idealised description of the actual data generating process (DGP). However, there are three reasons why the econometrician should beware of accepting the equivalence of a theory and the data generating process. First, certain theoretical variables cannot be observed or have a different meaning from the observed data. The most famous example of this dichotomy in applied economics has been Friedman's concept of permanent income whose data cannot be observed. Second, the amount of revisions statistical offices undertake before 'correct' data series are published makes it plain that measurement errors are a common feature. A third handicap is that there often exist several data series which might correspond to the theoretical variables, and that, therefore, there is scope for erroneous model specification.

A proper econometric methodology ought to be aware of these caveats and should ideally lead to the *best* possible approximation of the DGP by discriminating rationally between alternative representations. We follow a methodology that is well advanced in the literature and that accounts for these considerations by placing both specification and estimation process within a probabilistic framework.² This ensures that concepts such as theoretical and

²see Spanos (1986) and refer to the next section which will discuss the underlying statistical assumptions of the modelling procedure in detail.

empirical models, or theoretical variables and observed data series are regarded as distinct, and it permits the use of statistical test procedures to discriminate between alternative models by eliminating mis-specified models from a set of possible econometric models. The adopted methodology goes back to Fisher [1890–1962] who postulated “modelling of a probability model [...] as a generalised description of the actual data generation process (DGP), as the realisation of a sample from a process” (Spanos, 1986, p.8). This paradigm was recognised by Haavelmo (1944) as providing the statistical framework within which systematic statistical inference (i.e. estimation, testing and prediction) was possible.

During the next 30 years or so, econometricians used a different methodology — one, however, which was blamed for the breakdown of many econometric relationships in the 1970s. The abandonment of fixed exchange rates (the Bretton Woods agreement) and the two oil price crises changed the economic climate from one that moved fairly placidly and monotonously to one where key economic variables fluctuated heavily in short periods of time. Conventional modelling methodology was ill-equipped to cope with these structural changes for a number reasons. It relied too heavily on static economic theories rather than dynamic ones, it took no account of the temporal structure of the observed data series, it ignored the possibility that several data series might correspond to the same theoretical variables, and it largely disregarded any underlying statistical properties of econometric models and therefore paid little attention to thorough testing of estimated relationships.³

Davidson *et al.* (1978), and Hendry and Mizon (1978) took the lead of Sargan (1964) who was among the first economists to open up the strict modelling methodology in order to allow a role for the data in determining the specification of economic models. Sargan assumed the exact form of the model that was tested to be unknown and thereby assumed implicitly a distinction between a theoretical economic model and an econometric model. The role of economic theory was reduced to influencing the long run properties of econometric economic models through ‘error-correction methods’ (ECM). The short-run dynamics of the model were influenced by the temporal structure of the data. The distinction between a theoretical and an econometric model was justified on three accounts. First, it is deemed highly unlikely that the observed data that are chosen are in fact unique measurements of the theoretical variables involved. Second, it seems equally unlikely that the

³see Hendry (1980), Sims (1980) or Leamer (1983).

nature of the observed data series chosen, i.e. time series, cross-section or panel data, does not have any influence on the specification of the economic model. In fact, early studies of the consumption function involving the estimation of the average propensity to consume have shown that the estimated coefficients vary with the type of data chosen. And third, there might not be a one-to-one relationship between the statistical parameters and the theoretical parameters.

These points highlight the inherent difficulties in the construction of an econometric model. For the practitioner, the methodology advocates a general-to-specific respecification approach that is guided by several model selection criteria. In the general-to-specific respecification approach, a general hypothesis is progressively simplified in such a way that new specifications are accepted by statistical tests. It is important to realise that consecutive mis-specification testing and acceptance of the chosen specification are necessary for obtaining an econometric model, but they are not sufficient. Since there are no fixed rules as to how to obtain unambiguously the *best* approximation to the DGP, certain model selection criteria are commonly employed in addition to constant mis-specification testing.⁴ These consist of — *inter alia* — theory consistency, robustness (including near-orthogonality of explanatory variables), weak exogeneity and encompassing.

Some of these criteria are straightforward. It is, for example, desirable that econometric models be consistent with at least one economic theory (there may of course be alternative theories). Equally desirable is to obtain parameter estimates that remain constant throughout the estimation horizon. Other criteria are less intuitive. Weak exogeneity is necessary to condition the endogenous variable on the regressor set. It also has consequences on the choice of estimator that is used for a particular equation. If the RHS variables were not weakly exogenous, they would be endogenous and had to be modelled and estimated jointly in a simultaneous system by an appropriate systems estimator, say FIML or 3SLS. Otherwise, if the regressors are weakly exogenous, the equation may be consistently estimated by, for example, OLS.

Encompassing is another important criterion as it seems desirable if, in addition to providing an adequate parametrisation of the actual DGP, an econometric model is able to explain the results that rival models obtain with a different specification. This can be shown using the example of a simple log-linear model

⁴see Hendry and Richard (1983).

$$y_t = \beta_1 x_t + \beta_2 x_{t-1} + \beta_3 y_{t-1} + \epsilon_t. \quad (4.1)$$

This general model contains various model types as restricted sub-models,⁵ which are commonly employed in econometric modelling. Among them are the static regression model, partial adjustment models and error correction mechanism models, each entailing appropriate parameter restrictions. The error correction representation of (4.1) has attracted much attention as a way of specifying dynamic equations. The interest in this model arises from the common occurrence in economic theory of homogeneity or proportionality restrictions. By imposing the restriction $\sum \beta_i = 1$ in (4.1) the following ECM equation results

$$\Delta y_t = \beta_1 \Delta x_t + (\beta_3 - 1)(y - kx)_{t-1} + \epsilon_t, \quad (4.2)$$

with $k = \frac{\beta_1 + \beta_2}{1 - \beta_1}$ and $y = kx$ as the long run proportionality condition. Consequently, error correction models are dynamic representations which reproduce in equilibrium the associated equilibrium theory. An interpretation is that agents marginally adjust y_t from y_{t-1} in response to changes in the previous 'error' $(y - kx)_{t-1}$ with proportion $(\beta_3 - 1)$. Interestingly, (4.2) offers an account of why a small value of β_1 is compatible with proportionality in the long run. Because the ECM formulation is in differences, i.e. Δx , and in levels, i.e. $(y - kx)$, regressors become near-orthogonal, and this avoids problems of multi-collinearity. The economic justification for the use of ECM in formulating economic models is given by the partial adjustment theory in conjunction with second order autoregression.

The practical developments of econometrics have led to the adoption of ECM. This, in turn, has led to a reappraisal of the statistical foundations of much of econometric theory. Benefiting from research into pure statistics and time-series properties of data series, Granger and Weiss (1983) have suggested the concept of cointegration. This rests on the notion of an integrated series, which is

A series with no deterministic component which has a stationary, invertible, ARMA representation after differencing d times, is said to be integrated of order d , denoted $x_t \sim I(d)$ (Engle and Granger (1987)).

A cointegrated series can then be defined as follows

⁵see Hendry and Richard (1983) for a typology.

The components of the vector x_t are said to be *co-integrated of order d , b* , denoted $x_t \sim CI(d, b)$, if (i) all components of x_t are $I(d)$; (ii) there exists a vector α ($\neq 0$) so that $z_t = \alpha' x_t \sim I(d - b)$, $b > 0$. The vector α is called the *co-integrating vector*. (Engle and Granger (1987)).

The concept of cointegration is relevant to econometrics for two reasons. First, it provides a theoretical justification for ECMs⁶. Second, it is useful from a practical modelling point of view in that it enlarges the scope of long run relationships in econometric models. Whereas ECMs usually involve the ratio of two variables⁷, cointegrating vectors may contain a number of variables or expressions, provided only that all are integrated of the same order⁸.

This has described the methodology behind the econometric specification of our model. The estimation procedure of each equation followed the following scheme. Start with a dynamic linear equation of the type (4.2), adjusted for the appropriate number of regressors. This form has been restricted and reparametrised until a valid econometric model was obtained. The process was accompanied by sequential testing of any misspecification of the statistical generating mechanism (GM). In the case of cointegrating equations, we followed the two-step procedure suggested by Engle and Granger (1987). At the first step a levels regression is run. Included are those variables that are thought to influence the endogenous variable in the long run. As mentioned above, all included variables must be integrated of the same order. The regression error is then saved and introduced as a regressor into the estimation that is estimated in the second step. This usually involves regressors in differenced form, and again it is important that all of them are integrated of the same order. This can be tested using procedures developed by Dickey and Fuller (1979), and by Sargan and Bhargava (1983).

Testing for cointegration first requires to test whether a particular series x_t is integrated, and this is done by testing whether its autoregression has a unit root. For instance, in its first order form, the test is whether $\alpha = 1$ in

$$\Delta x_t = -\alpha x_{t-1} + \epsilon_t,$$

⁶see Engle and Granger (1987) for a proof that ECMs generate cointegrated series, and that conversely cointegrated series can be represented as an ECM.

⁷see the example of the consumption function in Davidson *et al.* (1978), or Sargan's wage equation (1964), *inter alia*.

⁸see for example, Hall (1986).

where ϵ_t is a white-noise error. If so, x_t follows a random walk. This can be tested using the Dickey-Fuller, DF , and the Augmented Dickey-Fuller, ADF , test statistics. The null hypothesis of either test is that a series is a random walk. Rejection of the null implies stationarity and requires large, negative values of the t -statistic. Engle and Granger (1987) have calculated a set of critical values, which at the 5% level are 3.37 for the DF and 3.17 for the ADF test statistic of at least 100 observations. Since our sample is much smaller, any results can only be taken as suggestive rather than conclusive. Recursive estimation and the resulting t -values help to identify whether the estimated α is driven towards unity in view of shifts in the sample, which may cause biasedness in the test statistics of DF and ADF . After establishing the order of integration for a set of variables, the cointegration test is similar to the above test applied to the residuals of a static regression of $I(1)$ variables. A problem with the current generation of cointegration test statistics is that Engle and Granger only report critical values for equations with 2 or 3 variables. In the absence of critical values for equations with more than 3 variables we rely again on RLS (recursive least squares) estimates and suggest stationarity if the estimate of α over time differs significantly from zero.

4.3 STATISTICAL ASSUMPTIONS OF ESTIMATION PROCEDURE

The previous section discussed general aspects of estimation methodology and stressed the importance of mis-specification testing in the methodology adopted in this thesis. In this section, we now discuss in detail the statistical assumptions upon which the estimation procedure is based and we discuss and present a set of mis-specification tests commonly employed.

The estimation methodology adopted in this study is put forward in Hendry and Richard (1982, 1983)⁹ and is based on the notion of the data generating process (DGP). This is simply equivalent to the joint probability distribution of the vector of endogenous variables, $\mathbf{y}_t$. The joint distribution can be written as

$$\prod_{t=1}^T D(\mathbf{y}_t | \mathbf{Y}_{t-1}, \mathbf{Z}_{t-1}; \theta)$$

⁹see also Gilbert (1986).

where $\mathbf{Z}_{t-1} = (z_1, \dots, z_{t-1})'$, a vector of regressor variables, and $\boldsymbol{\theta}$ is a vector of parameters of the joint density function D .

The joint density function D , in turn, is the expression of a statistical model, which is specified in terms of three interrelated concepts: the statistical generating mechanism (GM), the probability model and the sampling model. These concepts can be briefly explained in the context of the dynamic linear regression model, the model type that has been used throughout this thesis. The statistical generating mechanism is a probabilistic vehicle that provides an approximation to the actual DGP. It is specified in very general terms as

$$y_t = \beta'_0 \mathbf{x}_t + \sum_{i=1}^m \alpha_i y_{t-i} + \sum_{i=1}^m \beta'_i \mathbf{x}_{t-i} + u_t, \quad t > m.$$

Economic theory does only influence the choice of observed data series and the general form of the estimable model, but it does not, for example, dictate the size of m , the number of lags. The next concept upon which the statistical models is based is the probability model. This embodies the probability distribution that underlies the statistical generating mechanism and is specified as

$$\Phi = \left\{ D(y_t | \mathbf{Z}_{t-1}^0, \mathbf{X}_t; \boldsymbol{\theta}^*) = \frac{1}{\sigma_0 \sqrt{2\pi}} \exp \left\{ -\frac{1}{2\sigma_0^2} (y_t - \boldsymbol{\beta}^{*'} \mathbf{X}_t)^2 \right\}, \right. \\ \left. \boldsymbol{\theta}^* \in \mathbb{R}^{m(k+1)} \times \mathbb{R}_+, t > m \right\}.$$

The last concept, the sampling model, provides the link between the probability model and the observed data series.

The estimation process proceeds from the general specification of the statistical generating mechanism to an econometric model. However, a valid econometric model requires that all assumptions that underlie the statistical model are valid. We now discuss these assumptions and the mis-specification tests that have been used throughout the estimation procedure to test their validity.

4.3.1 Assumptions on the statistical generating mechanism

The first assumption refers to the definition of the systematic component of the statistical generating mechanism.

$$[1] \quad \mu_t = E(y_t | \sigma(Y_{t-1}^0), X_t^0 = x_t^0) = \beta_0' x_t + \sum_{i=1}^m (\alpha_i y_{t-i} + \beta_i' x_{t-i}).$$

This assumption is made in order to contain all the systematic information of $D(Z; \psi)$ into the conditioning set of y_t . From the specification of μ_t it follows that the non-systematic part of the statistical generating mechanism, u_t , can be interpreted as a ‘noise’ term that is common in the engineering literature. In order to ensure that the information which μ_t contains is maximised, the optimal size of m , the number of lags, has to be chosen and of course tested. The implication of $m < m^*$ would be that omitted lagged Z_t s would form part of the unmodelled part of y_t , which means that the error term will no longer be non-systematic. Ultimately, this will invalidate the consistency and asymptotic properties of the parameter estimates. If $m > m^*$ the problem of multi-collinearity would arise. The correct size of m can be easily tested by calculating a test-statistic $\tau(y)$ which is based on an F -test for linear restrictions of the following type:

$$\tau(y) = \frac{RRSS - URSS}{URSS} \left(\frac{T-k}{m} \right),$$

where $RRSS$ and $URSS$ stand for restricted and unrestricted residual sums of squares. T and k refer to the unrestricted model and stand for the number of observations and the number of regressors respectively; m indicates the number of restrictions imposed.

Another way of testing the correct number of lags is to apply the tests that are usually employed to verify the independent sample assumption. The Lagrange multiplier (LM) test for $AR(p)$, where $p \geq 1$, can here be used to test indirectly whether $m < m^*$, where m^* is the optimal number of lags. The Durbin Watson cannot be applied when there are lagged dependent variables among the explanatory variables in the equation.

The second assumption defines what the (statistical) parameters of interest are.

$$[2] \quad \theta^* \equiv (\alpha_1, \alpha_2, \dots, \alpha_m, \beta_0, \beta_1, \dots, \beta_m, \sigma_0^2).$$

This assumption stresses that at the outset the statistical GM is not assumed to coincide with either the theoretical model or the actual DGP. This implies that at this stage there is a difference between the statistical parameters and

the (economic) theoretical parameters. The statistical parameters of interest provide only a statistically sufficient parametrisation if the theoretical parameters are defined as functions of the statistical parameters, i.e. theoretical parameters are only well-defined if they are related to well-defined statistical parameters. However, the determination of the theoretical parameters of interest is a matter of specification testing.

[3] X_t is strongly exogenous with respect to θ^* .

The assumption of strong exogeneity requires that X_t be weakly exogenous with respect to θ and that Y_{t-1}^0 do not Granger-cause X_t . The exogeneity assumption entails the following advantage. The issue of endogeneity is now related to the parametrisation of the model and therefore is no longer a problem of estimation bias. Weak exogeneity is difficult to test directly but it is argued (Engle *et al.* (1983)) that when assumptions [6]–[8] are valid weak exogeneity can be assumed. This is because marginalisation and conditioning of the model are incorrect unless assumptions [6]–[8] are valid. The second requirement for strong exogeneity is that lagged dependent variables must not Granger cause X_t , the vector of assumed explanatory variables.

The question of whether the regressor set is exogenous or not influences the choice of the estimator. If all regressor variables are weakly exogenous, a single equation estimator, such as OLS, is commonly used. If however potentially endogenous variables are contained in the regressor set, a systems estimator, such as FIML, has to be used to counteract the simultaneity bias, which would arise if a single equation estimator was used. Some econometric models are totally estimated by FIML. Examples are the Bergstrom-Wymer model (Bergstrom, 1975), which comprises 10 behavioural equations, or the model presented in Hamzavi-Rad (1988), which consists of 8 behavioural equations. However, these last two models are nonlinear in parameters as well as in variables and are for that reason alone estimated by the systems estimator FIML. But a limitation to the use of FIML as an estimator is imposed by the very large computer resources it requires. These rise rapidly with the number of equations to be estimated. For this reason, all of the major quarterly macroeconometric models of the UK economy (NIESR, LBS, BE and HMT)¹⁰ are mainly estimated with single estimation methods. These models comprise

¹⁰These acronyms translate as follows: NIESR = National Institute of Social and Economic Research, LBS = London Business School, BE = Bank of England, HMT = Her Majesty's Treasury.

a large number of behavioural equations — around 90 for the National Institute model and 700 for the Treasury model. In another example, Davis (1987) uses OLS throughout to estimate a medium sized model of around 45 behavioural equations.

- [4] The parameters $\alpha \equiv (\alpha_1, \alpha_2, \dots, \alpha_m)'$ satisfy the restriction that all the roots of the polynomial

$$\left(\lambda^m - \sum_{i=1}^{m-1} \alpha_i \lambda^{m-i} \right) = 0$$

are less than one in absolute value.

Restrictions on α are needed to ensure that $\{y_t, t \in T\}$ as generated by the statistical GM is an asymptotically independent stochastic process.

- [5] $\text{rank}(\mathbf{X}^*) = m(k+1)$ for all observable values of $\mathbf{Y}_T^0 - m, T > m(k+1)$.

If $\text{rank}(\mathbf{X}^*) = n < m(k+1)$, then a unique θ^* does not exist. As a consequence, multi-collinearity will arise. This, however, is not a very common occurrence. In practice, the problem which arises most is that of ‘near collinearity’. Since we distinguish between a statistical model and an economic model the problem of ‘near collinearity’ is closely related to the statistical, and *not* the theoretical, parametrisation of the equations in question.

4.3.2 Assumptions on the probability model

The next assumptions refer to the statistical properties of the probability model. The first of these requires the distribution of the joint density to be normal.

- [6] (i) $D(y_t / Z_{t-1}^0, \mathbf{X}_t; \theta^*)$ is normal

If the underlying distribution was not normal, maximum likelihood estimation could not be employed. An alternative estimation method could however be used. More critical would be that certain test statistics, e.g. some for

heteroskedasticity and structural change, would be invalid because they depend on the normality assumption.

Normality problems can be tested using the skewness and kurtosis indicators in the following test statistic proposed by Jarque and Bera (1980)

$$\text{Normality} = \frac{T-k}{6}(SK^2 + \frac{1}{4}EK^2) \stackrel{H_0}{\sim} \chi^2(2),$$

where k is the number of regressors and

$$SK = \frac{1}{T-1} \sum_{t=1}^T (x_t - \bar{x})^3 / \left(\frac{1}{T-1} \sum_{t=1}^T (x_t - \bar{x})^2 \right)^{1.5}$$

and

$$EK = \left\{ \frac{1}{T-1} \sum_{t=1}^T (x_t - \bar{x})^4 / \left(\frac{1}{T-1} \sum_{t=1}^T (x_t - \bar{x})^2 \right)^2 \right\} - 3.$$

Under the null hypothesis the series being tested is assumed to be normally distributed.

The next assumption requires the functional form of the regressors to be linear.

$$(ii) \quad E(y_t / \sigma(Y_{t-1}^0), X_t^0 = x_t^0) = \beta^{*'} X_t^* - \text{linear in } X_t^*.$$

The implications of nonlinearity are that the estimates of β^* and σ^2 would be biased and inconsistent. Moreover, most testing procedures would also become invalid. In the context of the dynamic linear regression model linearity problems can be tested with the RESET test statistic. This tests whether the original model is correct by including powers of $\hat{y}_t$ s in an auxiliary equation. An example of a first order test is the equation

$$y_t = \alpha_0 + \alpha_1 x_{it} + \gamma \hat{y}_t^2.$$

The test calculates whether $H_0: \gamma = 0$.

This assumption refers to the variance of the regression equation and requires it to be constant and therefore free from any influence of the regressors.

$$(iii) \quad var(y_t | \sigma(Y_{t-1}^0), X_t^0 = x_t^0) = \sigma_0^2 \text{ — homoskedastic (free of } X_t^*).$$

The assumption of homoskedasticity is interlinked with that of normality and one cannot be rejected without rejecting the other too. This can be tested with the White's test or the ARCH test. For example, in its first order the ARCH test (autoregressive conditional heteroskedasticity) tests the hypothesis $\alpha_1 = 0$ in the model:

$$\hat{u}_t^2 = \alpha_0 + \alpha_1 \hat{u}_{t-1}^2.$$

and

$$ARCH = TR^2 \sim \chi^2(r)$$

under $H_0: \alpha_1 = 0$. However, following Harvey (1981) and Kiviet (1986) the F -form is reported.

White's heteroskedasticity test (see White (1980)) is based on an auxiliary regression of the squared residuals, $\hat{u}_t^2$, on all squares of the original regressors. In its first order form it is

$$\hat{u}_t^2 = \alpha_0 + \alpha_1 x_{it}^2$$

The test statistic is calculated as follows

$$\text{Heteroskedasticity} = \frac{R^2}{1 - R^2} \frac{T - k - l}{l} \stackrel{H_0}{\sim} F(l, T - k - l).$$

The null hypothesis is $H_0: \alpha_1 = 0$.

A third test of heteroskedasticity can be used to judge very generally whether the functional form of the equation is acceptable or whether the equation is misspecified. The test is again based on an auxiliary regression of the squared residuals, $\hat{u}_t^2$. The regressors, however, now include the cross products of the original regressors as well as all its squares. In its first order form the regression takes the following form

$$\hat{u}_t^2 = \alpha_0 + \alpha_1 x_{ijt}^2 \quad \forall i, j = 1, \dots, k,$$

with k being the number of regressors. The test statistic is calculated in the same manner as is the above test for heteroskedasticity as

$$\text{Functional form} = \frac{R^2}{1-R^2} \frac{T-k-l}{l} \stackrel{H_0}{\sim} F(l, T-k-l).$$

Another important assumption of the probability model is that of parameter constancy.

[7] θ^* is time invariant.

Time variance of the parameter estimates is a consequence of incorrect conditioning of the variables. Whether estimated parameter values change over time or not can be ascertained from two test statistics provided — the Forecast statistic and the Chow test. The Forecast test is calculated as

$$\text{Forecast} = N^{-1} \sum_{T_2+1}^{T_2+N} \frac{f_t^2}{\hat{\sigma}_{T_2}^2} \stackrel{H_0}{\sim} \chi^2(N)/N,$$

where $f = y - \hat{y}$, the forecast error, and the null hypothesis is $H_0: \beta_1 = \beta_2$; $\sigma_1^2 = \sigma_2^2$, which implies structural constancy of the models in time periods 1 and 2, the base period and the forecast period. Kiviet (1986) notes that the Forecast statistic judges the numerical constancy of the estimated parameter values and is not a specification test, something for which the Chow test is better suited. He also remarks that the values of the Forecast statistic are always larger than those of the Chow test, which is calculated as follows

$$\text{Chow} = \frac{RSS_{T+N} - RSS_T}{N \cdot RSS_T} (T_2 - T_1 + 1 - k) \stackrel{H_0}{\sim} F_{T_2 - T_1 + 1 - k}^N$$

where T refers to the restricted sample size, N refers to the number of forecast periods, and k refers to the number of regressors. The null hypothesis is the same as for the Forecast test above.

4.3.3 Assumptions on the sampling model

The next assumption refers to the sampling model of the statistical model

- [8] $\mathbf{y} \equiv (y_{m+1}, y_{m+2}, \dots, y_T)'$ is a stationary, asymptotically independent sample sequentially drawn from $D(y_t/\mathbf{Z}_{t-1}^0, \mathbf{X}_t; \theta^*)$, $t = m+1, m+2, \dots, T$, respectively.

The independent sample assumption is the most crucial of the eight assumption considered because most results depend on it. In particular, if the independent sample assumption was invalid, the estimates of β and σ^2 would be biased and inconsistent. Moreover, most mis-specification tests would be invalidated. It is important to note that in the context of the above proposed methodology the error term is assumed to be an innovation process and that therefore the systematic component of the statistical GM has to be respecified in order to take into account the time dependent information embedded in the sample, a process which Spanos (1986) coined re-specification approach. The testing of the independent sample assumption can be done by calculating a Lagrange multiplier test based on the statistic

$$LM(\mathbf{y}) = TR^2 \stackrel{H_0}{\sim} \chi^2(mk).$$

Moreover, the test statistics which are normally used to detect error-autocorrelation can be used within the present framework as well, for the following reason. The error term in the statistical generating mechanism $\{u_t, t > m\}$ is assumed to be a normal, stationary and asymptotically independent process. This process can be approximated to any degree by an ARMA(p, q) stationary process with large enough p and q . The standard error autocorrelation tests then test whether or not the parameters in the ARMA(p, q) process are different from zero. If they are the error is no longer non-random and the systematic part of the model has to be respecified. For first-order autocorrelation the well-known Durbin-Watson test can be used. The Durbin-Watson statistic tests for autocorrelated errors in

$$u_t = \rho u_{t-1} + \epsilon_t$$

under $H_0: \rho = 0$. The test statistic is calculated as

$$DW = \frac{\sum_{t=T_1+1}^T (\hat{u}_t - \hat{u}_{t-1})^2}{\sum_{t=T_1}^T \hat{u}_{t-1}^2}.$$

The DW statistic is only valid if there are no lagged dependent variables on RHS of the regression equation. If there are, the DW test is biased towards accepting H_0 , and the reported F -test for autocorrelation should be used in this case.

4.4 PRESENTATION AND ESTIMATION OF MODEL

In this section we present a small annual macroeconometric model of the UK economy, which is designed to highlight the effects of UK oil production on the economy. The general model structure will be outlined on a sector-by-sector basis. Each sector's function and role with respect to oil in the economy will be discussed, and then followed by a more detailed presentation of the unestimated equations in the model. Estimation results will be discussed subsequently on an equation-by-equation basis.

4.4.1 General Model Structure

The general structure of the econometric model is based on the theoretical model of Chapter 3. Output is demand determined in traditional Keynesian form, with estimated equations of all of its main constituents: consumption, investment, exports, imports. Government expenditure is taken to be as a policy variable. Both imports and exports are divided into an oil part and a non-oil part to trace better the developments that originate from UK oil production, which is also taken as a policy variable under broad control of the UK government. Changes in the value of UK oil production — i.e. changes in the price or the produced quantity of oil — affect oil exports in the first instance. Variations in oil exports then change total output in the economy, and further changes on the demand side of the economy follow suit, affecting consumption, investment, and imports.

The equation structure of the real sector is as follows.¹¹ Equation (A.1) is an identity determining the contribution of oil to the gross domestic product. It is based on a simple price times quantity evaluation, where the sterling oil price, *POILS*, is deflated by the model's proxy of prices, the consumer price index, *PC*. *SUKB* is the quantity of oil produced and *SUKBAD* is some adjustment factor. Equation (A.2) is an unestimated behavioural equation which stipulates that 60% of the contribution of oil to GDP is exported. Clearly, the value of 60% is to be regarded as an average value, which seems appropriate for the time period studied but which will probably have to be modified once oil exploration diminishes because of geological factors.¹² Equation (A.3) determines how much of its GDP the economy saves by producing its own oil. This identity can also be found in LBS (1986). Equations (A.4) and (A.5) determine total exports and total imports; both magnitudes consist of a non-oil part (*XOX* and *IM*) and an oil part (*XOIL* and *IMSAV*). Total final expenditure and gross domestic product are determined in equations (A.6) and (A.7). Finally, real personal disposable income, *RPDI*, is determined in equation (A.8) as the basic difference between GDP and real income tax, *RINCTAX*. Since the model does not contain a sector where GDP is built up from income, equation (A.8) also contains an adjustment factor accounting for the differences in the national accounts.

In equations (A.9)–(A.10), real expenditure tax, *REXP**TAX*, real income tax, *RINCTAX*, and potential GDP, *GDPT*, are determined through simple least-squares fits. Equation (A.11), determining potential or trend GDP, depends on two time trends, whereby *TR70* accounts for lower GDP growth during the 1970s and early 1980s. A similar equation can be found in LBS (1986). Non-oil GDP is determined in equation (A.12). And for notational convenience, equations (A.13) and (A.14) depict the ratios of *GDPE* and *GDPT*, and *AFC/GDPE* in a more succinct form. The remaining equations of the real sector, equations (A.15)–(A.18), are all fully estimated and will be discussed in turn in the following section.

Supply side effects of changes in oil production work through the exchange rate and prices in the economy. Of great importance to an open economy, such as the UK economy, is the exchange rate. In the theoretical

¹¹See Appendix A for the listing of the complete model; Appendix B lists variable definitions and data sources.

¹²Similar assumptions have also been made by other studies. See, for example, Motamen (1983) or LBS (1986).

model of Chapter 3, the exchange rate moves instantaneously to neutralise any imbalances between foreign and domestic levels of interest. These might occur in our econometric model as a consequence of government policy, since foreign interest rates are taken as exogenous and domestic rates to be under control of the UK government. A distinguishing feature of the theoretical model of Chapter 3 is the additional influence of the current account on the exchange rate. The effects of changes in oil production therefore affect the exchange rate via the current balance. The exchange rate, in turn, transmits any changes into the price sector, and then into the demand side of the economy. There are two types of price equations — one covering the trade sector, the other determining domestic prices. Prices of imports and exports, in the trade sector, depend on the exchange rate, but also pass on any changes in the economic system to the current balance. Domestic price equations — for wages, consumer and producer prices — are affected by overseas prices that will reflect any changes in exchange rates, and they are affected by domestic conditions in the goods market.

The price sector, the balance of payments and the exchange rates are described by equations (A.19)–(A.32), of which equations (A.19)–(A.26) are identities. In equations (A.19) and (A.20), two foreign price indices — the dollar oil price, *POILD*, and the international wholesale price index, *INWWPI* — are converted into domestic currency units using the dollar exchange rate, *DOLLEXR*, and the effective (nominal) exchange rate index, *EXRAT*. The nominal balance of payments, *BAL*, is determined in equation (A.21) as the difference of total exports and total imports, both converted into nominal quantities through their respective price index, *PEX* and *PM*. The real interest rate differential, *RINTDIF*, between the UK economy and overseas is simply the difference between the two quantities that are determined in equations (A.22) and (A.23) — the domestic and the overseas real interest rates. Finally, the last two identities of this sector describe the nominal exchange rate and the dollar exchange rate. The nominal exchange rate is obtained in a standard transformation involving the real exchange rate, *REXRAT*, and the ratio of foreign and domestic wholesale prices. For simplicity, the change of the dollar exchange rate follows that of the nominal exchange rate, as described by equation (A.26). This simplifying assumption is justified, since the dollar exchange rate determines largely the movement of the effective exchange rate index (the nominal exchange rate). As before, the behavioural equations of the price and foreign sector of the model, equations

(A.27)–(A.32), are fully estimated and will be discussed in detail in the next section.

We continue with the monetary sector. The supply of money is demand determined, with two estimated behavioural relationships for the stock of bank lending to the private sector and the stock of bonds in the economy. Other quantities in the determination of money supply are taken to be exogenous. Changes in the oil sector affect the monetary sector through the induced changes in the stock of private wealth. However, following Keynesian tradition, there is no direct link between the monetary sector and the rest of the economy. The only link there is, is indirect and constituted by the treasury bill rate. Through this variable the government is assumed to influence the economy and thus to respond to changes caused by variations in the value of oil production.

The monetary sector is described by equations (A.33)–(A.43) of which equations (A.33)–(A.41) are identities. The total real tax take of the government, *RALLTAX*, is shown in equation (A.33) to be the sum of real expenditure tax and real income tax. The total government tax receipts are used in equation (A.34) to obtain the real public sector borrowing requirement, *RPSBR*. This is converted in equation (A.36) as additions of the real public sector borrowing requirement and the real current account balance to the previous period's stock of real wealth.¹³ Equations (A.37), (A.39), and (A.40) transform real quantities into nominal ones. Because of their close interdependence, the rate of change of consols follows that of the exogenous treasury bill rate, as shown in equation (A.38). Finally, equation (A.41) shows the important asset market identity which shows the composition of the money supply, *M3S*, in its flow form.

4.4.2 Private consumption

Private consumption makes up around 50% of total final expenditure, and even a higher proportion of gross domestic product. Therefore, an understanding of

¹³As in equation (A.34), an adjustment factor is necessary also in this equation to compensate for the lack of a proper current price sector. This has been left out in order to keep the model simple and to concentrate the analysis on the interaction of oil with the rest of the economy.

what factors influence and determine consumption are of crucial importance to policy makers and hence to macroeconomic forecasters.

At the early stages of macromodelling developments, three distinct consumption theories influenced the modelling approaches of its determination. Keynes, in his General Theory (1936), relates actual levels of personal income to consumption. Later developments by Friedman (1957) and Ando and Modigliani (1963) suggest longer term influences on current consumption decisions and therefore link current and lagged levels of income and wealth to the level of consumption expenditure. Even though models based on these theoretical underpinnings performed well until the early 1970s, they were found to be misspecified in view of the inability to forecast shifts and to explain factors associated with higher inflation levels after the first large oil price increase in 1973/74.

The response of the macromodellers to higher inflation levels during the 1970s is surveyed by Davis (1984). An important theoretical contribution was made by Deaton (1977) who explains the higher levels of saving with the concept of *rational money illusion*. According to this, consumers save rather than spend for as long as the actual inflation rate exceeds the expected one. The important practical modelling contribution came from Davidson *et al.* (1978) who use a model combining differences of variable terms with an error-correction formulation specified to imply proportionality of income to consumption, and who incorporate various lags of consumer prices in their equation.

Other researchers have kept the basic structure of Davidson *et al.*, but have also variously included other terms into the equation. Bean (1978), for example, uses real wealth and, alternatively, the acceleration of the unemployment rate as explanatory variables. Hendry and von Ungern-Sternberg (1979) add liquid assets to the variable set, whereby the long run consumption-income ratio depends on economic growth, inflation, and the assets-income ratio. In a further development of Hendry and von Ungern-Sternberg, Hendry (1981) includes the real interest rate into the equation in order to model influences on liquid assets. Davis (1984) in his comparative study of the major consumption functions finds that this inclusion is “an important factor in the determination of consumption” which contributes to the relatively good performance of this type of equation.

Since 1985, however, most equations — in particular Davidson *et al.*

(1978) — that fared well during the 1970s have broken down. The equations for consumer non-durables have been underpredicting, and the equations for durables have been overpredicting actual events. One noticeable feature of consumers' behaviour has been a sharp drop in the savings ratio from around 16% in 1979 to about 4% in 1987. Various explanations have been put forward¹⁴. Among them are the role of financial deregulation, the importance of housing wealth, and the role of interest rates and demographic factors. The changes that are being made to existing equations, however, do not affect the general explanatory variable set¹⁵, rather they concern using various definitions of existing variable concepts and relate therefore to the problem of associating a particular economic theoretical variable with available economic data series. For the wealth variable, for example, some modellers include housing wealth (LBS), others include mortgage debt (NIESR), others again use as their wealth variable the ratio of net financial wealth to inflation adjusted income (Bank of England and HMT). However, these matters concern recent changes that fall beyond our investigation period and we therefore ignore them.

It is clear from this brief survey that the general variable set used in consumption studies consists of the following theoretical concepts: real personal disposable income, wealth, inflation, and interest rates. What data series are used in practice, and what level of disaggregation is chosen often depends on the scope of the modelling exercise. Since our model focuses on the interaction of oil and the economy at an aggregate level, the estimation of a consumption function was started with the above mentioned minimum set of variables.

We started the investigation by analysing the time series properties of the variables involved. Table 4.3 shows the Dickey-Fuller, *DF*, and the augmented Dickey-Fuller, *ADF*, test statistics for each variable.¹⁶ It is evident that none of the variables is stationary, but the size of the statistics for *CON*, *RPDI*, and *TREBILL* suggests that these variables are integrated of order 1. The values for real wealth, *WEALPC*, leave some doubt about its degree of integration, but in consideration of the small sample size it was decided to include all of these variables into a levels regression in order to see whether these variables would form a cointegrating vector. The estimation results are shown in Table 4.1, and the associated stationarity tests¹⁷ indicate that the

¹⁴see, for example, Currie *et al.* (1989).

¹⁵apart of course for the inclusion of demographic variables to account for the relative increase of old people in society.

¹⁶refer to page 30.

Table 4.1: Estimation results of consumption[†]

$$\Delta \ln CON = \underset{(2.55)}{-0.012} + \underset{(9.35)}{0.715 * \Delta \ln RPD I} - \underset{(2.13)}{0.085 * \Delta \ln PC} - \underset{(2.06)}{0.482 * COIN_{t-1}}$$

$$R^2 = 0.899$$

$$DW = 2.05$$

$$\sigma = 0.00761$$

$$RSS = 0.0009268$$

Sample: 1966 to 1985, 20 observations

Estimation method: OLS

Equation diagnostics:

Autocorrelation: $F(1,15) = 0.65$

ARCH: $F(2,12) = 0.75$

Normality: $\chi^2(2) = 0.03$

RESET: $F(1,15) = 0.15$

Forecast: $\chi^2(3/3) = 1.02$

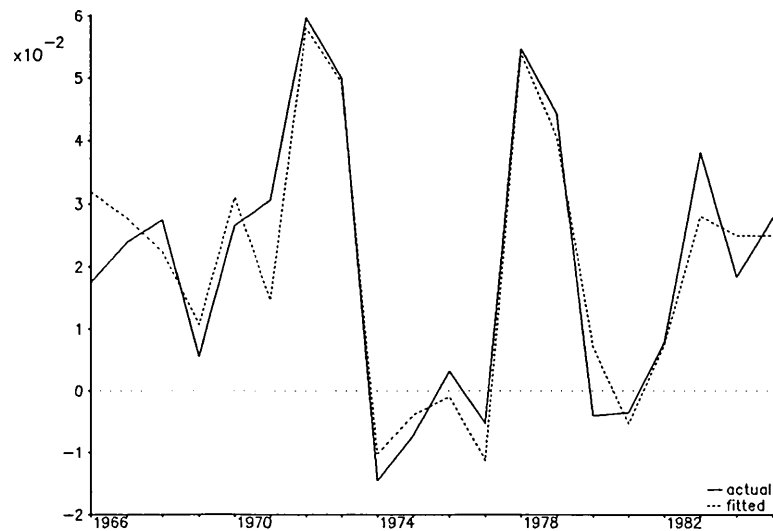
Chow: $F(3,13) = 0.94$

Cointegrating vector:

$$\ln CON = 0.087 - 0.002 * TREBILL + 0.929 * \ln RPD I + 0.037 * \ln WEALPC$$

[†] *COIN* denotes the cointegrating vector of the equation

Figure 4.1: $\Delta \ln CON$ — actual v fitted



¹⁷The stationarity tests of this equation and following equations are also listed in Table 4.3 on page 30.

errors of this regression are indeed stationary and can hence be used in a regression of difference terms. The dependent variable of this regression was therefore taken as the $\Delta \ln CON$, and as explanatory variables $\Delta \ln RPDI$, $\Delta \ln PC$, and the cointegrating vector, $COIN$, were chosen. The regression results are again listed in Table 4.1. This shows that all of the variables are well determined. The estimated equation passes all of the misspecification tests; the forecasting performance is good as is the Chow-test for parameter stability.

The estimated equation implies that consumption is influenced in the short run by real personal disposable income, as well as by inflation, and in the long run by real disposable income, the price level, nominal wealth and the interest rate. The short run elasticity of consumption with respect to income is 0.715; the elasticity with respect to the consumer price index is nearly -0.1 . The data did not support the inclusion of a short run wealth effect, which coincides with common sense as the stock of wealth only changes slowly and any variations take time to be noticed by the consumer. A consequent shift in consumer behaviour is therefore only expected after a certain time lag. In the long run consumption responds to an increase in income with a unitary coefficient, the elasticity with respect to real wealth is 0.038, and that with respect to the nominal interest rate is -0.0026 . The elasticity with respect to the consumer price index is -0.053 .¹⁸

In Davidson *et al.* (1978), the short run elasticity with respect to income is slightly lower than ours at 0.48 and their inflation elasticity is -0.12 which is higher than our estimate. It may be argued that part of the effect of our higher income elasticity may be compensated by a lower inflation elasticity. However more recently, NIESR (1988) estimated a consumption function with an income elasticity of 0.69, which is close to our estimate of 0.715. This higher value may be due to the cointegration specification chosen, which implies a different data set especially in the long run. Earlier studies that made use of error correction methods have included a single ECM variable in the equation, which implies long run proportionality of income to consumption.¹⁹ In contrast to this, NIESR's estimated long run elasticity with respect to income is 0.79, which compares favourably with our estimate. As far as real wealth is

¹⁸It has to be pointed out that our values are difficult to compare exactly with those of other studies because time periods, variable definitions, and periodicity of equations often differ.

¹⁹see Davis (1984) for a discussion of these.

concerned, NIESR obtain a long run elasticity value of 0.05, which is slightly higher than our estimate of 0.038. The real interest rate affects consumption in NIESR with a value of -0.0016 , whereas our estimate of the nominal interest rate is -0.002 . In conclusion it may be said that our results differ from those studies that employed simple error correction methods in the estimation procedure, but they conform closely to studies which have employed the more modern approach of cointegration.

Because of its large share of GDP, consumption is an important transmission variable, whenever the steady state of the economy is disturbed. Changes in the oil sector affect private consumption through several variables. Disposable income will rise after an increase in oil production and therefore boost consumption. An additional boost in the longer term to consumption comes from the stock of real wealth, which will also rise consequent upon an increase in oil production — provided, however, that consumer prices do not rise faster. The induced extra consumption activity will recede, once inflation and/or interest rates have risen. Interest rates will rise as part of the government's economic policy to reduce overheating in the economy.

4.4.3 Investment

Even though investment's proportion of GDP is not as large as that of consumption, it is much more volatile and therefore thought to be chiefly responsible for business cycles²⁰. For this reason, theoretical economists have spent considerable effort in explaining investment behaviour in the economy. The theory most often put forward is based on the *accelerator* principle²¹ and assumes that there exist an optimal level of capital stock. New investment is thought to bridge the gap between the desired level and the existing level. The accelerator principle is employed often in empirical studies²² on the grounds that it performs well. Nonetheless, it has been criticised by the neoclassical economists as an *ad hoc* scheme²³. Neoclassical theory places investment

²⁰see Hicks (1950).

²¹for an exposition, see Wallis (1977).

²²for example in Arestis and Hadjimatheou (1982) or in NIESR (1988).

²³see Jorgenson (1963).

decisions in an overall optimisation framework, where in the search for an optimal combination of factors, substitution effects and therefore relative factor prices enter the formulation of an investment theory. However, the neoclassical approach, in turn, has been criticised on a number of grounds (Arestis *et al.*, 1982). A criticism, for example, is its assumption of a fixed type of production function in order to cater for substitution effects. Cobb-Douglas, CES, or translog production functions are commonly chosen in empirical studies²⁴. However, the criticisms that were made in the discussion of estimation methodology above apply here too. The observed data series do not influence the specification of the functional form at all. Rather, a number of fixed functional forms are tried and selected on grounds of relative performance, which may not imply that they satisfy statistical estimation criteria.

In our model, we adopt the underlying proposition of investment theory — be it Keynesian or neoclassical — that a systematic relationship exist between the desired capital stock and the level of output. Furthermore, this relationship is assumed to vary with the cost of capital, either in absolute terms or — in the neoclassical case — relative to the cost of other input factors.

Before specifying the data set, we survey quickly what investment equations other UK econometric studies have chosen. The investment sector in our model is as the consumption function taken at an aggregate level, that is we allow one equation to explain total investment in the economy. In contrast, the quarterly forecasting macroeconomic models disaggregate the investment sector into several sub-sectors. The NIESR model VIII (1985), for example, divides total investment into nine categories, of which only four however are endogenous. These are investment in private dwellings, investment in the manufacturing sector, investment in the distribution, financial and business services sector, and investment in the rest of the economy. Similarly, the LBS model, as described by Budd *et al.* (1984), has behavioural investment equations for the non-oil manufacturing sector and for the housing sector, but the model has also disaggregated investment into manufacturing and distribution inventories. The variables that influence the two main sectors, manufacturing and housing, are similar in both models. Housing depends on some form of house price inflation index, disposable income, and an appropriate series of interest rates. In addition, the NIESR model has as explanatory

²⁴see Fuss *et al.* (1978) for a survey of functional forms and their application in empirical work.

variables the relative rate of return on investment in housing and the flow of funds into building societies. Investment in manufacturing, in the LBS model, depends on gross domestic product and the share of company profits in national income; in the NIESR model, it depends on past levels of capital stock, retirements from this stock and expectations about future output levels.

Bond and Knöbl (1982) feature one endogenous equation for manufacturing investment. The theoretical underpinning is neoclassical and as the substitution term unit labour costs relative to other countries' labour costs are included in the equation.²⁵ This relative cost term exerts pressure on the manufacturing sector when labour costs are pushed up by an appreciated exchange rate in response to higher oil output. Profitability and growth are falling thus exhibiting Dutch Disease phenomena. Bruno and Sachs (1982) employ a CES production function, but their model is based on 'guesstimates' rather than estimates.

Since our model is more aggregated than either of the NIESR or LBS model but attempts to explain the same phenomena, these variables in our formulation are proxied by the following: gross domestic product, the treasury bill rate, and the price level. GDP is intended to capture the effects of personal income in the equation for housing investment, but also the effects of economic activity in the equation for investment in the manufacturing sector. The treasury bill rate proxies a wide range of interest rates — those prevalent in the housing market as well as those which companies use to decide on investment in the manufacturing sector. Lastly, the price level reflects inflation in the housing market.

The analysis of the time series properties of these variables is again shown in Table 4.3.²⁶ The *DF* and *ADF* test statistics for investment, *INV*, gross domestic product, *GDPE*, and the treasury bill rate, *TREBILL*, suggest these series to be integrated of order 1. The time series of the consumer price index seems to be integrated of order 2, since a minimum requirement for the test statistics to show a stationary series — that of negative values of *DF* and *ADF* statistics — is not met. However, the RLS (recursive least squares) estimate of $\Delta \ln PC$ in Figure 4.4 indicates that consumer prices are integrated of order 1, since two areas of relative constancy are divided by a break in 1977/78. This break can be related to the oil price increases of 1978/79. We

²⁵As an aside, this term is statistically insignificant in the estimation, as are 3 others out of 7 parameters in total. Economic conclusions should thus be treated with caution.

²⁶See page 30.

Table 4.2: Estimation results of investment[†]

$$\Delta \ln INV = 0.018 + 1.083 * \Delta \ln GDPE - 0.285 * \Delta \ln PC - 0.793 * COIN_{t-1}$$

(0.86) (3.26) (1.76) (2.63)

$$R^2 = 0.726$$

$$DW = 2.27$$

$$\sigma = 0.02594$$

$$RSS = 0.0080717$$

Sample: 1970 to 1985, 16 observations

Estimation method: OLS

Equation diagnostics:

ARCH: $F(2,8) = 0.39$

Normality: $\chi^2(2) = 1.01$

RESET: $F(1,11) = 0.49$

Forecast: $\chi^2(3/3) = 2.33$

Chow: $F(3,9) = 1.55$

Cointegrating vector:

$$\ln INV = -4.465 + 1.557 * \ln GDPE - 0.005 * TREBILL - 0.167 * \ln PC$$

[†] *COIN* denotes the cointegrating vector of the equation

Figure 4.2: $\Delta \ln INV$ — actual v fitted

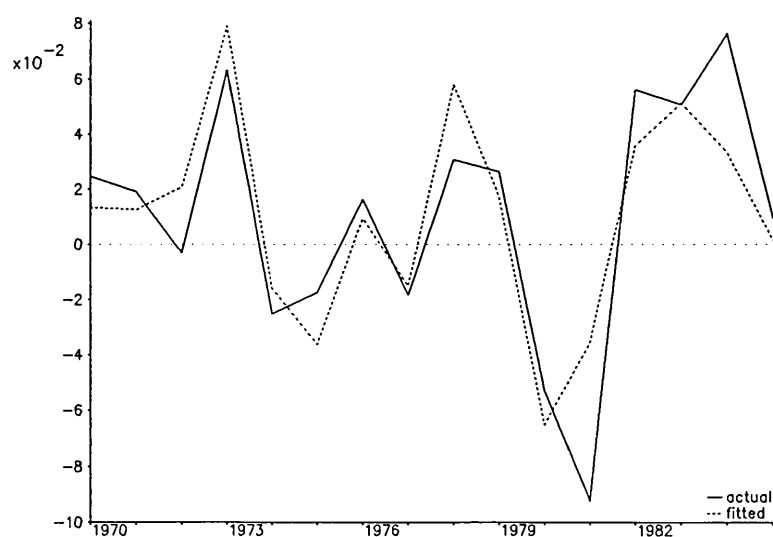
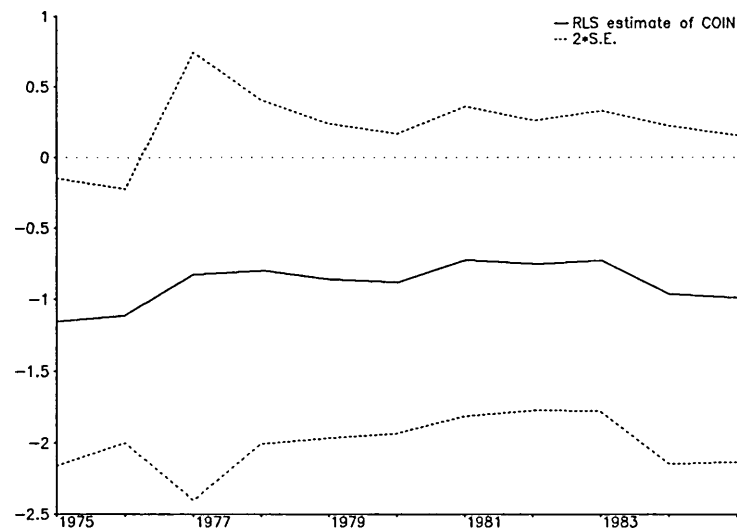
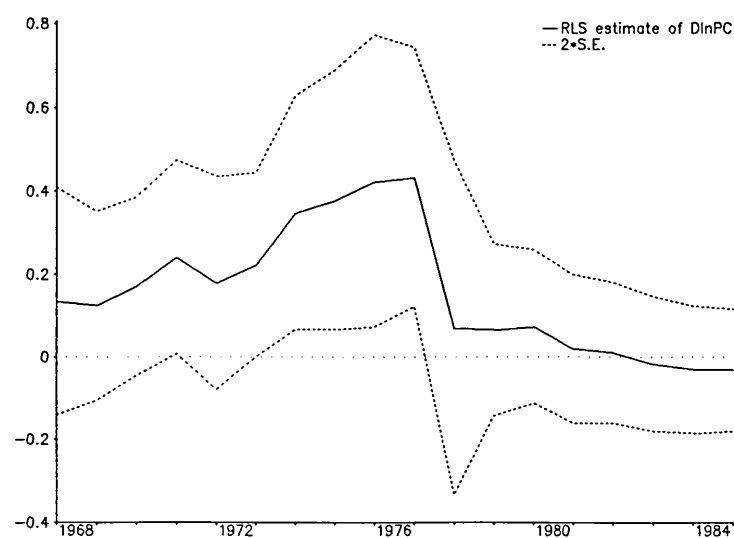


**Figure 4.3: RLS estimation of investment
cointegration vector**



assume therefore for practical purposes PC to be integrated of order 1, which allows us to test whether INV , $GDPE$, $TREBILL$, and PC form a cointegrating vector. This requires that the regression errors form a stationary series. The DF and ADF test statistics of -3.57 and -2.89 (see Table 4.3) do not unambiguously suggest stationarity, but a subsequent RLS estimation of the error process shows this to be constant (see Figure 4.3).

Figure 4.4: RLS estimation of $\Delta \ln PC$



The estimation results of the complete investment equation are shown in Table 4.2. They show that total investment depends in the short run on growth of total output, inflation, and the change in the real interest rate; the long run effects are captured by the cointegrating vector, i.e. by the level of output, the price level, and the nominal interest rate. The variables are well determined in all cases, except for the short term inflation term, which just fails the significance test at the 5% level. It is however significant at the 10% level. The exclusion of this term worsened every other test statistic, especially the R^2 and σ , the standard regression error, so that it was kept in the equation on grounds of goodness of fit. Moreover, none of the misspecification tests indicates any violation of the underlying theoretical statistical assumptions of the estimation process.

The short run elasticity with respect to income is unity, but the long run income elasticity is much larger at 1.54. Nonetheless, a long run elasticity larger than unity is common in applied econometric research of the UK economy. NIESR (1988), for example, report a unity short term coefficient and a long term coefficient of about 2.5. A 1% increase in short term inflation will lower investment by 0.285%; in the long run the elasticity is lower at 0.167. Nominal interest rates do not play a role in the short term, but they feature in the long term.

The investment function in its estimated form implies for our analysis that increases in oil wealth, which ultimately feed into GDP, will be reinforced because of accelerating investment activity. Factors that dampen this induced process are general inflation, indicating overheating of the economy, and higher levels of the interest rate, the monetary policy instrument with which the government is able to stifle excess demand for money and goods alike and thus reduce inflation.

4.4.4 Exports and Imports

The UK as a medium sized economy is a very open economy. Openness in the economic sense can be measured by the relative share of exports or imports in GDP, and Figure 4.5 shows that either measure increased by more than 50 per cent since 1955. The increase for imports has been fairly steady, whereas exports stayed constant around 20 per cent of GDP until 1967 after which a strong increase set in. The trend measuring openness is similar for other

Table 4.3: Time series properties of selected variables

variable	<i>DF</i>	sample size	<i>ADF</i>	sample size
<i>TREBILL</i>	−2.31	29	−1.56	27
Δ <i>TREBILL</i>	−7.11	28	−4.17	26
$\ln$ <i>RPDI</i>	−1.53	29	−2.42	27
$\Delta \ln$ <i>RPDI</i>	−3.93	28	−3.56	26
$\ln$ <i>PC</i>	2.76	29	−.25	27
$\Delta \ln$ <i>PC</i>	−1.67	28	−1.41	26
$\ln$ <i>WEALPC</i>	−1.06	19	−1.89	18
$\Delta \ln$ <i>WEALPC</i>	−1.95	18	−.67	17
$\ln$ <i>INV</i>	−2.68	29	−2.99	27
$\Delta \ln$ <i>INV</i>	−4.15	28	−1.68	26
$\ln$ <i>GDPE</i>	−1.45	29	−2.48	27
$\Delta \ln$ <i>GDPE</i>	−4.94	28	−2.39	26
$\ln$ <i>XOX</i>	−.82	29	−1.25	27
$\Delta \ln$ <i>XOX</i>	−4.17	28	−2.09	26
$\ln$ <i>XWM</i>	−1.23	29	−1.81	27
$\Delta \ln$ <i>XWM</i>	−4.70	28	−1.28	26
$\ln$ <i>REXRAT</i>	−2.02	27	−2.20	25
$\Delta \ln$ <i>REXRAT</i>	−3.77	26	−2.64	24
$\ln$ <i>TFE</i>	−1.01	30	−1.48	28
$\Delta \ln$ <i>TFE</i>	−4.61	29	−3.44	27
$\ln$ <i>IM</i>	−.63	29	−1.29	27
$\Delta \ln$ <i>IM</i>	−5.00	28	−4.24	26
consumption*	−6.60	19	−2.55	18
investment*	−3.57	19	−2.89	18
exports*	−2.35	27	−3.16	25
imports*	−4.90	19	−2.04	18

* cointegrating variable of respective equation

industrialised countries, although levels differ. Table 4.4 shows the US economy to be the least open of the G7 group of industrialised countries and all other countries except West Germany to be less open than the UK.

Table 4.4: Comparison of trade measures

country	measure	1955	1985
France	exports	15.1	23.5
	imports	23.2	24.0
	terms of trade	114.1	98.2
Germany	exports	20.0	35.4
	imports	17.9	31.5
	terms of trade	112.1	112.3
Italy	exports	10.1	21.0
	imports	12.1	22.9
	terms of trade	90.1	91.8
Japan	exports	11.5	16.5
	imports	10.0	12.7
	terms of trade	114.6	129.7
USA	exports	4.4	7.1
	imports	4.3	10.1
	term of trade	102.3	70.1

key: exports denote exports as a proportion of GDP
imports denote imports as a proportion of GDP
source: calculated from IFS, 1986

Figure 4.5: Openness of UK economy

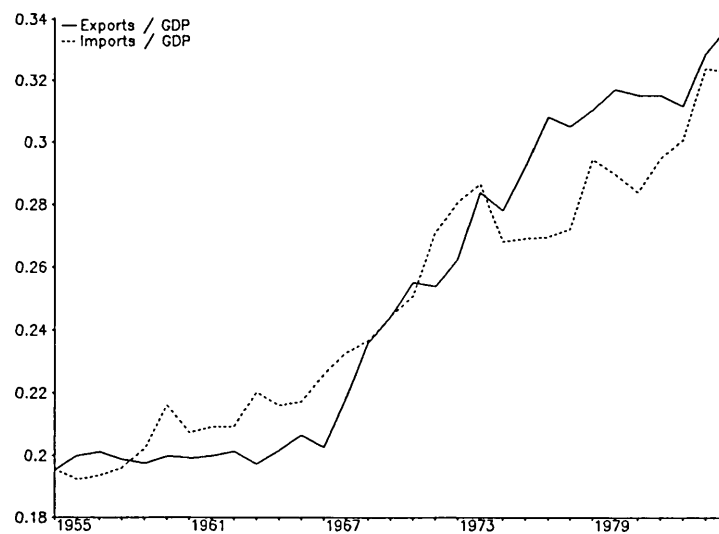
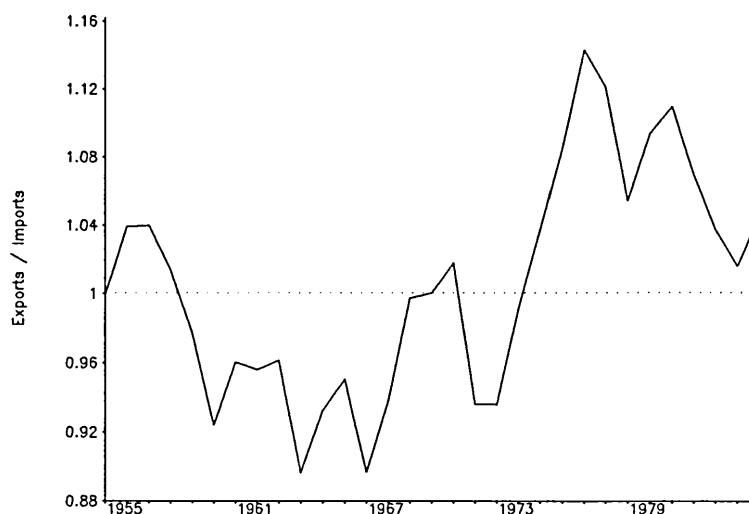


Figure 4.6: UK terms of trade



A second measure of trade performance is the terms of trades indicator, which is the ratio of exports to imports and which describes the volume of imports that a country's exports can buy. Figure 4.6 shows the terms of trades for the UK economy between 1955 and 1985, and Table 4.4 lists comparative values for the other G7 countries. The UK terms of trades show that until 1973 the volume of exports was insufficient to finance the country's imports, and they hence reflect the UK's recurring problem of balance of payments crises. However, oil exports boosted the value of exports during the 1980s. The terms of trades for other countries show Italy to be in a similar position as the UK — it does not export enough to finance its imports. The trend of the terms of trades for France runs opposite to the UK's: it started from a position of strength but showed imports to be greater than exports in the 1985. Germany and Japan especially are shown to be the major balance of payments surplus nations, whereas the US suffered a setback during the years of the Reagan administration in the 1980s.

Exports and imports have both been disaggregated into two categories: one containing oil, the other without, i.e. oil exports and import savings of oil, and non-oil exports and non-oil imports. This division has been chosen to highlight the influence of oil in the economy, and it is common practice in all other models that deal with UK oil extraction. The division is also warranted by the theoretical proposition that higher oil exports lead to Dutch disease problems of a reduction in non-oil exports.

Non-oil exports and imports have been modelled as demand functions, featuring an income term and a relative price term to account for possible substitution effects. In the case of non-oil exports, the income term refers to world income, which is proxied here by the level of world exports of manufactures. The relative price term is modelled as the real exchange rate, which by definition is the ratio of domestic prices to foreign prices that have been converted into domestic currency units.

The analysis of the time series properties of the variable set are reported in Table 4.3. They suggest that all of the variables involved — non-oil exports, XOX , the index of world exports of manufactures, XWM , and the real exchange rate, $REXRAT$ — are integrated of order 1. Since one condition for variables to form a cointegrating vector is met, namely that all variables be integrated of the same order, a regression was run on the levels of the variable set. Table 4.5 shows the estimates, the DF and ADF test statistics for stationarity of the resulting regression errors are again shown in Table 4.3. The ADF test is just significant; in addition, the RLS estimates in Figure 4.8 show the stationarity of the error process. The variables do therefore appear to form a cointegrating set, which was included in the second stage of dynamic estimation of non-oil exports.

The second regression involved the first difference of the log of exports, $\Delta \ln XOX$, as the dependent variable, and as explanatory variables $\Delta \ln XWM$ and the lag of the cointegrating vector. The results show both variables to be well determined, and the equation reaching a high degree of explanatory power. Most of the misspecification tests are passed with ease. Parameter stability is not rejected by the Chow test, but the equation fails the associated χ^2 -test of forecasting performance. However, the graph of the estimated versus the actual path of non-oil exports shows that even though the equation is overpredicting, it is still able to track the turning points well.²⁷ The data does not support the inclusion of a short term influence of the exchange rate, which is appropriate as it takes time to change the production process in order to stimulate exports again (the J-curve effect).

The estimated short run demand elasticity with respect to the index of world exports of manufactures is 0.567. The long run influence hardly differs from this with a value of 0.572. In the long run, relative prices also influence non-oil exports, with an elasticity of 0.34.

²⁷see Figure 4.7.

Table 4.5: Estimation results of non-oil exports[†]

$$\Delta \ln XOX = \underset{(12.82)}{0.565} * \Delta \ln XWM - \underset{(4.98)}{0.590} * \ln COIN_{t-1}$$

$$R^2 = 0.884$$

$$DW = 1.71$$

$$\sigma = 0.01893$$

$$RSS = 0.0093193$$

Sample: 1958 to 1985, 28 observations

Estimation method: OLS

Equation diagnostics:

Autocorrelation: $F(1,25) = 0.46$

ARCH: $F(4,18) = 1.91$

Normality: $\chi^2(2) = 0.49$

RESET: $F(1,25) = 0.00$

Heteroscedasticity: $F(4,20) = 0.32$

Functional form: $F(5,19) = 0.26$

Forecast: $\chi^2(3/3) = 2.94$

Chow: $F(3,23) = 2.27$

Cointegrating vector:

$$\ln XOX = 4.019 + 0.572 * \ln XWM - 0.340 * \ln REXRAT$$

[†] *COIN* denotes the cointegrating vector of the equation

Figure 4.7: $\Delta \ln XOX$ — actual v fitted

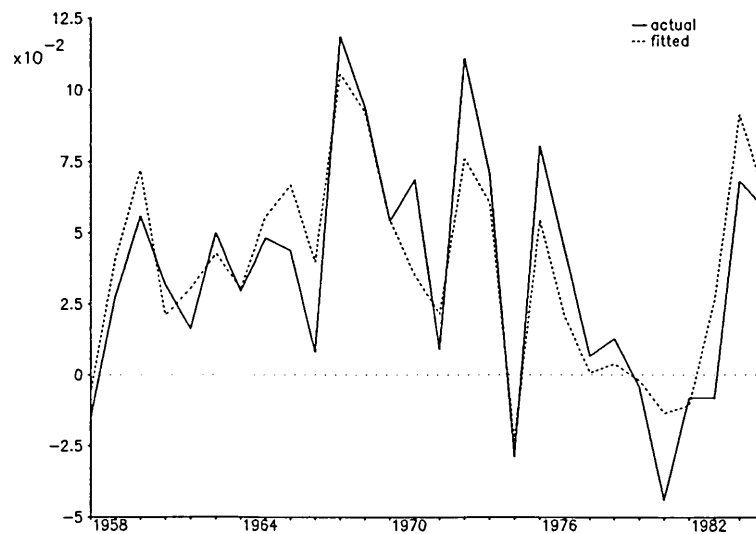
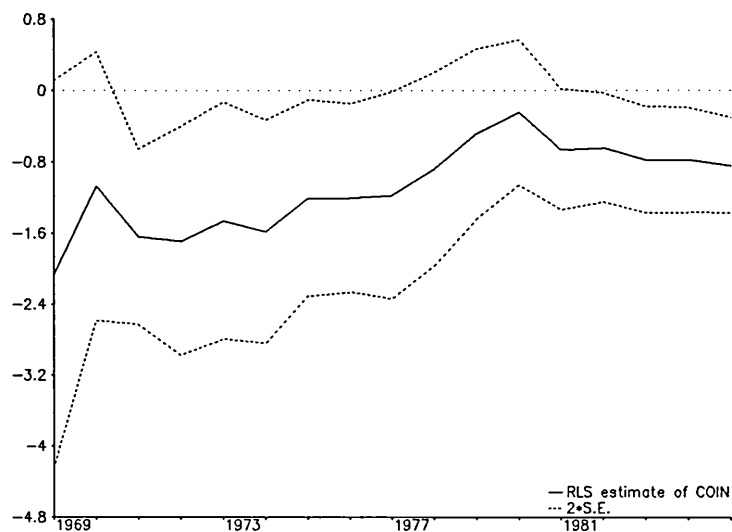


Figure 4.8: RLS estimation of non-oil exports
cointegration vector



In the case of non-oil imports, the income term in the equation is modelled by total final expenditure, TFE ; but the relative price term is the same as in the non-oil export equation — the real exchange rate, $REXRAT$. The time series analysis of the involved variables is again shown in Table 4.3. The figures suggest that all variables are integrated of order 1; hence they can be incorporated into a cointegration regression. Table 4.6 shows the long term estimates, but the cointegration tests for stationarity of the residual errors are shown in Table 4.3. The DF test value of -4.9 unambiguously suggests that the error process is stationary, but the ADF test value of -2.04 leaves some doubt. As a further aide the cointegration regression was rerun using RLS, and the resulting residuals plus the 2 standard error bands are shown in Figure 4.10. The plotted recursive residuals seem stationary, and hence we reject the hypothesis that the variables do not form a cointegrating vector.

The regression results of the subsequent equation that included short term difference terms as well as the long term cointegration vector shows that in the short run imports are only influenced by the income term, TFE . Any short term price influence was not supported by the data. The implied short term income elasticity is 1.58. The variables are well determined, since the relevant t -statistics show them to be significant. Moreover, none of the misspecification show any violation of the underlying statistical assumptions; the forecast performance as well as the test for parameter stability are acceptable.

Table 4.6: Estimation results of non-oil imports[†]

$$\Delta \ln IM = 0.005 + 1.577 * \Delta \ln TFE - 1.300 * \ln COIN_{t-1}$$

(1.31) (13.08) (6.13)

$$R^2 = 0.930 \qquad DW = 2.04$$

$$\sigma = 0.01334 \qquad RSS = 0.0030231$$

Sample: 1966 to 1985, 20 observations
 Estimation method: OLS

Equation diagnostics:

Autocorrelation:	$F(1,16) = 0.03$
ARCH:	$F(1,15) = 0.92$
Normality:	$\chi^2(2) = 0.30$
RESET:	$F(1,16) = 0.18$
Heteroscedasticity:	$F(4,12) = 0.36$
Forecast:	$\chi^2(3/3) = 1.39$
Chow:	$F(3,14) = 1.34$

Cointegrating vector:

$$\ln IM = -6.214 + 1.827 * \ln TFE + 0.158 * \ln REXRAT$$

[†] *COIN* denotes the cointegrating vector of the equation

Figure 4.9: $\Delta \ln IM$ — actual v fitted

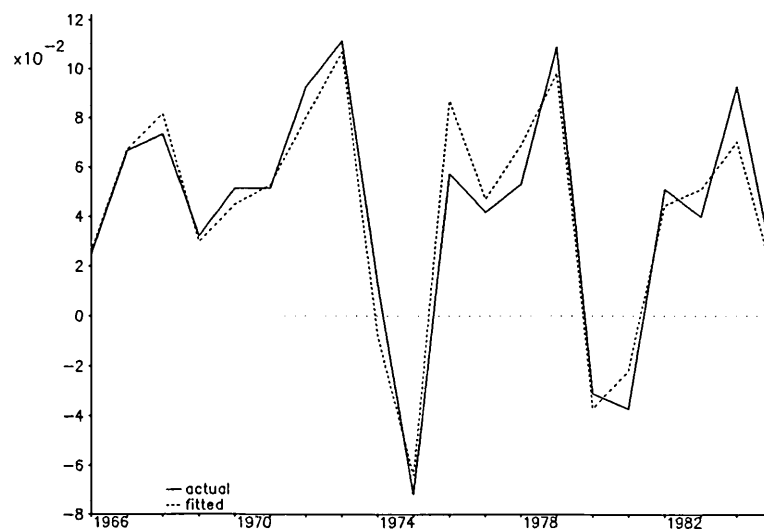
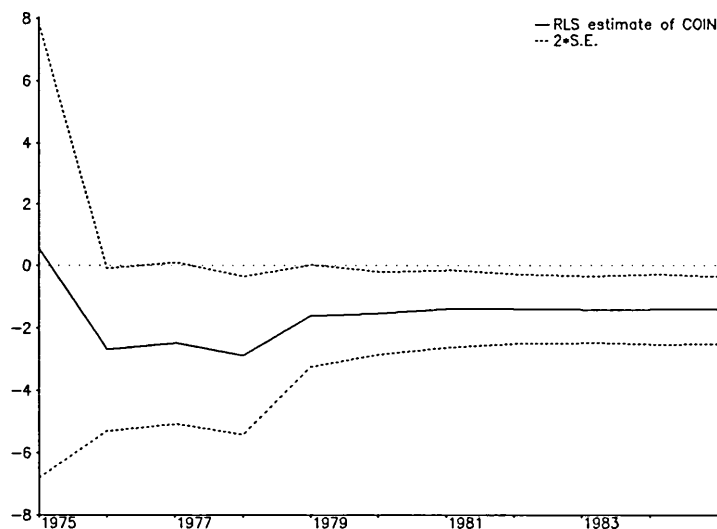


**Figure 4.10: RLS estimation of non-oil imports
cointegration vector**



In the long run, imports are influenced by income, TFE , and by the relative price term, $REXRAT$. The long term elasticity with respect to TFE is 1.83 and higher than its short term equivalent. The long term price elasticity is -0.16 , which implies that a 10 per cent increase in import goods prices will lead to a 1.6 per cent reduction of imports.

The obtained income elasticities of exports and imports highlight a curious phenomenon of the UK economy — the combination of a low export elasticity and a high income elasticity. Similar values have been found by other studies. Houthakker and Magee (1969), for example, found an income elasticity of 1.66 and an export elasticity of 0.86, a value which is higher than ours. But Enoch (1978) found export elasticities ranging from 0.53 to 0.88, thus confirming our estimate. The problematic consequence of this particular combination of elasticities is a loss of international competitiveness of UK industry and persistent current account deficits.²⁸ The danger of this happening is, however, reduced if oil production is increased. As already stated above, total exports are immediately improved because much of the oil production is exported. In the longer term, however, induced changes on the demand side and in prices and the exchange rate will feed into exports and imports. Higher total output will obviously increase total imports, which will also rise if the real exchange rate has been boosted by an improved current account. Nonetheless, the total effect on the current account is uncertain, as a

²⁸for a discussion of the international competitive position of British industry, see Blackaby (1979).

higher exchange rate also improves non-oil exports and, in addition, influences prices of exports and imports.

4.4.5 Export and import prices

Relative export and import prices feature in the determination of the balance of payments identity. The export price index equation is set up as a weighted average of domestic prices and wholesale prices of competing industrial nations. This specification has also been adopted by Davis (1987) and NIESR (1988) *inter alia*. The import price index depends on wholesale prices of competing nations, thus reflecting their cost structure. Built into the variable that represents international wholesale prices, *WWPIS*, is the real exchange rate. This ensures that international wholesale prices are modified according to the relative strength of UK domestic prices.

The estimation results of the two trade price equations are listed in Tables 4.7 and 4.8. Before discussing the economic interpretation of the estimated parameter values, attention needs to be given to the estimation procedure that has been used here. Initially, all equations were estimated by the single equation estimator OLS. However, problems at the simulation stage of the analysis suggested several variables in the price equations to be potentially endogenous and therefore to be estimated by a systems estimator.²⁹ Re-estimation using FIML of 2 groups of price and exchange rate equations produced better results. One group contains the foreign price variables and the real exchange rate, reported in this and the following sub-section; the other comprises the domestic price variables.

The estimates of the export price equation show in Table 4.7 that domestic prices are the prime determinant with a short term elasticity of 0.971. International wholesale prices have a less important influence, their short term elasticity is 0.143. This structure of influence changes little in the long term: the domestic price elasticity is 0.917 and the international price elasticity is 0.103. The estimated values do not add up to unity, either in the short term or in the long term, but since the deviations are not large from this theoretical requirement we did not impose this and thereby avoided any violence to the data.

²⁹see also the discussion in Section 4.3.1 of this chapter.

Estimates of the import price equation in Table 4.8 show a smaller influence of international wholesale prices in the short term than in the long term. The short term elasticity of 0.652 compares with a long term elasticity of 0.93. The dummy variable $D74$ has been included in the equation to account for the sharp increase in oil prices in 1974.

Table 4.7: Estimation results of export prices

$$\Delta \ln PEX = \frac{-0.021}{(3.10)} + \frac{0.971}{(16.96)} * \Delta \ln PIMO + \frac{0.143}{(4.01)} * \Delta \ln WWPIS$$

$$- \frac{1.037}{(6.10)} * \ln PEX_{t-1} + \frac{0.951}{(6.00)} * \ln PIMO_{t-1} + \frac{0.107}{(3.63)} * \ln WWPIS_{t-1}$$

$DW = 1.76 \quad \sigma = 0.00616 \quad RSS = 0.0007599$

Sample: 1966 to 1985, 20 observations
Estimation method: FIML³⁰

Table 4.8: Estimation results of import prices

$$\Delta \ln PM = \frac{0.652}{(8.21)} * \Delta \ln WWPIS - \frac{0.222}{(3.01)} * \ln PM_{t-1} + \frac{0.206}{(2.77)} * \ln WWPIS_{t-1} + \frac{0.155}{(4.46)} * D74$$

$DW = 1.18 \quad \sigma = 0.02083 \quad RSS = 0.0086776$

Sample: 1966 to 1985, 20 observations
Estimation method: FIML³¹

Export and import prices play an important role in determining the current account. However, it is difficult to gauge the relative response of both variables to a change in the oil sector. Export prices are predominantly influenced by domestic wholesale prices, foreign prices only play a minor role. This relationship is reversed in the case of import prices, where foreign prices exert a dominant influence. Quite how foreign prices, as determined in equation (20) of appendix 4.1, react depends on the relative movement of wholesale prices and the real exchange rate. Both are likely to rise in response to higher oil production. *A priori*, the real exchange rate should rise sooner than domestic prices, since the effects of higher oil exports are transmitted quickly to the real exchange rate (via an improved current account).

³⁰jointly estimated with import prices and the real exchange rate.

³¹jointly estimated with export prices and the real exchange rate.

Overheating and therefore higher inflation is a more long term consequence of improved oil exports.

Figure 4.11: $\Delta \ln PEX$ — actual v fitted

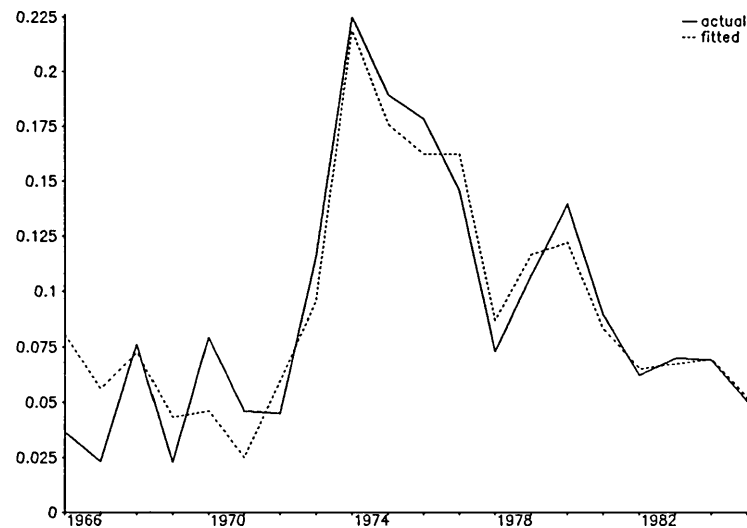
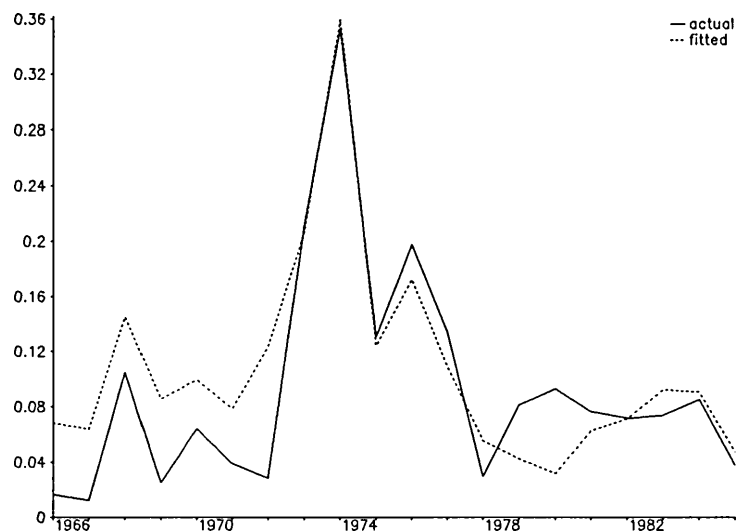


Figure 4.12: $\Delta \ln PM$ — actual v fitted



4.4.6 Real effective exchange rate

The collapse of the Bretton Woods agreement in 1972 replaced fixed exchange rates with floating exchange rates. For economists this meant the beginning of a search process for a coherent theory of the determination of the exchange rate

— a variable they used to regard as exogenous. In a sense, this search is still going on, since numerous surveys³² and practical modelling experience have shown that a satisfactory theory of exchange rate determination is still non-existent. This does not mean that there are no theories. Indeed, several have been proposed: power purchasing parity (PPP), the monetary approach, uncovered interest parity, the asset market approach, etc., some of which we discuss briefly.

Power purchasing parity assumes that relative price levels of trading countries are or become constant. This implies that the nominal exchange rate is related to the movement in relative prices. Frenkel (1981) reports on the failure of PPP to explain exchange rate movements fully.

The monetary approach to the determination of the exchange rate assumes strict PPP, which implies that the real exchange rate is fixed, and that the nominal exchange rate depends on the change in money supply in different countries. A more sophisticated form of the monetary approach only assumes PPP to hold in the long run, because prices are thought sticky in the short run. Then the monetary exchange rate model can be expressed in terms of real interest rate differentials in addition to the relative money supply schemes.³³

Another property of exchange rate theories is the uncovered interest rate differential (UIP). This assumes that domestic and foreign bonds are perfect risk-free substitutes, a condition which links the expected movement in the exchange rate to interest rate differentials.³⁴

The asset market approach to the determination of exchange rates assumes that assets are imperfect substitutes of each other and that demand equations for each type of asset exist. For a given stock of foreign assets, exchange rate and interest rates can then be derived by solving the system of asset demand equations.³⁵

Finally, the balance of payments approach to the determination of the exchange rate inverts the balance of payments identity to determine the real interest rate. The current balance and the capital account are determined in separate equations as are imports and exports. In its final formulation the

³²see for example the contributions in Bhandari *et al.* (1983).

³³an exponent of this theory has been Frankel (1983), but see Spanos and Taylor (1984) for an empirical account.

³⁴see Davidson (1985) for an empirical application.

³⁵see Backus (1984) for an empirical evaluation.

balance of payments approach links the real interest rate to relative changes in output, differences in rates of return on capital, the current balance, and changes in real wealth.

Most of the large UK macromodels use some form of UIP, although the asset market approach is used by the LBS model, and the balance of payments approach by the CUBS model. Fisher *et al.* (1989), however, show that model properties of the UK forecasting models are extremely sensitive to the choice of exchange rate equation. In simulation exercises they substitute their *preferred* exchange rate equation into each model and show that the GDP response to a government expenditure simulation is about the same for each model, whereas model responses vary when the original exchange rate equation is used. Their preferred equation is based on a modified UIP condition, which relates the expected exchange rate to an interest rate differential and a current account term.

In our model, we have adopted a similar approach and used the real interest rate differential, $RINTDIF$, and the real current balance, $\frac{BAL}{PIMO}$, as explanatory variables in the determination of the real exchange rate, $REXRAT$. Table 4.9 shows the estimation results of the exchange rate equation.

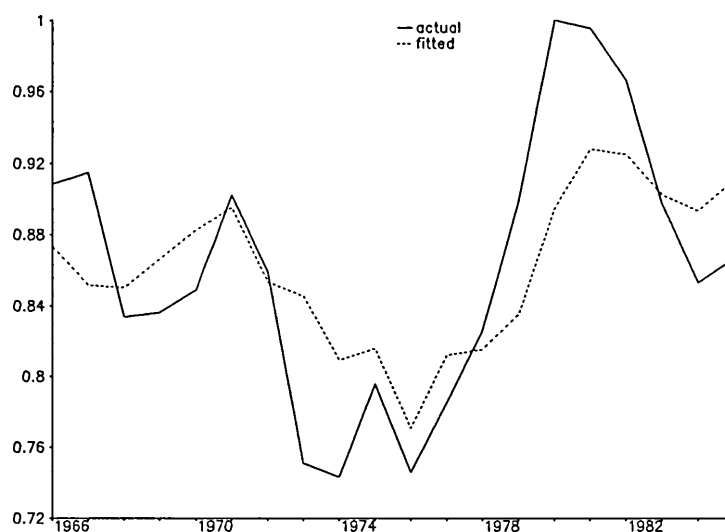
Table 4.9: Estimation results of the real exchange rate

$REXRAT = 0.402 + 0.010 * \frac{BAL}{PIMO} + 0.533 * REXRAT_{t-1} + 0.452 * RINTDIF_{t-1}$			
	(3.40)	(2.45)	(1.96)
$DW = 1.30$	$\sigma = 0.03832$	$RSS = 0.0293613$	
Sample: 1966 to 1985, 20 observations			
Estimation method: FIML ³⁶			

The short term elasticity of the real exchange rate with respect to the real interest differential term is 0.452, a value that matches very closely the equivalent estimate in Fisher *et al.* (1989). The respective elasticity with respect to the real current balance is 0.01. This differs slightly from the estimate of 0.24 in Fisher *et al.*, but they use the ratio of current balance and GDP as a regressor, whereas we have used the real current balance.

³⁶jointly estimated with import and export prices.

Figure 4.13: *REXRAT* — actual v fitted



The important role of the exchange rate has already been highlighted above in the discussion of other variables in the trade sector. It suffices here to re-iterate The main transmission mechanisms through which changes in the oil sector will be passed on to the rest of the economy. An immediate change in the real interest rate will be caused by the real current balance. Although this variable depends on various other variables, it is assumed that substantially higher oil exports will outweigh any counteracting movements in the price variables; the real exchange rate is therefore expected to rise. Changes in interest rates do not have an immediate effect on the exchange rate, but cause a lagged response. This may reflect the government's general attitude to use its policy variables in response to events, rather than anticipating them. In this case, this implies that the government will use interest rates to quell any further demand for money and thereby reduce inflation that may have been caused in the wake of additional spending because of higher oil wealth.

4.4.7 Domestic prices

There are three domestic price equations in the model: consumer prices, producer prices and one equation determining wages. All equations are modelled to account for cost-push as well as demand-pull factors. Tables 4.10 to 4.12 list the estimation results of the price equations. Similar to the group of trade price equations and the exchange rate, the domestic price equations

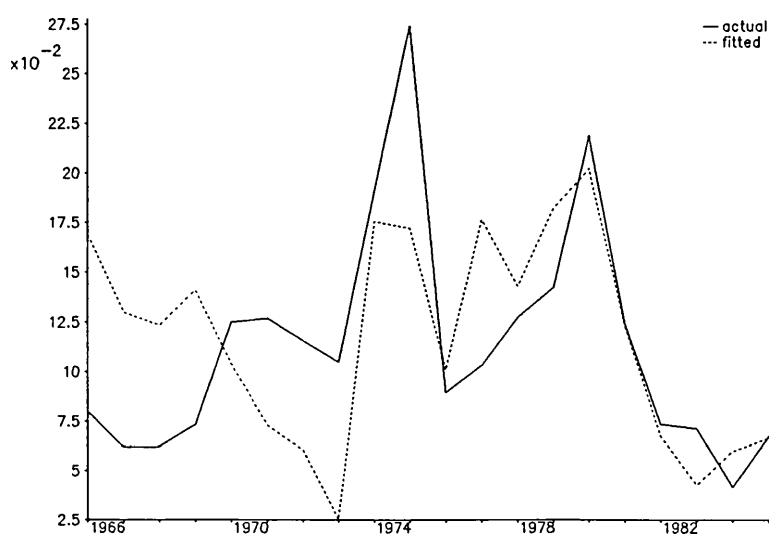
have also been estimated as a system for much the same reasons, but also because preliminary simulation exercises showed the model to solve badly or not at all when single equation estimates of the domestic price equations were used. This seemed to indicate substantial simultaneous equation bias which, however in this case, has subsequently been avoided by the adoption of the FIML estimator.

Table 4.10 shows that in the short run wages depend mainly on consumer prices but also on average working hours. This last influence has also been found significant by Hall (1986). In the long run, wages are influenced additionally by a demand-pull factor, the ratio of GDP to trend-GDP. The long run elasticity with respect to consumer prices is 1.16, a value which rejects the unity homogeneity postulate. However, other researchers have also found large values (e.g. Hall (1986)).

Table 4.10: Estimation results of wages

$\Delta \ln WHR = 0.031 + 0.829 * \Delta \ln PC - 0.334 * \Delta \ln AVH - 0.568 * \ln WHR_{t-1}$		
(2.90)	(8.06)	(3.12) (10.00)
$+ 0.663 * \ln PC_{t-1} - 0.412 * \ln AVH_{t-1} + 0.926 * \ln \left(\frac{GDP}{GDPT} \right)_{t-1}$		
(9.83)	(2.82)	(6.66)
$DW = 1.77$	$\sigma = 0.01512$	$RSS = 0.0045718$
Sample: 1966 to 1985, 20 observations		
Estimation method: FIML ³⁷		

Figure 4.14: $\Delta \ln WHR$ — actual v fitted



³⁷jointly estimated with consumer and producer prices.

Producer prices in the model are determined by costs. These costs arise from domestic as well as international sources. Domestic costs are usually associated with labour costs, whereas international costs are associated with the prices of raw materials or intermediate goods that domestic producers need to import in order to produce their own goods. The domestic costs arise mainly from wage costs, *WHR*, whereas international costs arise from international wholesale prices, *INWWPI*, as well as raw material prices. This last influence is proxied by the oil price index converted into domestic currency, *POILS*.

Table 4.11: Estimation results of producer prices

$$\Delta \ln PIMO = 0.038 + 0.327 * \Delta \ln WHR + 0.075 * \Delta \ln POILS + 0.025 * D77$$

(10.37)
(9.57)
(9.63)
(4.81)

$$- 0.413 * \ln PIMO_{t-1} + 0.114 * \ln WHR_{t-1}$$

(11.81)
(3.70)

$$+ 0.106 * \ln WWPIS_{t-1} + 0.087 * \ln POILS_{t-1}$$

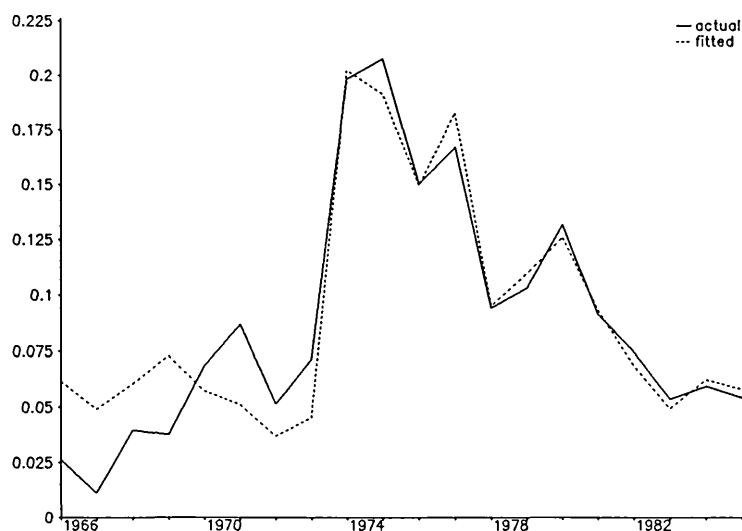
(7.34)
(10.78)

DW = 2.04 σ = 0.00427 *RSS* = 0.0003649

Sample: 1966 to 1985, 20 observations

Estimation method: FIML³⁸

Figure 4.15: $\Delta \ln PIMO$ — actual v fitted



The estimation results are shown in Table 4.11.

Consumer prices are modelled to account for both cost-push and demand-pull factors. The cost-push influences are proxied by *PIMO*, the

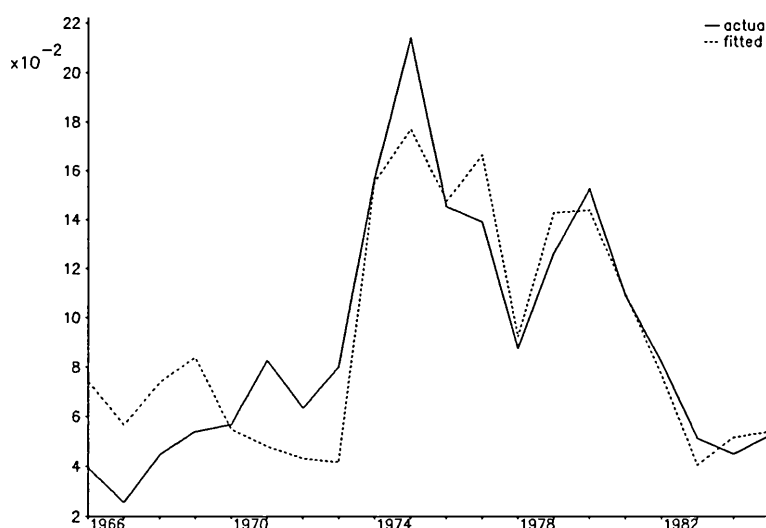
³⁸jointly estimated with consumer prices and wages.

domestic wholesale price index, and by *WWPIS*, the international wholesale price index converted into domestic currency. As described above, labour costs have been modelled to be included in *PIMO*, and so they affect consumer prices indirectly, too. Important demand effects come through to consumer prices inflation from the growth rate of the economy, *GDPGDPT*.

Table 4.12: Estimation results of consumer prices

$\Delta \ln PC = 0.030 + 0.355 * \Delta \ln PIMO + 0.053 * \Delta \ln POILS + 0.212 * \Delta \ln AFGDPE$		
(5.46)	(6.50)	(7.53)
$- 0.214 * \ln PC_{t-1} + 0.150 * \ln PIMO_{t-1} + 0.030 * \ln POILS_{t-1}$		
(4.32)	(3.07)	(3.74)
$DW = 1.71$	$\sigma = 0.00770$	$RSS = 0.0011852$
Sample: 1966 to 1985, 20 observations		
Estimation method: FIML ³⁹		

Figure 4.16: $\Delta \ln PC$ — actual v fitted



The results of this equation show that in the short run, consumer prices are only influenced by domestic wholesale prices. Additional short term influences of oil prices, GDP growth, or GDP growth relative to its trend growth were rejected by the data. As mentioned above, the long run influences on consumer prices are more diverse. There, a mixture of domestic and international wholesale prices as well as the growth of GDP have an influence.

³⁹ jointly estimated with producer prices and wages.

The price sector's role in the transmission process of changes in the oil sector to the rest of the economy can be summarised as follows. The main influences to the domestic price sector arrive from the exchange rate, the relative rise of GDP, and the oil price. Given that an expansion of oil exports provides a boost to the real exchange rate, domestic wholesale and consumer prices are likely to fall initially. This is because the strength of the exchange rate makes purchases of foreign goods (oil and other wholesale goods) cheaper. However, in the longer term when additional oil wealth has augmented output and led to increased domestic spending, wage costs are likely to rise. Higher wages will then feed into domestic wholesale and consumer prices and from there affect the real side of the economy. Effects of increased inflation in the real side of the economy have been discussed above.

4.4.8 Bank lending to the private sector

Bank lending to the private sector constitutes one of the two estimated relationships in the determination of the demand for money. It is modelled here to depend on wealth, and the price of money — the interest rate. As many other equations that include monetary variables, the estimation of the equation for bank lending to the non-bank private sector suffers from a certain lack of degrees of freedom. The gathering of monetary data series of the UK economy generally began in 1963. Some particular data series, in this case the wealth variable, *WEALTH*, begin at a later date. The estimation period spans therefore only a time horizon of 19 years, and some mis-specification tests were not carried out because of lacking degrees of freedom. However, Figure 4.17 shows that the estimated equation fits the actual data reasonably well. There is no autocorrelation present, and neither the forecast test nor the Chow test for parameter stability reveal any problem.

The interpretation of the estimated parameters, which are all statistically significant, reveals the following. A very strong influence on bank lending is exerted by changes in nominal wealth, which has a short term elasticity of 1.924. It has to be noted that none of the regressors have a contemporaneous impact on bank lending, as all explanatory variables are lagged once. The interest rate term has the right sign and implies a reduction of bank lending when interest rates are pushed up by the government. The ratio of wealth and the stock of bank lending implies that in the long run bank lending expands

Table 4.13: Estimation results of bank lending

$$\Delta \ln RSBLPR = \underset{(2.89)}{1.924} * \Delta \ln WEALTH_{t-1} - \underset{(2.59)}{0.019} * TREBILL_{t-1} \\ + \underset{(3.79)}{0.096} * \ln \left(\frac{WEALTH}{SBLPRIVS} \right)_{t-1} + \underset{(5.55)}{0.336} * \ln C7173$$

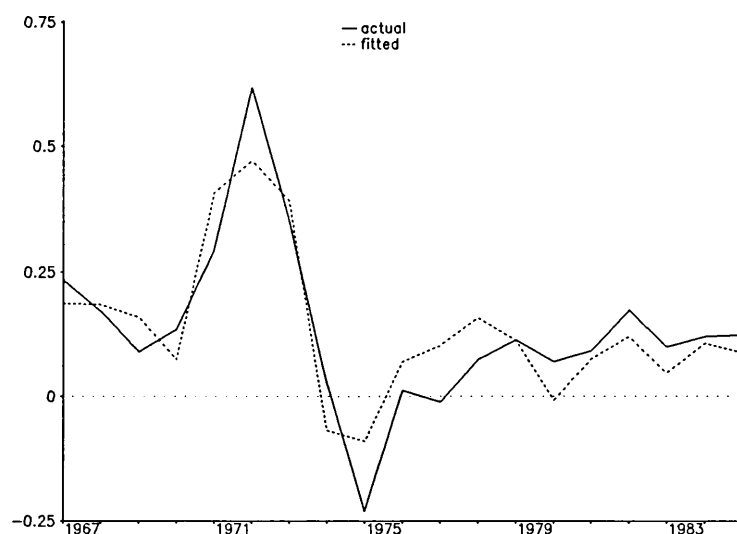
$$R^2 = 0.865 \quad DW = 2.33 \\ \sigma = 0.09254 \quad RSS = 0.1113348$$

Sample: 1967 to 1985, 19 observations
Estimation method: OLS

Equation diagnostics:

Autocorrelation:	$F(1,12) = 0.56$
ARCH:	$F(1,11) = 0.78$
Normality:	$\chi^2(2) = 0.75$
RESET:	$F(1,12) = 1.60$
Forecast:	$\chi^2(2/2) = 0.11$
Chow:	$F(2,13) = 0.09$

Figure 4.17: $\Delta \ln RSBLPR$ — actual v fitted



at the same rate as nominal wealth grows. Another long term influence comes from the interest rate term, *TREBILL*, which has the same coefficient as in the short term. Finally, the included dummy accounts for the turbulences that were caused by the introduction of the Competition and Credit Control in May

1971 as the demonstration of the 'new approach' of the Bank of England to the problem of credit allocation in the economy.

Given this estimated function, changes in the oil sector thus affect bank lending through private wealth and the interest rate. Private wealth will rise if more oil is produced and therefore raise the demand for money, but the government controlled interest rates will dampen any unacceptable excess demand.

4.4.9 Government debt sales

The other estimated constituent of the demand for money determines government debt sales, or the sales of bonds for short. Naturally, as equation (A.42) of Appendix A shows, the effect of bonds is to absorb excess liquidity in the money market. Bonds therefore enter equation (A.42) with a negative sign, whereas the stock of bank lending has a plus sign attached to it.

The explanatory factors in this equation are basically the same as those in the equation determining the stock of bank lending, namely, wealth and interest rates. However, the consol rate was chosen instead of the treasury bill rate as the appropriate interest rate. The equation for government debt sales is also affected by the problem of lacking data, which results in too few degrees of freedom to carry out all the available mis-specification tests. However, based on the existing test statistics, shown in Table 4.14 and Figure 4.18 the equation seems well determined. The *DW*-statistic does not show any first-order autocorrelation which forms the basis for the correct interpretation of the other, satisfactory test statistics.

The estimation results show real wealth to be significant, rather than nominal wealth, which featured in the determination of the stock of bank lending. Also note the correct sign of the interest rate term, implying an increase in bond sales as interest rates rise — which is the expected opposite effect to that of interest rates in the determination of bank lending.

Table 4.14: Estimation results of bond sales

$$\Delta RSGD = \underset{(2.18)}{-3.179} + \underset{(5.39)}{0.360 * \Delta WEALPC} + \underset{(2.80)}{0.375 * RCNSL_{t-2}}$$

$$R^2 = 0.789$$

$$DW = 2.63$$

$$\sigma = 1.39418$$

$$RSS = 31.0998076$$

Sample: 1967 to 1985, 19 observations

Estimation method: OLS

Equation diagnostics:

$$\text{ARCH:} \quad F(1,14) = 1.27$$

$$\text{Normality:} \quad \chi^2(2) = 0.99$$

$$\text{RESET:} \quad F(1,15) = 0.00$$

$$\text{Heteroscedasticity:} \quad F(4,11) = 2.31$$

$$\text{Forecast:} \quad \chi^2(3/3) = 0.39$$

$$\text{Chow:} \quad F(3,13) = 0.34$$

Figure 4.18: *RSGD* — actual v fitted



4.5 CONCLUSIONS

The main purpose of this chapter has been the presentation and discussion of a small econometric model of the UK economy, highlighting the importance and influence of oil on the economy. Prior to this, we discussed the issue of estimation methodology. We stressed the importance of an estimation procedure that distinguishes between the parameters or variables of an economic model and those of an econometric model, that employs a battery of misspecification tests to test the underlying statistical assumptions, and that allows the data a role in determining the specification of econometric models. Successful econometric models can be obtained within the framework of this methodology by following the *general-to-specific* modelling procedure. This is, a general specification of a particular model is reparametrised and simplified until the specific model violates none of the underlying statistical assumptions and fulfils a number of other design criteria, of which the requirement that the parameters of the model be interpretable in terms of economic theory is but one example.

The estimation methodology has been successfully applied to our econometric model. The model's structure is based on the theoretical model presented in Chapter 3. Output is demand determined, and there are estimated behavioural relationships of its main constituents: consumption, investment, non-oil imports and non-oil exports. Oil exports depend on oil production, which is one of the three policy variables under control of the government. The other two are government expenditure and the treasury bill rate. The spending effects caused by increases in the value of oil production are transmitted to consumption expenditure and investment mainly via changes in total output and in the stock of private wealth. However, both consumption and investment are also affected by inflation and interest rates. It is through these variables that supply side effects are passed on to the rest of the economy.

The trade sector, with the determination of the current account and the exchange rate, is another important part of an economy as open as the UK economy. The current balance is modelled to affect the stock of private wealth, and hence this constitutes another link between oil production and the demand side of the economy. Following the structure of the model developed in Chapter 3, the current account also influences the real exchange rate, thus providing a vital link between trade flows and the assets market. Apart from

this influence on the exchange rate, the real interest rate differential between the domestic economy and overseas is also shown to influence the real exchange rate. The exchange rate influences foreign price variables — here the foreign wholesale price index and the oil price index — which in turn feed into domestic price variables, and thus pass on any changes originating in the oil sector.

The monetary sector has a rather less important role in the model, as there are no two-way links between it and the rest of the economy. The variable that links the sector to the other parts of the model is the treasury bill rate. This means that repercussions of conditions in the monetary sector will only reach the rest of the economy, if the government uses its available monetary instrument, the treasury bill rate, to pursue certain monetary policies. Money supply is assumed to accommodate any change in money demand, which is constituted here by two main factors — the stock of bank lending and sales of government bonds. Other, smaller constituents are taken to be exogenous.

The next chapter will deal with the presentation and estimation of a model of the international oil market.

Chapter 5

An Econometric Model of the International Oil Market

5.1 INTRODUCTION

It emerged from the literature survey in Chapter 2 that most analyses of the effects of UK oil on the economy disregard one vital aspect — its impact on the international oil market. Later on in this thesis (see Chapter 6), it will be argued that this impact is sizable and that the UK therefore has a certain influence over the determination of the international oil price. This in turn is important for the UK — as well as most other economies — because of the large share of oil consumption in total energy consumption in these economies.

In order to be able to test this claim, we will present an econometric model of the international oil market in this chapter. This model will be linked in the next chapter with the model of the UK economy, which was developed in the previous chapter. A particular feature of the oil model is that it uses UK oil production as an input variable and provides the international oil price as an output variable. This constitutes a proper feedback mechanism, since the international oil price is used as an important input variable in the UK model. We begin, however, with a description of the historical development of the oil market and its various market players — especially that of OPEC, the organisation which has dominated the market since the 1970s. This is followed by a discussion of the many attempts to model the oil market. Drawing on this discussion, our own model is presented in the last section of this chapter.

5.2 HISTORICAL DEVELOPMENT OF OIL MARKET

Oil was already known to Ancient Egypt and used then as a substitute for burning materials, such as wood and coal. But since supplies were limited, its general use was restricted to the household. The discoveries of oil fields in Pennsylvania, USA, in 1859 changed this pattern and started the modern and industrial exploitation of oil. Shortly afterwards, the internal combustion engine was developed and with it a new and vast area of applications opened up. Since then, oil consumption has grown in close harmony with the industrial development of the world's economies. Apart from being used in the domestic sector for heating, oil now has major uses in the industrial and transport sectors of economies.

With the growing industrial use of oil, the market for oil became larger and more important to the world's economies. Because of their geographical advantage a few American companies — notably John D. Rockefeller's Standard Oil Trust, which because of its overwhelming size was split up into more than thirty companies — dominated the supply of oil initially. By the mid-1950s, however, new oil fields had been discovered all around the world but mainly in the Middle East, and with it part of the control of the international oil market passed on to non-American oil companies. Up to the late 1960s, the market was controlled by a group of American and European oil companies (Exxon, BP, Shell, Gulf, Standard Oil of California, Texaco, and Mobil), also called the Seven Sisters.

In September 1960, OPEC (Organisation of Petroleum Exporting Countries) was founded in order to secure a 'fairer' share of the proceeds from oil exploitation.¹ The producer countries noted a large margin between the marginal production cost of one barrel of crude oil and the price that consumers in the industrialised economies paid for the refined oil products: marginal production was estimated to cost between 10 and 20 cents, whereas in 1960 retail gasoline prices reached \$30 per barrel. Since this immense profit margin was distributed by favouring the international oil companies and their national treasuries,² the desire of the producing countries to increase their share of the profits was obvious.

¹see Griffin and Teece (1982).

²In 1961, for example, 52% of the profits went to the consuming countries' treasuries, 42% to the international oil companies, but only 6% of the profits went to the oil producing countries.

These large profits, of course, attracted new firms into the market, and the market share of the Seven Sisters declined from 98.3 per cent in 1950 to 76.1 per cent in 1969. The increased competition caused the oil price to decline and, in turn, lowered the oil companies' profits. But since the tax revenues accruing to the oil producing countries were based on these profits, the producer countries saw their tax receipts melting away. As a response, they pushed the oil companies to a higher oil production, but this led to a vicious circle of ever decreasing prices, profits, and tax receipts.

Because of their inferior market position, none of the oil producing countries was able to influence the market in order to push up the oil price. They were also hindered by the large spare capacity that existed — the US, for example, had excess capacity of 2 million barrels per day (mbd) and was willing to help its allies if the market had tightened suddenly.

For these reasons, the oil producing countries combined forces in OPEC mainly in order to stabilise the oil price level and therefore to secure a steady income from the resource. Other goals of the organisation were to help one another against the market power of the Seven Sisters (Ghanem, 1986; p.33/34).

During the 1960s, there was exceptionally strong economic growth in the world, especially in the main oil consuming nations, the OECD countries. Therefore, oil consumption itself grew rapidly and the international oil market changed its face from one characterised by excess supply to one in which excess demand was looming. This is exemplified by the oil demand of the US economy: whereas during the 1950s US oil production plants had ample excess capacity, the production peak was reached in the late 1960s, and the US was forced to compete with the other oil importing nations for the supplies of Middle Eastern oil. The fundamental change in the market pattern encouraged OPEC to strengthen its position with respect to the international oil companies, first by changing the tax system, second by introducing production controls, and third by preparing the nationalisation of the concessions which gave the oil companies the right to extract the oil resource. The intention to nationalise the concessions was spelled out in a declaration in 1968,³ which implied that the goal of OPEC was not only to maximise profits, but also to achieve ultimate control of all oil operations. Even though little notice of this was taken by the concerned companies in the immediate aftermath of the declaration, the

³see Ghanem (1986), pp.111ff.

nationalisation of oil operations in Algeria in 1971 provided a taste of what was to follow.

During the 1960s, however, the effects of these measures were mixed. The introduction of production controls had little impact, as did the threat to nationalise concessions. Much more effective were the changes to the tax system. Originally, taxes were based on the market price of oil, which, however, had fallen since the late 1950s. To overcome the resulting loss in income, OPEC basically introduced an excise tax, which was unaffected by the market price. Although this meant that the oil companies had to pay higher taxes to the producing countries, their tax payments to the national treasuries were reduced by the amount of the extra foreign tax payments. So it was the national treasuries whose income was reduced since, over all, the oil companies did not pay any more taxes. The oil companies therefore put up little resistance against the introduction of the excise tax. Coinciding with the ever increasing thirst for oil of the industrialised economies, several political events paved the way for a further strengthening of OPEC market power. These were the closure of the Suez Canal in 1967 — an immediate consequence of the third Arab-Israeli war. Another event was the overthrow of the Libyan monarchy and its replacement by a government led by Colonel Ghadafi; Libya soon asked for an increase in the tax reference price which it received. This led to the Teheran conference in 1971, where it was decided to increase the tax reference price from \$1.80 to \$2.18; to increase the tax rate from 50 per cent to 55 per cent; and to let the tax reference price grow at an annual rate of 7.5 per cent.

The next significant political event was the start of the Arab-Israeli war in 1973, after which the Arab members of OPEC announced a further increase in the tax reference price, production cutbacks, and an oil embargo to the USA and the Netherlands. Panic buying of oil set in and this pushed the oil price to \$15 per barrel temporarily, later the market price settled at \$10. In November 1974, Saudi Arabia increased its tax rates and royalties so that its tax receipts went up from \$7 a barrel to \$10.50, which was indirectly established as the new floor price. During the same period, i.e. between October 1973 and November 1974, all the major oil concessions to the international oil companies were nationalised.

In the following years up to 1978 relative calmness set in: the major industrial nations had recovered from the mild recession, industrial production and oil consumption had reached pre-1973 levels, and the nominal oil price

increases of 10 per cent in 1975, and 5 per cent in 1976 and 1977 had no adverse economic effect on the industrialised economies because inflation levels were still high so that in real terms the oil price declined over the period.

The picture changed when in September 1978 the revolution started in Iran. Following this, Iranian oil production declined by 50 per cent, and even further during the ensuing Iran-Iraq war. Even though Saudi Arabia increased its daily production limit to 9.5 mbd, the spot market oil price was pushed up to \$32 by the end of 1980. The aftermath of the price explosion was characterised by various phenomena which pointed to a weakening of OPEC market power. First, in 1980 there was great confusion in the market, since no unified price structure existed. In fact, individual countries charged what the market was willing to yield; prices spread from \$34 for Saudi Arabian oil to \$40 for oil from Algeria (Ghanem, 1986; p.160). Second, most economies suffered a major recession after 1980/1, which had dampening effects on oil demand. World oil demand dropped by 20 per cent — which was more than after the 1973/4 oil price rises. OPEC oil producers, however, were hit harder and demand for their oil declined by 45 to 50 per cent. Third, the rigorous energy conservation programmes instigated by the International Energy Agency showed that the slump in oil consumption would not pass once the industrialised countries recovered from the world recession, but that the trend of long term oil demand was lower. Fourth, OPEC market power was further weakened by the ever increasing production of non-OPEC oil, which had increased by an annual 6 per cent since 1976. Most of the non-OPEC production came from North America, Alaska, and Mexico, but important fields had come on stream in the North Sea as well. These facts caused the OPEC countries to a new conference in 1983 where the official oil price was cut from \$34 to \$29, and formal production quotas were set for all member countries.

5.3 MODELLING OF THE OIL MARKET IN THEORY AND PRACTICE

Because OPEC caused the two price explosions in the 1970s, which catapulted the oil market from the relative calmness of the late 1960s into the limelight for world attention, most modelling studies of the international oil market are

basically concerned with the explanation of OPEC pricing behaviour. In what follows, we set out the major modelling attempts.

5.3.1 Theoretical models of OPEC behaviour

In the literature, there are four basic model types: the dominant producer model, the competitive model, the target revenue model, and the political model. The first two model types, the dominant producer model and the competitive model, both assume wealth maximisation of the countries or groups of countries involved. The approach of wealth maximisation is based upon Hotelling's paper (1931) on exhaustible resources.⁴ The Hotelling rule⁵ stipulates that the owner of an exhaustible resource chooses prices or quantities over time such that the net present value of the profits, which accrue over time from the resource, is maximised. Under the assumption of a competitive market, prices are found to grow at the rate of the interest; when monopolistic conditions are assumed, it is marginal revenues that rise with the interest rate.

In the dominant producer model (see Adelman, 1982) the main market player — which because of its large market share is always assumed to be Saudi Arabia — sets the price and allows the other members of the cartel to sell whatever they produce. The leader, i.e. Saudi Arabia, will then supply the amount of oil that balances supply and demand in the market. Its market role therefore is that of a swing producer because it will absorb fluctuations in the patterns of supply and demand. This role carries with it the risk that the (high) monopoly price induces more production by the competitive fringe producers which, translated into the reality of the world oil market, consist of other OPEC producers as well as non-OPEC producers. Consequently, the market leader's production rate would be squeezed further and further thereby diminishing its revenues — unless of course it sets a different, lower price that makes some part of the fringe production uneconomic. Within the framework of a simple version of this model, which assumes that the dominant producer chooses the price that maximises his wealth over time, he has two options to set his discount rate: he either sets a high discount rate — which implies that he values current profits more than future profits — or he sets a low discount rate — implicitly valuing future profits more than current ones. In the first case he

⁴see also Dasgupta and Heal, 1978.

⁵see also Chapter 2.

sets a high price now; this of course leads to the erosion of his future market share because the high profits now invite new entrants to the competitive fringe and boost the production rate of the existing members. In the second case, he sets his price lower now in order to discourage new entry to the fringe and also to discourage the existing fringe members from expanding their current production; this pricing policy is called limit pricing because of the market leader's intention to limit to zero new entry to his market.

The model can be criticised on two general grounds: one is that the predictions of the theory do not coincide with actual observations, the other is that some assumptions are regarded as unrealistic. First, the model implies that with time the dominant producer's market share declines. This, however, is at odds with the reality of OPEC, because Saudi Arabia's market share has not declined; in fact, as shown in Table 5.1, it increased from 15.3 per cent in 1973 to 21.7 per cent in 1981. On the other hand, the expansion of non-OPEC production since the oil price rises in the 1970s is consistent with the dominant producer model; therefore a collusive element is often brought into the theoretical analysis (e.g. Hnyilicza and Pindyck, 1976) by assuming a 'cartel core' (usually Saudi Arabia, UAE, Kuwait, Qatar, and Libya) which is assumed to behave like the dominant producer.

Second, this model type has been criticised on several theoretical fronts (Gately, 1984). In order to allow mathematical tractability several simplifying assumptions are introduced: first, the omission of an adequate lag structure does not allow these models to analyse properly the reaction to OPEC price increases of world oil demand and non-OPEC oil supply. Second, the assumption of perfect foresight conceals that OPEC does not know with certainty how variables enter the functions of world oil demand and non-OPEC oil supply, nor does it know the exact parameter values of elasticities, GNP growth, or the cost of alternative energy forms. Furthermore, whatever the actual price path, OPEC's wealth would be considerable in any case and, therefore, the theory of wealth maximisation may be irrelevant to the decision making processes of the individual OPEC countries.

Another theory of OPEC behaviour is advanced by the property rights model. This model type assumes that all oil producers operate within a competitive market. Its main proponents, Johany (1978) and Mead (1979)⁶, try to explain the price rise in 1973/74 by the change in ownership of the oil

⁶cited in Griffin and Teece (1982) pp.29 ff.

Table 5.1: Share of WOCA production
in percent

year	OPEC	NA	ONO	UK	USA	Saudi Arabia	Iran	Iraq
1960	41.69	45.11	13.21	0	42.24	6.60	5.62	5.06
1961	42.21	43.85	13.94	0	40.64	6.91	5.94	4.92
1962	45.92	41.78	12.30	0	38.40	7.01	6.12	4.58
1963	46.85	40.55	12.59	0	37.16	7.01	6.34	4.99
1964	48.34	38.40	13.26	0	35.01	6.91	6.83	5.01
1965	49.10	36.90	14.01	0	33.43	7.51	7.08	4.88
1966	48.73	36.20	15.07	0	32.65	8.18	7.21	4.75
1967	49.90	36.06	14.04	0	32.44	8.27	8.29	3.91
1968	51.51	34.88	13.60	0	31.30	8.24	8.27	4.38
1969	54.88	32.82	12.30	0	29.27	8.10	9.12	4.12
1970	55.27	31.61	13.12	0	27.88	8.79	9.52	3.87
1971	59.93	30.18	9.89	0	26.35	10.66	10.81	4.03
1972	61.65	29.50	8.85	0	25.25	12.99	11.44	3.32
1973	64.65	27.12	8.23	0	22.64	15.25	12.24	4.19
1974	65.29	26.24	8.47	0	21.95	17.55	12.74	4.15
1975	62.21	26.63	11.16	0.06	22.70	15.80	12.21	5.12
1976	64.34	23.46	12.21	0.50	20.14	17.64	12.25	5.00
1977	63.10	22.85	14.05	1.52	19.65	18.39	11.36	4.68
1978	60.33	23.61	16.06	2.18	20.47	16.57	10.51	5.10
1979	59.88	22.66	17.46	3.05	19.29	18.18	6.04	6.61
1980	55.49	24.05	20.45	3.34	20.56	20.20	2.99	5.35
1981	50.76	25.46	23.78	3.98	22.10	21.68	2.88	1.94
1982	45.60	26.73	27.67	4.86	23.34	15.32	5.51	2.31
1983	42.40	27.06	30.54	5.43	23.58	12.02	5.67	2.54
1984	41.07	27.02	31.91	5.74	23.36	10.58	4.88	2.72
1985	38.78	27.84	33.38	5.98	24.14	8.11	5.01	3.23

fields in the Middle East. They argue that up to the early 1970s the international oil companies were the *de facto* owners of the oil fields: the concessions which they were granted by the producer countries allowed them to produce at will; the risk of nationalisation was negligible. Hence, the oil production depended on the oil companies' discount rate, which — according to

the theory — was very high. That is the oil companies produced “as if the were no tomorrow” (Johany, 1978 again cited in Griffin and Teece, 1982), selling as much oil as possible. This put downward pressure on oil prices and, in turn, pushed the oil companies to increase their production rates even more. The resulting loss in revenues caused the producing countries to found OPEC; with it came the transfer of the property ownership of the oil fields. Once the transfer was complete, the oil producers were the ‘proper’ owners of the resource and oil production then depended solely on their discount rate, which was much lower than that of the oil companies. Thus, production was reduced and the scene for a price rise was set. Even though this theory is capable of explaining the first oil price rise in 1973/4, there is no satisfactory explanation of the second round of price rises in 1979/80. By then, the producer countries had seized the ownership of most oil fields, and therefore, they had no further incentive — at least according to the property rights model — to push prices up a second time.

Teece (1982) put forward another explanation of OPEC’s pricing behaviour in his target revenue model. OPEC is viewed as a group of nations whose oil production decisions are made in order to cover the requirements of the respective national budget. These budgetary demands depend on the size and the degree of development — i.e. the absorptive capacity — of the economy. One distinguishing feature of this type of model is that it leads to a backwards sloping supply curve: if prices are below those needed to finance the budgetary requirements, production will obviously rise; however, if prices are higher than are needed for the financing purposes in the economy, production will fall. The analysis of the target revenue model in an intertemporal dimension leads to the conclusion that this model type might be better suited for a short term analysis of OPEC pricing behaviour than a longer term analysis. This is because as economic development progresses investment targets necessarily rise which, in turn, necessitate higher revenue targets; in the long run, therefore, the supply curve turns out to be a function of the changing level of the country’s economic infrastructure. The model assumes that all funds for investment purposes originate from oil exports. This, however, is a simplifying assumption, as most oil countries set up large investment pools in the western economies (e.g. the Kuwaiti stake in BP) to safeguard themselves against the collapse of the oil price and against the certainty that the oil resources will dry up in the future. The assumption might nevertheless be justified because the fruits of foreign investment depend on currency

fluctuations, which as in the case of the dollar might be large and might devalue the investment extensively. Another reason against foreign investment might be political risks; the country in which the oil profits are invested might confiscate or freeze them because of political disagreements, as happened in the case of Iran and the US.

A last group of theoretical models purporting to explain OPEC behaviour is that of political models, which maintain that the pursuit of wealth maximisation is not the only consideration for the leadership of any country. Other important aspects for a nation are its security and the extension of its political influence. Because of their stress on political motives behind the actions of nation states these models are of a more qualitative rather than quantitative type. They therefore lend themselves better to an intuitive explanation of past events than to an exact numerical prediction of future production or price levels. Moran (1982) addresses the question whether economic considerations have precedence over political and security considerations; in his view "political and security concerns wag the economic tail and where they have conflicted, the former have prevailed".

5.3.2 Predictive models of OPEC behaviour

In the previous section we surveyed several theories of OPEC's behaviour. In this section we discuss modelling attempts for the purpose of fairly exact numerical predictions of OPEC's production and pricing policies. In his econometric study Griffin (1985) has complained that "the standard practice to date has been to reach onto the shelf of economic models, to select one, to validate its choice by pointing out to selected events not inconsistent with the model's predictions, and then to proceed with some normative exercise. For all practical purposes, the model is treated as a maintained hypothesis." In order to test the claim of models to represent reality, Griffin has chosen the above discussed theories to select the one which most accurately fits the actual data. He used quarterly data covering the period 1971:1 through 1983:III to test a simple version of each theory; and he concluded that the partial market-sharing cartel model (a derivative of the dominant producer model) was the least rejected model type. This view of OPEC as some form of cartel is shared by other studies. Pindyck (1978), for example, assumes a cartel as a price leader that holds a fixed quantity of reserves and faces production by a competitive

fringe. He solves his model as an optimal control problem where the cartel has to select a price path that maximises its discounted profits over time. The ensuing production level balances total oil supply — i.e. the sum of the cartel's output plus the competitive fringe's output — and oil demand in the international oil market. Apart from giving insight into the working of OPEC, any such model's success is measured by its ability to explain and to predict the pattern of the world oil price. Measured against this yardstick, Pindyck's model performs very well during the first oil price shock in 1973/74, but is unable to explain the price doubling of 1979/80, and to determine the actual initial price level. This failure to model the oil price path correctly may be due to the model's theoretical underpinning⁷ or to the simplifying assumptions that the model requires to be solved successfully, as mentioned in the previous section.

A looser definition of cartel has been employed in many models that were used in the Energy Modeling Forum (EMF, 1982)⁸. With the aim to model the world oil market rather than any specific OPEC behaviour, the OPEC nations are subsumed under one sector, as all the models that are used in the EMF study divide the world market into three sectors: oil consumers, non-OPEC oil producers, and OPEC oil producers. More specific assumptions about the exact cartel form are omitted: Gately (1983) for example assumes for his model — a slightly different version of his EMF study with Kyle and Fischer — that OPEC is an "imperfectly disciplined cartel that is uncertain about the true parameter values underlying the market". OPEC's crucial decision about the oil price that it sets⁹ is therefore modelled in a rather simple fashion by the Gately *et al.* study, as well as by six others of the remaining ten EMF models. OPEC pricing behaviour is based upon some capacity utilisation target and follows a rule-of-thumb: when the market is tight, raise the price; but when market conditions are weak, let the price slip. The target, which this policy is trying to achieve, is usually set exogenously (see fig. 9 of Gately, 1983, p.330); only few models try to endogenise the 'optimal' level of capacity

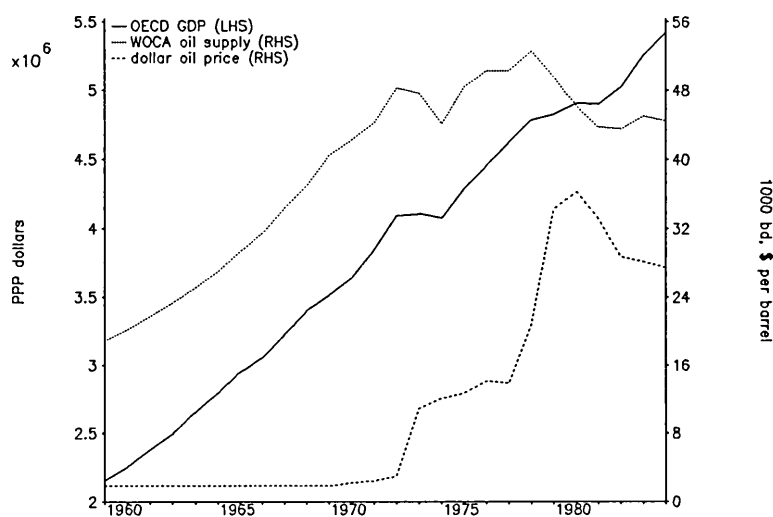
⁷see Pindyck (1982).

⁸The EMF study group used ten models of the world oil market (Gately-Kyle-Fischer, IEES-OMS, IPE, Salant-ICF, ETA-MACRO, WOIL, Kennedy-Nehring, OILTANK, Opeconomics, and OILMAR) to identify — among other things — the reasons why models built for the same purposes often give contradictory projections of future events.

⁹Other models assume that OPEC sets a production level; some market clearing mechanism is then employed to determine the corresponding oil price. The projections of either model type are however not dependent upon the modellers' decision whether OPEC sets a production level or the oil price.

utilisation¹⁰. The analysis of world oil supply during the last decade has been centred invariably on the study of OPEC behaviour because of the organisation's dominance over the recent past and because of its very large oil reserves. As we have seen, in most model types OPEC oil supply is determined by its pricing behaviour, which in turn depends on the model's analytical approach: if the OPEC countries are assumed to be wealth maximisers, then an optimal oil trajectory is calculated by the model; in most other cases, however, the current oil price is a function of last period's capacity utilisation. The remaining two sectors of most models, world oil demand and non-OPEC oil supply, are treated in a similar, and fairly simple, fashion by many models.

Figure 5.1: GDP, oil demand and oil price



The study of world demand for oil concentrates on the relationship between oil demand and its most likely determining factors, which are the rate of economic development in the oil consuming countries and the oil price. See Figure 5.1 for the close correlation between industrial development and oil consumption in the OECD countries. Despite the close resemblance of the two time series, the estimates of the oil price and income elasticities in various econometric studies differ to such an extent that doubts about the validity of the studies have been expressed (EMF, 1980). Kouris (1983) has found that possible explanations for the divergence of results are differences in the

¹⁰Of the EMF models, only the IPE model endogenises production capacity by linking it to expected future oil demand.

definitions of the variables, the time period under study, and the functional form that was chosen for the analysis.

The EMF models (EMF, 1982) differ in their treatment of the oil demand sector as follows: some model explicitly the oil input to the capital stock of the economies, other models simply use oil demand functions to determine the amount of oil consumed. Secondly, most models have exogenous income and price elasticities; indeed for the Energy Modeling Forum (EMF, 1982) the values of the elasticities were set the same for all studies so that a comparison of the models' behaviour was possible. Gately (1983), however, estimated his demand equation parameters. The values of the short run price elasticity are much smaller than their long run counterparts for all models. Lastly, some models' price predictions were consistently lower than other models' predictions; this was attributed to the inclusion of feedback from the growth in oil demand to the growth of GNP, in which case a lower demand for oil would depress GNP growth and, in turn, would reduce oil demand even further. This would lead to an over supply of oil in the international market and would put downward pressure on the oil price to bring about a new market equilibrium. In most other models GNP growth is assumed to be exogenous; thus a downturn of oil demand would leave GNP growth and the oil price unaffected.

The non-OPEC supply sector is modelled in different ways by the 10 EMF studies. Two models assume non-OPEC oil production as an exogenous factor. Four models employ explicit supply curves to determine oil output; in each case supply is supposed to adjust very slowly as a result of changed oil prices. In another model non-OPEC oil production is set at a constant reserve-production ratio, where rising lagged prices induce new discoveries, albeit at a slow rate. Those three models that work in an intertemporal optimisation framework cast non-OPEC supply decisions as an optimal control problem, where the level of production depends on the objectives set: in two models the non-OPEC producers maximise discounted profits, whereas in the ETA-MACRO model the countries are assumed to maximise the discounted utility of consumption by varying the level of investment in the oil industry. The analysis of the EMF study group has shown¹¹ that the differing assumptions implicit in the modelling of the non-OPEC supply sector constitute a significant factor for the differing and contradictory oil price predictions of the various models. Another possible explanation for the variety of model predictions that

¹¹EMF (1982) p.18.

exist may be that many models have not been estimated econometrically; rather their parameters have been imposed in an ad hoc fashion. It was mentioned above that for the purpose of adequate comparisons several elasticity parameters were set equal for all the models that took part in the analysis of the EMF study group on world oil; Gately (1983) estimates some demand function parameters¹², but imposes the price elasticities for his supply functions. Drollas (1986) has proposed a fully estimated supply model for the US; his model is fairly detailed and consists of nine equations — six behavioural equations and three identities.¹³ He concludes that a model can be built using purely economic factors — the oil price in his case — in order to determine oil supply by calculating the number of exploratory wells, production wells, and wells that are shut in. The cumulative number of wells drilled acts a proxy for the nearing inevitable exhaustion of oil resources by exerting a long term negative influence on the discoveries per exploratory well. This geological effect has been modelled by Baldwin and Prosser (1987)¹⁴ in a different, and simpler way: in their econometric study of the international oil market they make use of Hubbert's work on the depletion of US oil resources.

Hubbert's method¹⁵ is based on the observation that annual production plotted against time produces a bell-shaped curve; moreover, the area beneath this curve equals the amount of cumulative production. Thus, with a suitable approximation of this curve it is possible to determine future rates of annual oil production or the ultimate level of oil resources in the ground. The prediction of the total reserves is the more precise the farther production has gone past its peak; likewise the prediction of annual production rates is the better the more accurate is the estimate of the ultimate resource level. In practice, oil production is preceded by the discoveries of the resource. The time lag between these two quantities is usually fairly constant during the main extraction phase.¹⁶ Thus with an accurate knowledge of the cumulative discoveries it is possible to determine annual oil production rates for at least the main extraction period. Even though Hubbert's method can be criticised¹⁷

¹²It is ironic that one of them is statistically insignificant.

¹³A drawback of his model may be the sophisticated data requirements — some data series had to be extrapolated backwards since actual data was not available.

¹⁴This internal CEEB-report has subsequently been published as: Baldwin, N. and Prosser, R. (1988) 'World oil market simulation', *Energy Economics*, vol. 10, pp. 185-198.

¹⁵see Hubbert (1979) for his synopsis of his own contributions or Renshaw and Renshaw (1980) for a critical appraisal of his work.

¹⁶refer to Baldwin and Prosser (1987).

because future production and resource levels depend solely on time, and not on any economic factors, the following intuitive rationale behind the bell shape of production and discovery curves can be provided. Initially, discoveries and production rise slowly because the knowledge of the local geology is poor and the exploratory technology not fully developed. But as geological and technological understanding improves discoveries and production rise at an exponential rate. During this period most of the large fields are discovered. Later, new discoveries and production rates level off, approaching their limit. More sophisticated and expensive techniques have then to be used in order to find the remaining fields.

5.4 AN ECONOMETRIC MODEL OF THE INTERNATIONAL OIL MARKET

In this section we outline our own econometric model of the international oil market by making use of the theoretical and practical modelling attempts that have been surveyed in the previous section of this chapter. The model is basically an adaption of the model in Baldwin and Prosser (1987). This has been done for several reasons. First, the model is an equilibrium model of the international oil market, where total demand and total supply are equalised mainly by movements in the price of oil. The adoption of this model type has also been chosen by many other studies. A second feature, however, of the model is its view of OPEC as some form of cartel. This is plainly justified by the market power of OPEC member states and is also reflected in many other studies.¹⁷ The consequence of assuming OPEC to act as a cartel affects the exact specification of how the oil price is determined within the model. Here, we rely on the specification that has been used by most of the models that are analysed in the EMF study (1982), which assumes OPEC to adjust its own production rate in order to keep the oil price within a 'suitable' bandwidth. OPEC, in other words, is assumed to act as a swing producer in the world oil market.

¹⁷see Drollas (1986), p.156.

¹⁸see, for example, Pindyck (1978, 1982); Gately (1984); or Salant (1976).

The model can roughly be divided into three segments — one where oil demand is determined, one determining the supply of oil, and the last one determining the international oil price. The next sub-sections will deal with the specification and estimation of each segment in detail. Prior to that, however, a note on the scope of the analysis of the oil market. We are restricting the analysis to WOCA — the world outside communist areas, rather than dealing with the whole of the international oil market. This is common practice and done mainly because oil trade of the COMECON countries¹⁹ and China with the rest of the world is negligible. There are no imports into the Comecon countries and China, as their own oil production is adequate to ensure self-sufficiency. Exports to WOCA are minimal, they are indeed small enough to be considered an exogenous factor in our model.

5.4.1 The demand side

The demand side of the oil model is in its most aggregate form: there is one equation determining oil demand in WOCA, the world outside communist areas. The reasons for choosing such an aggregate representation are twofold. First, the aim of this study lies not in an analysis of the international oil market *per se*, but in the determination of its output variable, the price of oil. This is because the oil price features as an important input variable of the UK macro-economic model and thereby constitutes one of the two links between the UK economy and the international oil market.²⁰ Second, an aggregate representation is justified because the major oil consuming countries, the OECD countries, all have very similar patterns of oil consumption. The energy consumption-to-GDP ratio is a measure of energy intensity, and a comparison of ratios of the OECD countries²¹ shows the energy/GDP ratio rising until the early 1970s. Then, however, the ratio declined, showing effects of energy efficiency. In contrast to this is the trend of the energy/GDP ratio for the LDCs (less developed countries). Here, the ratio remained constant until 1975 and began then to rise, reflecting a greater share of industry in their national output.

¹⁹Council for Mutual Economic Assistance; members are USSR, Bulgaria, GDR, Czechoslovakia, Cuba, Mongolia, Poland, Rumania and Hungary.

²⁰The other link, of course, being the rate of UK oil production.

²¹see BP (1986), p.35.

As in many demand systems, world oil demand is proposed to depend on an income term and a price term. For a rationale of this choice, consider Figure 5.1,²² which shows WOCA oil consumption together with OECD GDP and the oil price. The graphs show clearly the undisturbed growth pattern of oil consumption and GDP until 1973, the year in which OPEC dictated to the world the first of two oil price leaps. Additionally, one can see that until 1973 both GDP and oil consumption rose — whereby oil consumption rose faster than GDP — but that after the recession in 1974 and especially after 1979/80 oil consumption was reduced sharply even though GDP still grew, albeit at a slower rate than previously. Where GDP had grown by a third from 4000 billion dollars to 5500 billion dollars between 1973 and 1985, WOCA oil consumption actually fell from a level of 47000 barrels per day (bd) to a level of 45000 bd. Given the much higher level of oil prices it seems that oil as an energy source has priced itself out of the market to be substituted by other, cheaper energy sources. A second explanation for the lower level of energy demand is that the economies have learned to use less energy altogether in order to produce the same amount of GDP.

Estimation of the equation — see Table 5.2 — followed the same general-to-specific procedure that was outlined and used in Chapter 4. The variables used in the estimation procedure are those depicted in Figure 5.1, *viz.* WOCA oil consumption, *WOCA*, OECD GDP, *GDP*, and the oil price, *POILD*, which however, is here used in its deflated form, *OPI*. The oil price has been deflated in order to be consistent, since OECD GDP, *GDP*, is measured in constant 1975 CU (currency units)²³.

The re-specification and testing procedure yielded an equation, where the endogenous variable is the energy/GDP ratio. The implicit assumption of unity income elasticity in the short and long term is supported by statistical tests. The resulting short term price elasticity is 0.036, a value that is virtually identical to the one in Baldwin and Prosser of 0.04. We expect slight differences in estimation results, since variable definitions and data sources differ marginally. This refers to the choice of the oil price deflator and that of the measure of WOCA GDP. Baldwin and Prosser use an intricate procedure

²²see page 12.

²³see Baldwin and Prosser (1987) for the rationale, and Summers and Heston (1984) for data sources.

Table 5.2: Estimation results of world oil demand

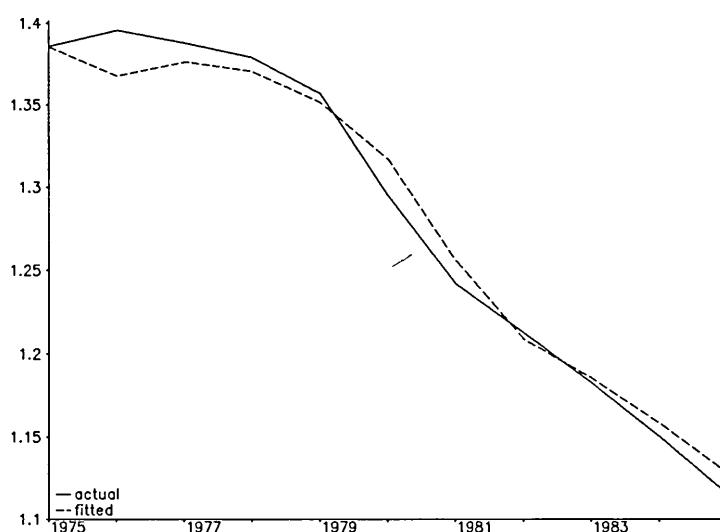
$$\ln \frac{DWOCA}{WOCAGDP} = \underset{(9.10)}{-0.036} \ln OPI + \underset{(2.37)}{0.129} + \underset{(27.04)}{0.996} \ln \left(\frac{DWOCA}{WOCAGDP} \right)_{t-1}$$

$R^2 = 0.984$ $DW = 1.26$
 $\sigma = 0.01327$ $RSS = 0.0028169$
 Sample: 1967 to 1985, 19 observations
 Estimation method: OLS

Equation diagnostics:

ARCH:	$F(1,14) = 0.12$
Normality:	$\chi^2(2) = 0.65$
RESET:	$F(1,15) = 3.82$
Forecast:	$\chi^2(3/3) = 1.24$
Chow:	$F(3,13) = 0.46$

Figure 5.2: $\ln \frac{DWOCA}{WOCAGDP}$ — actual v fitted



to obtain “real exchange rate adjusted crude oil prices”.²⁴ For the sake of simplicity and consistency with the rest of the overall model, we use the index of world wholesale prices, *INWWPI*, as a deflator for the dollar oil price. With respect to the choice of GDP measure, WOCA GDP has been proxied here by OECD GDP — again for the sake of simplicity. This seems justified *a priori*, because of the overwhelming share that OECD output has in WOCA’s total output. The choice is also justified *a posteriori* by the similarity of our

²⁴Baldwin and Prosser (1987), p.13.

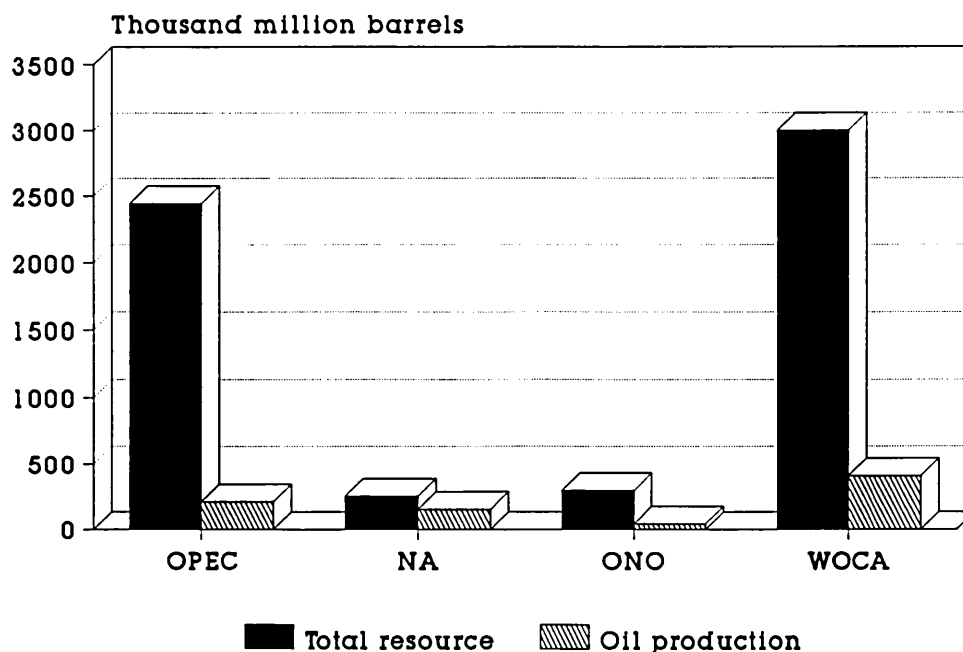
results with those of Baldwin and Prosser who use a more comprehensive GDP series.

Economic interpretation, finally, shows that the strongest influence on oil demand comes from GDP, i.e. the general development of economies. Also shown however is the clear and statistically significant corrective role of oil prices in the trend of oil demand.

5.4.2 The supply side

The supply side of the oil model is more disaggregated than the demand side. There is a basic division between OPEC producers and non-OPEC producers, but closer analysis and the aim of this study have suggested further division of the group of non-OPEC producers into three subgroups. These contain North American (NA) production, UK production, and other non-OPEC-non-UK oil suppliers (which consists mainly of the other independent oil suppliers).

Figure 5.3: Total recoverable resource and cumulative oil output to end 1982



Source: BP, Grossling & Nielsen (1985)

The first division of all oil suppliers into two groups — one consisting of OPEC and the other of non-OPEC producers — follows the practice of most energy supply models and is evident from Figure 5.3. This bar chart confronts the estimated total recoverable resource with cumulative production figures ending in 1982 of the three areas that we consider in our model: OPEC, North America, and ONO (other non-OPEC producers, including the UK). These three areas form WOCA, whose figures are included in the chart as well. The first impression is the large size of the estimated, total recoverable resource of the OPEC area. Indeed, OPEC's total resource is estimated to be about 81.5 per cent of WOCA's. The two non-OPEC areas both have similarly sized resources with North America harbouring about 8.5 per cent and ONO the remaining 10 per cent of WOCA's total resource. The division of the supply side into an OPEC group and a non-OPEC group thus is justified because of OPEC's large total resource in comparison to the other suppliers.

The subdivision of the non-OPEC suppliers into a group consisting of North America and another consisting of Other Non-OPEC (ONO) suppliers can be appreciated by considering the second important feature of Figure 5.3. This feature is the size of cumulative production figures relative to the total recoverable resource, i.e. the amount of oil that has already been extracted from the total recoverable resource. Here, OPEC's cumulative oil production up to the end of 1982 amounted to about 8.7 per cent of the total recoverable resource; the corresponding figure for ONO is about 14 per cent. North America, however, had already extracted about 60 per cent of its total resource²⁵. The implications of North America's special reserve position become clear if one recalls Hubbert's observations that the life-time extraction pattern of an oil resource can be represented graphically by a bell-shaped curve. That is, production, which is fluctuating around the bell-shaped pattern, is steadily increasing before 50 per cent of the resource have been extracted. Beyond that point the production path is falling. This observation is illustrated in Figure 5.4, which shows annual production figures for North America, OPEC, ONO, and WOCA. A comparison of the North American and ONO production paths shows that despite the much higher oil prices from 1973 onwards North American oil production did not increase, rather it was

²⁵The estimates for the figures of the total recoverable resource are based on Baldwin and Prosser's assumption (Baldwin and Prosser, 1987, p. 29) that the relationship between the proven reserves in the three producer areas is the same for that between the total recoverable resource in the areas. Specifically, at the end of 1985 OPEC had about 80 per cent of WOCA's proven oil reserves; the assumption is now that OPEC's total recoverable resource is 80 per cent of WOCA's too.

kept a steady level of around 12000 bd. In sharp contrast to this, ONO production expanded throughout the time period thereby taking full advantage of the higher price level. The increased production in the ONO countries was possible because less than 50 per cent of its total resource had been extracted and therefore new oil fields were still being discovered and brought on stream. Because this different extraction behaviour seems rooted in the large gap between the amounts of oil that can still be extracted in North America and in the ONO group, we have subdivided the non-OPEC group further.

Figure 5.4: Annual oil production — selected areas

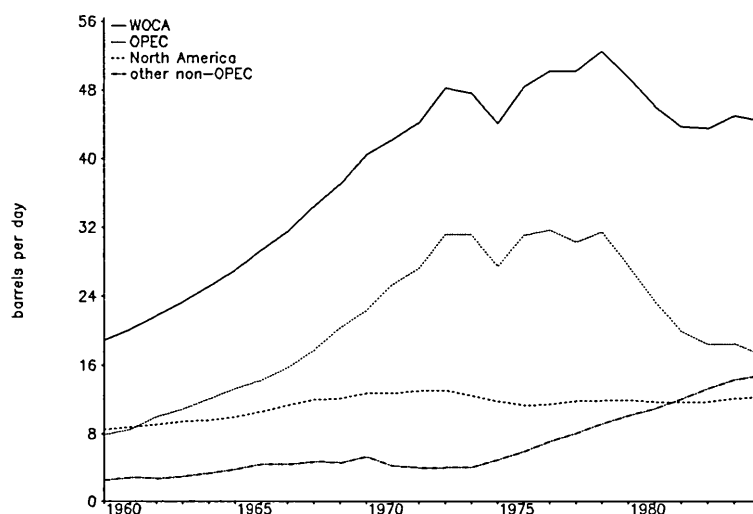


Figure 5.4 and Table 5.3²⁶ help to deepen the understanding of the market behaviour of the main suppliers in the three supply groups. The main North American supplier is the US, whose oil production has been the largest during the whole of the time period studied. In level terms, US oil production reached a peak in 1970, declined until 1976, and increased gently until the end of the time period because of the two oil price rises in the 1970s, which made more fields profitable. In relation to WOCA oil production, however, US production grew much more slowly, only after 1980 has US oil production had consistently higher growth rates than WOCA as a whole.

The largest OPEC producer is Saudi Arabia. Like the US, its oil production rose during the 1960s, but with the exception of two troughs in 1975 and 1978 the overall increase continued until 1981, after which OPEC oil

²⁶Figure 5.4 depicts annual oil production levels of various market participants. Table 5.3 instead lists the difference between the country's annual production growth rate and that of WOCA; e.g. in 1961 the US figure is -4.04, which means US oil production grew 4.04 percentage points more slowly than WOCA's oil production.

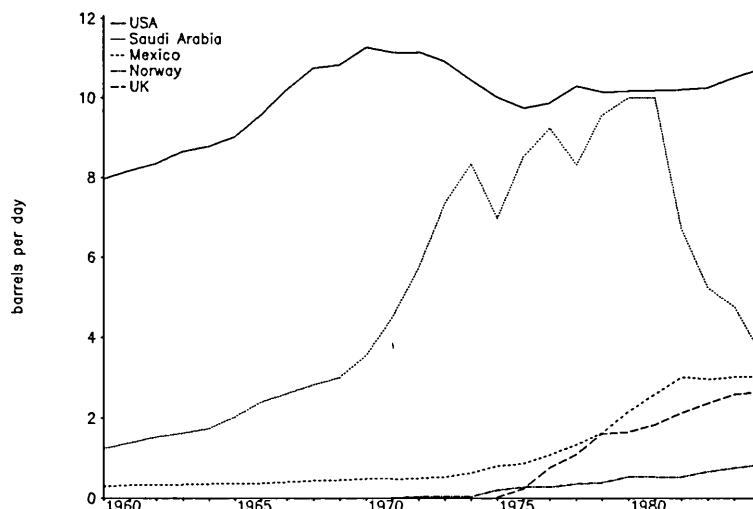
production fell to a level it had reached in 1970. Another difference to the US picture emerges when growth rates are compared. In the main, OPEC oil production grew faster than WOCA oil production, and when US growth rates overtook WOCA's, OPEC's rates were about 20 percentage points lower than WOCA's.

Table 5.3: Deviation of production growth rates
from WOCA's growth rates
in percent

year	OPEC	NA	ONO	UK	Norway	Mexico	USA	Saudi Arabia
1961	5.93	-2.97	-6.68	0	0	0.76	-4.04	4.97
1962	-12.77	-5.09	-8.10	0	0	-4.33	-5.96	1.61
1963	2.59	-3.15	-6.94	0	0	-3.31	-3.47	-0.06
1964	5.74	-5.72	-7.74	0	0	-4.82	-6.23	-1.60
1965	6.04	-4.21	-7.64	0	0	-6.51	-4.85	9.41
1966	8.23	-2.06	-8.54	0	0	-5.73	-2.54	9.73
1967	-7.37	-0.40	-7.34	0	0	3.04	-0.67	1.22
1968	-3.37	-3.57	-9.26	0	0	-2.83	-3.85	-0.42
1969	-10.32	-6.37	-7.75	0	0	-1.70	-7.00	-1.92
1970	7.28	-4.02	-9.21	0	0	-4.38	-5.20	9.33
1971	-25.77	-4.74	-4.54	0	0	-4.96	-5.72	22.22
1972	-10.95	-2.37	-4.49	0	428.85	-0.29	-4.38	22.85
1973	-7.63	-8.78	-9.17	0	3.33	-0.70	-11.28	19.02
1974	2.88	-3.23	1.25	0	-4.31	18.72	-3.00	14.93
1975	28.76	1.41	7.91	0	454.35	33.24	3.16	-9.23
1976	6.01	-13.06	-5.24	850.39	38.77	-0.53	-12.36	12.70
1977	7.26	-2.68	5.03	214.88	-6.04	20.13	-2.53	4.46
1978	10.77	3.31	4.72	43.18	27.45	22.62	4.20	-9.92
1979	4.07	-4.23	1.57	41.43	4.61	17.86	-6.05	10.22
1980	17.63	5.80	6.43	9.01	43.11	38.09	6.23	10.43
1981	14.60	5.44	8.69	18.08	3.38	26.82	6.96	6.81
1982	14.42	4.76	7.75	20.91	8.31	21.35	5.30	-27.85
1983	10.01	1.23	2.53	11.64	25.10	-1.25	1.02	-21.37
1984	4.40	-0.17	-1.83	5.84	11.51	-1.28	-0.95	-12.39
1985	4.63	3.01	1.80	4.19	12.15	1.28	3.28	-23.09

Of the third supply group, Figure 5.5 shows production levels of the UK, Norway, and Mexico. Unlike the two previous groups, which showed ups and downs in their production profiles, all three ONO countries increased their production steadily throughout the whole time period. Moreover, even in relative terms, ONO production growth rates were consistently higher and so by a large margin than the rates of the other two groups.

Figure 5.5: Annual oil production — selected countries



The development of the production profiles of the three main supply blocks brings up one pertinent question: was the sudden switch in OPEC's pricing policy after November 1985 — when during the following months it lowered the official oil price from around \$28 to between \$10 and \$15 — caused by the steady increase in market share of the ONO countries, or was it independent from it? To find an answer to this question, a look at OPEC's production capacity levels and its oil revenues might help. From 1975 up to 1981, OPEC managed to employ between 80 to 93 per cent of its oil production capacity. However, during and after the world wide recession that was caused by the second large oil price increase in 1979/80, capacity levels fell steadily to just above 60 per cent in 1985. In order to sell all of their production, OPEC producers had to grant special price deals to customers, which resulted in a widening gap between the official oil price and the spot price in the world market. Whereas up to 1981 spot prices stayed mostly above the official oil price, this picture was reversed in the aftermath of the recession, with spot prices remaining consistently below the official price. The vicious circle of lower oil prices and lower production figures meant of course lower oil revenues

for OPEC: revenues fell from more than 260 billion US dollars (measured in constant 1980 prices) in 1980 to just above 100 billion US dollars in 1985. It therefore seems that the steady ONO oil production increase was responsible for the policy reversal of OPEC, because both OPEC targets, whether implicitly or explicitly pursued, had been pushed to unacceptably low levels. This establishes as well the market power and the political power that the authorities which are responsible for oil production policies in the UK and the other ONO countries can exercise. As has been shown, this power is considerable, and Chapters 6 and 7 analyse ways of how to use this power and what consequences arise from that use to OPEC themselves but also to the UK economy.

5.4.2.1 *Specification of supply side*

The specification of the supply side considers both geological as well as economic factors, whereby the incorporation of geological factors is based on Hubbert's work.²⁷ As mentioned above, Hubbert postulates that the life time cumulative production profile can be approximated by a logistic curve. The proper methodological steps on this route would be to estimate a logistic curve for cumulative discoveries, to lag this by a fixed time interval in order to obtain the corresponding logistic curve for cumulative supply, and then to differentiate this function to derive annual production figures. However, as Baldwin and Prosser (1987, p.26/7) point out, data problems make this avenue difficult to take. As a simplification, the logistic curve for cumulative supply can be estimated directly using readily available supply data as follows. Consider

$$CS_t = \frac{CS^u}{1 + A \cdot e^{-\frac{t}{a}}} \quad (5.1)$$

where CS_t is the cumulative supply at time t , CS^u is the ultimate recoverable supply of oil, and A and a are constants. The above cumulative supply curve can be estimated in its logarithmic form

$$\ln\left(\frac{CS^u}{CS_t} - 1\right) = \beta_0 + \beta_1 t + \epsilon_t \quad (5.2)$$

where $\beta_0 = \ln A$, $\beta_1 = -\frac{1}{a}$, and ϵ_t is the error term. Since CS^u is unknown, this equation has to be estimated iteratively by substituting different values for CS^u

²⁷see the discussion in the previous section, and Renshaw and Renshaw (1980) as a reference.

such that the residual sum of squares of the equation is minimised. Working backwards, the geological annual production curve can be determined by

$$GS_t = \frac{dCS_t}{dt} = CS_t - CS_{t-1} \quad (5.3)$$

where GS_t is the geologically determined supply at time t . Similarly to equation (5.2) and as a check for consistency, the cumulative discovery curve can be estimated by

$$\ln\left(\frac{CS^u}{CD_t} - 1\right) = \gamma_0 + \gamma_1 t + u_t \quad (5.4)$$

where CD is cumulative discoveries and the other terms are as above. And lastly, the proven reserves can be determined using the following identity

$$R_t = CD_t - \sum S_t \quad (5.5)$$

where $\sum S_t$ stands for the summation of each S value over the whole time period. The equation that was estimated for each of the supply blocks was of the form

$$S_t = F(GS_{t-i}, S_{t-j}, P_{t-i}), \quad (5.6)$$

where $0 \leq i \leq 3$, and $1 \leq j \leq 3$; P is the oil price. That is, actual supply was postulated to be a function, F , of the geological supply trend, lagged values of actual supply, and the oil price.

5.4.2.2 *Estimation of supply side*

The above discussion highlighted that estimation of the equations determining the oil supply in the two non-OPEC-non-UK areas, North America (NA) and other-non-OPEC-non-UK (ONOUK), first required estimating an equation determining the geological supply trend in either geographic area. Tables 5.4 and 5.5 show the estimation results of this for North America and ONOUK. Rather than estimating either equation in succession to iteratively determine the CS^u that minimises the RSS , we have used the figures computed by Baldwin and Prosser of 256 and 236 giga barrels in the respective equation. The parameter estimates, which are highly significant, are very similar to those obtained by Baldwin and Prosser. And they allow the determination of the

geological supply trends — as outlined above — which in turn are used in the determination of supply figures for both geographic areas.

Table 5.4: Estimation results of geological supply trends
in North America

$\ln \frac{CSNA^u}{CSNA} = 1.052 - 0.070 *TIME$	
(311.85) (303.41)	
$R^2 = 0.999$	$DW = 0.25$
$\sigma = 0.00885$	$RSS = 0.0018801$
Sample: 1960 to 1985, 26 observations	
Estimation method: OLS	

Table 5.5: Estimation results of geological supply trends
in OtherNonOpecNonUK areas

$\ln \frac{CSNOUK^u}{CSNOUK} = 3.154 - 0.085 *TIME$	
(183.19) (71.99)	
$R^2 = 0.995$	$DW = 0.13$
$\sigma = 0.04516$	$RSS = 0.0489523$
Sample: 1960 to 1985, 26 observations	
Estimation method: OLS	

Estimation results of these are shown in Tables 5.6 and 5.7. The endogenous variables in either equation are ratios of actual supply and geological supply, which implies a unity long term supply elasticity of geological supply trends. For North America, the supply elasticity of geological supply trends is also unity in the short term.

The price term in either equation is significant, but the size of its estimate differs. Oil supply is much more price responsive in the ONOUK area than it is in North America, with price elasticities of 0.105 and 0.06 respectively. This result is also obtained by Baldwin and Prosser and can be explained by both geological and economic factors. Hubbert's work shows that exploitation of oil in North America has proceeded well beyond its peak, and that future annual production rates are expected to decline further — as they have done since passing the peak. The situation in ONOUK area, however,

Table 5.6: Estimation results of actual oil supply
in North America

$$\Delta \ln \frac{SNA}{GSNA} = \underset{(9.15)}{-0.234} + \underset{(9.39)}{0.060} * \ln OPI_{t-3}$$

$$R^2 = 0.898$$

$$DW = 2.35$$

$$\sigma = 0.01205$$

$$RSS = 0.0014529$$

Sample: 1974 to 1985, 12 observations

Estimation method: OLS

Equation diagnostics:

Autocorrelation: $F(1,9) = 0.49$

ARCH: $F(1,8) = 0.00$

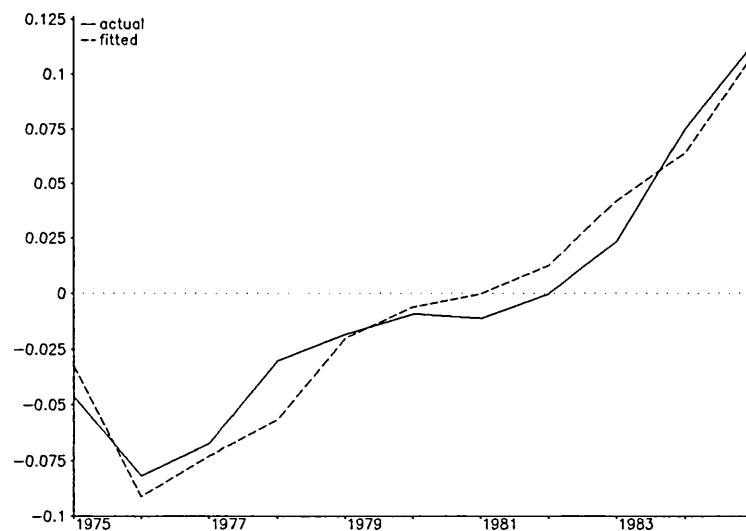
Normality: $\chi^2(2) = 0.70$

RESET: $F(1,9) = 0.10$

Forecast: $\chi^2(2/2) = 0.83$

Chow: $F(2,8) = 0.56$

Figure 5.6: $\ln \frac{SNA}{GSNA}$ — actual v fitted



differs sharply from this. There, exploitation is still expected to reach its peak since major new oil fields will most certainly be discovered and brought on stream. It is therefore clear that higher world oil prices will intensify and accelerate this process more than in an area, where no new major discoveries are expected, no matter what the level of oil price.

Table 5.7: Estimation results of actual oil supply
in OtherNonOpecNonUK areas

$$\ln \frac{SONOUK}{GSONOUK} = \underset{(11.94)}{0.707} * \ln \left(\frac{SONOUK}{GSONOUK} \right)_{t-1} - \underset{(4.65)}{0.406} + \underset{(5.04)}{0.105} * \ln OPI_{t-1}$$

$$R^2 = 0.982$$

$$DW = 1.70$$

$$\sigma = 0.02356$$

$$RSS = 0.0049973$$

Sample: 1974 to 1985, 12 observations

Estimation method: OLS

Equation diagnostics:

$$\text{ARCH:} \quad F(1,7) = 0.03$$

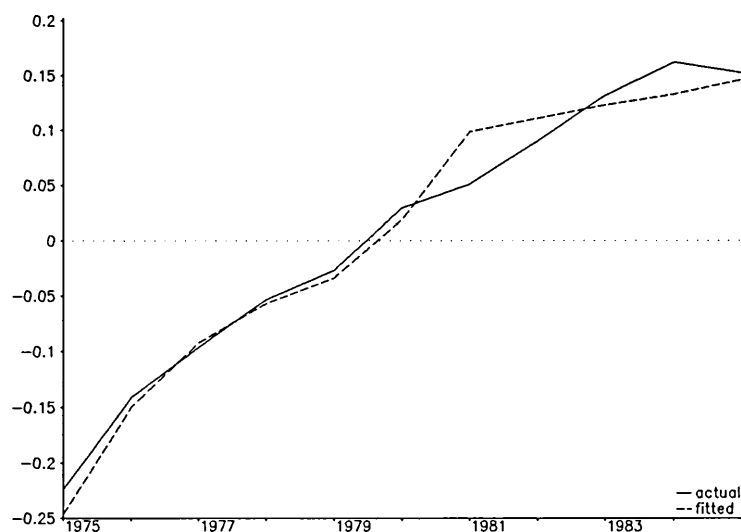
$$\text{Normality:} \quad \chi^2(2) = 1.06$$

$$\text{RESET:} \quad F(1,8) = 0.44$$

$$\text{Forecast:} \quad \chi^2(2/2) = 3.13$$

$$\text{Chow:} \quad F(2,7) = 1.58$$

Figure 5.7: $\ln \frac{SONOUK}{GSONOUK}$ — actual v fitted



5.4.3 The determination of the oil price

This section discusses how the oil price is determined within the model. It was discussed above that several models in the literature now use an oil price reaction function of the following form

$$\frac{P_t - P_{t-1}}{P_{t-1}} = \theta_0 + \frac{\theta_1}{1 - U_t} + \mu_t, \quad (5.7)$$

where P is the oil price, and U is the level of capacity utilisation that OPEC has achieved. The estimated form of this equation is shown in Table 5.8.

Table 5.8: Estimation results of oil price

$$\Delta \ln POILD = \frac{-0.184}{(2.75)} + \frac{0.048}{(4.67)} \frac{1}{1 - CU}$$

$$R^2 = 0.708 \quad DW = 2.00$$

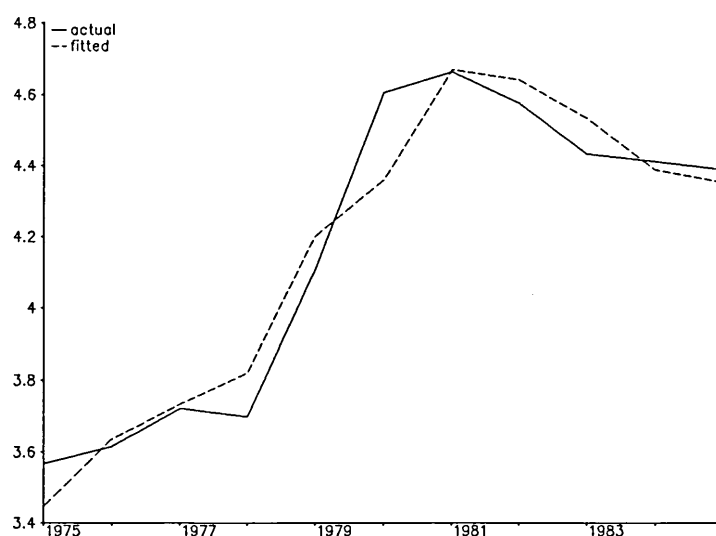
$$\sigma = 0.11363 \quad RSS = 0.1162056$$

Sample: 1975 to 1985, 11 observations
 Estimation method: OLS

Equation diagnostics:

ARCH:	$F(1,7) = 0.14$
Normality:	$\chi^2(2) = 1.57$
RESET:	$F(1,8) = 0.83$
Forecast:	$\chi^2(2/2) = 0.11$
Chow:	$F(2,7) = 0.08$

Figure 5.8: $\ln POILD$ — actual v fitted



The statistical tests show a successful estimation, with no autocorrelation and good forecasting and stability characteristics. The capacity utilisation estimate is well-determined. Slightly problematic is the R^2 value of 0.708. This arises because of the inability of the estimated equation to capture fully the price rises that were instigated by OPEC in 1979. Reassuring, however, is that all turning points are faithfully tracked.

5.5 CONCLUSIONS

The purpose of this chapter has been to present an econometric model of the international oil market that would link up with the model of the UK economy developed in Chapter 4. The linking variables are UK oil production, which feeds into the oil market, and the international dollar oil price, an output variable of the oil model feeding into the UK model. The model of the oil market has been adapted from recent developments in the literature.

Its basic structure is composed of a demand and a supply part, and an equation determining the international oil price. Since our interest in the oil market is more concerned with the oil supply of the various market participants, as opposed to oil demand, the model features only one equation for oil demand in WOCA — the world outside communist areas.²⁸ Oil supply, on the other hand, is disaggregated into the following four supply groups: OPEC, North America, UK, and other suppliers. Demand and supply are assumed to balance in each time period. This is achieved in the model by assuming that OPEC act as a swing producer, which requires it to adjust its own supply to balance demand and the accumulated supply of the remaining supply groups. Because of its pre-eminent role in the oil market, OPEC is furthermore assumed to set the oil price, where the oil price depends on OPEC's capacity utilisation. The model has been successfully estimated using the methodology that was applied in Chapter 4.²⁹

Prior to the presentation of the model, we reviewed the evolution of the oil market, and the many different theories and practical models that attempt

²⁸The categorisation of WOCA and CA is commonly used because of the general self-sufficiency in oil of communist countries (see Baldwin and Prosser (1987)).

²⁹The full listing of the econometric model can be found in Appendix A.

to explain and predict the volumes and prices which are determined in the international market place. We have also highlighted the role that the UK and the other independent oil producers play in the market, especially in so far in that they have been able to force the main market player, the OPEC producers, to alter dramatically their pricing behaviour. We have pointed out the relevance that this policy reversal had for the UK economy.

Chapter 6

Solution and Dynamic Properties of the Complete Model

6.1 INTRODUCTION

As part of the empirical analysis so far, we have presented in Chapters 4 and 5 econometric models of the UK economy and the international oil market. The two combined models will be used in the next chapter for counterfactual policy analysis, where optimal policy variables will be calculated on the basis of certain given policy objectives. Use of the model is, however, only justified if the model is an adequate representation of the underlying economic processes. This chapter is therefore concerned with the simulation (solution) of the complete model and with tests of its adequacy and validity. Such tests commonly consist in the analysis of the historical tracking performance and, as the next step, the analysis of the dynamic properties of the model.

The historical tracking performance is judged by the closeness of fit, i.e. by the degree to which individual equations are able to track their historical paths when the model is solved simultaneously. Although we have seen in the previous chapters that all individual equations fit their actual data reasonably well, this may differ once the model is looked at as a system and solved simultaneously, as input variables to the equations will differ. A second criterion for testing the validity of econometric models is to analyse the model's dynamic properties. This means to consider the dynamic multipliers of the system of equations and to compare them with prior theoretical models. Dynamic multipliers are the response of endogenous variables to a unit step change in any of the exogenous variables of the model.

The next section deals with some technical aspects of the solution of econometric models. We discuss briefly the type of algorithm used in solving the model and we present several 'measures' evaluating the goodness of fit of the model. We also discuss the type of dynamic multiplier used in the

evaluation of the model. In Section 3 we present the results of the historical tracking exercise, and various dynamic multipliers are reported in Section 4. Conclusions of the overall results are drawn in Section 5.

6.2 TECHNICAL ASPECTS OF MODEL EVALUATION

This section is concerned with some technical aspects of the evaluation of macroeconomic models. First, we will outline the algorithm that was used in the solution of the model. This is followed by a discussion of evaluation measures and of dynamic multipliers.

Large econometric models are seldom linear, more commonly they are nonlinear containing economic relationships that are linear in parameters but nonlinear in variables. Solving such models cannot be achieved by various closed form transformations, as is possible with linear systems. Instead, nonlinear systems are solved by iteration approximation. The most popular algorithm that is used for this type of application is the *Gauss-Seidel* algorithm. To see, how the algorithm works, consider a typical nonlinear equation of the economic model in its explicit form as

$$y_{it} = g_i(y_{1,t}, \dots, y_{n,t}, y_{1,t-1}, \dots, y_{n,t-p}, x_{1,t}, \dots, x_{m,t}, \theta_1, \dots, \theta_{r_i}) + e_{it}. \quad (6.1)$$

The practical steps of the Gauss-Seidel solution algorithm are as follows. First, for the whole set of functions, g_i , feed some initial guesses of y'_{it} into the RHS of the above implicit equation in order to generate the LHS. The initial guesses may be recent observations of the variables. Then feed the generated LHS values of y'_{it} back into the RHS to compute a new set of LHS values of y'_{it} . Stop this iterative process when two successively computed vectors of y'_{it} differ by less than a limiting amount, ϵ_i . In general, the Gauss-Seidel is a fast and reliable algorithm, but the number of iterations to reach convergence can differ from application to application.¹

¹All simulation results have been obtained by the STATOPT program (Becker, 1990) as implemented in the MSDOS operating system. A normal solution of the model takes 12 seconds on an IBM compatible computer equipped with an Intel 286-12 CPU.

Before using the model as a tool to make statements about economic policy or economic theory, simulations can be used to check its claim of being a truthful representation of actual economic events. To evaluate the 'goodness of the model', a number of simulations can be obtained. If actual data exist for the simulation period, the solution can then be compared with actual economic events. A more subjective test would be to simulate the model over a time period for which actual data do not exist and to judge whether the model's solution coincides with the researcher's expectations of future economic events. It is certainly possible to mix these two concepts by, for example, starting a simulation within a time range for which actual data exist and extending it into the future.

In the case where an objective comparison between simulated and actual economic events is possible, there is a need to measure the discrepancy between the two outcomes. There exist many types of error measures², of which the following are a selection that have been used in the evaluation of our economic model. First, there is the Root-mean-square-error, *RMSE*; then there is the Root-mean-square-percentage-error, *RMSPE*. The *RMSE* is defined as

$$RMSE = \sqrt{\sum_{t=1}^T (y_t - \hat{y}_t)^2 / T},$$

where y_t is the actual value at time t , and $\hat{y}_t$ is the estimated value at time t . Similarly, the *RMSPE* is defined as

$$RMSPE = \sqrt{\sum_{t=1}^T [(y_t - \hat{y}_t)/y_t]^2 / T}.$$

The *RMSE* is a generally liked error measure because of two appealing features — one theoretical and one practical. Its theoretical feature is that its square, the *MSE*, can be split up into a variance about the mean error and a squared bias

$$\frac{1}{T} \sum_{t=1}^T (y_t - \hat{y}_t)^2 = \frac{1}{T} \sum_{t=1}^T ((y_t - \hat{y}_t) - (\bar{y}_t - \bar{\hat{y}}_t))^2 + (\bar{y}_t - \bar{\hat{y}}_t)^2.$$

The attractiveness of this result is that the bias term, if it is recognised in the simulation as sizeable, can be counteracted in subsequent simulations by an offsetting constant adjustment term. The practical feature of the *RMSE* is

²see Pindyck and Rubinfeld (1981) for a discussion.

that it does not allow positive errors to absorb negative errors, something to which the *MSE* is prone and which would underestimate the actual error size. Another characteristic of the *RMSE* is that it penalises large errors more than the *MSE*.

Another area where dynamic simulations are useful is the general multiplier analysis. Originally, the multiplier measured the effect of a change in government spending on GDP, i.e.

$$dY/dG,$$

where Y stands for GDP and G for government expenditure. Now, multiplier analysis has been extended to the analysis of nearly any effect caused by any variable change.³ In linear models, impact multipliers and long-run multipliers can be calculated using standard formulae. For nonlinear models, however, this is often impractical, if not infeasible. Instead, multipliers are obtained as the result of two kinds of simulations — a base simulation and a perturbed simulation. The base simulation is the solution of the dynamic model (6.1), for given values of x_t . In the perturbed simulation, some values of x_t , say x_{jt} , are incremented by a factor δ . This increment may take the form of an impulse in one time period only, or it may be sustained for the whole time period of the simulation. The difference between the paths of the base and perturbed simulation will then be the dynamic multiplier. For the case, when the increment is sustained over the whole time period, the dynamic multiplier is calculated as the difference between the two solutions at any point in time, i.e.

$$\text{dynamic multiplier in sustained case} = (y_t^{\text{perturbed}} - y_t^{\text{base}}) / \delta.$$

In common with many other studies, we consider only sustained increases in exogenous variables. In either case, provided that the system is stable, the dynamic multiplier will converge to the long-run multiplier.

³see Klein and Welfe (1983) for a discussion.

6.3 HISTORICAL TRACKING PERFORMANCE

In this section, we use the above outlined principles in the presentation of our results. The tracking results come first. The simulation covers the period between 1975 — the first year of sizeable oil exploration in the North Sea — and 1985 when North Sea oil exploration seemed to have reached its peak.

The simulation results are reported in Tables 6.1 – 6.4. The figures shown in these tables are annual percentage deviations of the simulated paths from the actual paths. At the end of the simulation period the corresponding *RMSPE* values for each series are also shown. Table 6.1 shows the results of the real variables in the model.

Table 6.1: Tracking performance — real variables
% deviations from historical data

year	<i>GDPE</i>	<i>CON</i>	<i>INV</i>	<i>IMP</i>	<i>IM</i>	<i>X</i>	<i>XOX</i>
1975	-0.05	1.17	-0.70	1.73	1.69	0.61	0.58
1976	-1.09	-0.73	-1.46	1.82	0.83	-0.85	-1.48
1977	-1.40	-2.18	-1.55	-0.43	-2.85	-1.99	-2.95
1978	-0.48	-1.20	1.80	4.20	1.68	-0.08	-2.75
1979	1.25	0.01	0.52	-0.05	-2.15	1.47	-1.05
1980	1.24	2.07	0.66	4.39	1.60	3.42	1.42
1981	2.60	3.12	9.53	8.80	6.57	5.47	6.08
1982	0.81	1.85	1.57	3.61	1.73	1.77	3.34
1983	-0.11	0.03	1.23	2.11	2.29	1.11	5.08
1984	0.22	1.45	-2.77	-1.19	-1.70	-1.62	3.43
1985	-2.36	-1.06	-2.70	-1.30	-1.12	-5.41	-0.37
<i>RMSPE</i>	1.33	1.62	3.29	3.59	2.65	2.78	3.13

key: *GDPE* — GDP at 1980 prices
CON — consumers' expenditure at 1980 prices
INV — investment at 1980 prices
IMP — total imports at 1980 prices
IM — non-oil imports at 1980 prices
X — total exports at 1980 prices
XOX — non-oil exports at 1980 prices

At a first glance, the model tracks the actual paths reasonably well, with all variables having low *RMSPE* values. Especially for GDP (*GDPE*) and consumption (*CON*), the values are very low. Investment (*INV*) sticks out with a slightly higher than average *RMSPE* value of 3.29, but it is the experience of many model builders to have difficulty in explaining investment behaviour as satisfactorily as, for example, consumption behaviour. Another

reason may be that since the model is a very aggregated representation of the economy, the different actual investment patterns that are here captured in only one equation may not be driven by the same general variables. The estimated foreign trade variables, non-oil imports and exports — *IM* and *XOX* — have similar *RMSPE* values of 2.65 and 3.13 respectively. Total imports and exports, *IMP* and *X*, have slightly different *RMSPE* values since they also include import savings of oil and oil exports.

A closer look at the tracking performance of the real variables shows that the deviations of the variables follow a similar pattern. The deviation profile changes from underprediction — with a low in 1977 — to overprediction — with a peak in 1981 — and back to underprediction towards the end of the simulation period. Because of the close interrelationship of the variables and their dependence on price and income factors, the cause of this particular pattern of deviation may be found either in the performance of the income variables or in that of the price variables. However, since the income factor in the equation for non-oil exports is exogenous, and the equation still exhibits the same pattern of deviation, the cause for the deviation pattern seems to stem from the price variables, to which we now turn.

The tracking performance of the price variables in the model is shown in Table 6.2. A comparison of the *RMSPE* values of this table with those of Table 6.1 indicates a worse tracking record of the price variables and exchange rates. However, because of the close interdependence of the various variables of Table 6.2, most price variables have similar *RMSPE* values. The exception is the import price index, *PM*, which has an *RMSPE* value of 7.43. The respective *RMSPE* values of the exchange rates lie within the range of the price variables.

The analysis of the annual percentage deviations of each variable reveals two things: first, it shows that the deviation pattern of the price variables mirror that of the real variables; and second, it shows that the deviation pattern of the price variables in turn mirrors that of the nominal and real exchange rate. This seems to suggest that the ultimate cause for the deviation pattern of many variables in the model is the performance of the real exchange rate. Indeed, as Fisher *et al.* (1989) have shown that this variable is of utmost importance to the behaviour of most UK macroeconomic models. This is because of the openness of the economy that is much larger than, for example, that of the US economy for which imports and exports amount to a lesser

Table 6.2: Tracking performance — price variables and exchange rates
% deviations from historical data

year	<i>PC</i>	<i>PIMO</i>	<i>WHR</i>	<i>PEX</i>	<i>PM</i>	<i>REXRAT</i>	<i>EXRAT</i>	<i>BAL</i> ¹
1975	-4.22	-2.30	-10.19	-1.68	0.69	-4.33	-2.07	-1.00
1976	-4.17	-2.87	-6.33	-4.63	-4.88	0.28	3.25	-0.76
1977	-2.63	-3.57	-0.34	-4.17	-10.00	5.06	8.95	1.79
1978	-1.78	-3.89	-1.33	-1.84	-1.19	-4.76	-0.91	-2.26
1979	-0.15	-1.80	1.86	-0.48	-1.21	-7.67	-5.98	1.22
1980	-0.99	-0.98	0.23	-0.85	-3.02	-10.73	-9.84	0.89
1981	-1.55	-0.33	-0.05	-0.62	-4.74	-5.54	-5.23	1.07
1982	-2.35	-1.48	0.49	-0.81	-6.39	-0.87	0.62	2.74
1983	-4.12	-3.60	-4.06	-4.44	-8.27	4.99	8.91	2.20
1984	-5.79	-6.79	-4.78	-8.67	-13.29	11.81	19.95	3.86
1985	-7.21	-9.75	-7.07	-10.92	-12.75	7.84	19.49	-2.48
<i>RMSPE</i>	3.77	4.29	4.66	4.87	7.43	6.73	10.06	2.06

¹ deviations from historical data in billion pound sterling

key:

PC — consumer price index

PIMO — producer price index

WHR — hourly wage rate index

UNLC — index of unit labour cost

PEX — export price index

PM — import price index

REXRAT — real exchange rate index

EXRAT — nominal exchange index

BAL — balance of payments

percentage of its GDP.⁴ The variable that transmits changes in the real exchange rate to the price sector is the international wholesale price index converted into the domestic currency by the nominal exchange rate. This index determines domestic wholesale prices which via consumer prices feed into other price variables and the rest of the model.

We turn to the discussion of the monetary sector and Table 6.3, where the percentage deviation of the variables are listed. The *RMSPE* values reveal the tracking record of this sector as the worst in the model. This is not surprising for two reasons. First, monetary variables are the most volatile variables in any economy and hence difficult to model. Second, the degree of aggregation in our model simplifies and therefore probably obscures certain influences, which in turn worsens the overall tracking record. But since the monetary sector's influence on the rest of the model is small and the model's focus is on a different part of the economy, these deficiencies have been tolerated.

The oil market is captured fairly well by the model — as shown in Table 6.4. The *RMSPE* values for the demand and supply aggregates are low, with

⁴This is more fully demonstrated in Section 4.4.3 of Chapter 4.

Table 6.3: Tracking performance — monetary variables
% deviations from historical data

year	<i>M3S</i>	<i>PSBR</i> ¹	<i>SBLPRIVS</i>	<i>SGDETPRI</i>	<i>WEALPC</i>	<i>RALLTAX</i>	<i>RSBLPR</i>	<i>RSGD</i>
1975	6.71	-0.27	10.22	-1.80	-2.22	-0.92	15.07	2.52
1976	0.52	0.52	1.40	1.05	-1.89	-4.26	5.82	5.44
1977	11.13	1.04	15.60	1.50	3.80	-4.84	18.72	4.24
1978	28.37	1.43	43.95	4.97	2.59	-5.51	46.56	6.87
1979	31.32	0.73	40.26	2.77	5.42	-2.22	40.47	2.92
1980	21.49	-0.40	36.08	7.14	6.34	0.57	37.44	8.21
1981	11.84	-1.10	29.82	12.55	6.01	2.25	31.87	14.32
1982	3.61	0.02	17.64	13.64	8.72	-0.30	20.47	16.38
1983	-3.05	0.01	12.08	15.90	10.50	-1.00	16.89	20.87
1984	-4.23	0.19	7.52	13.21	13.41	-1.50	14.13	20.17
1985	-4.61	1.98	3.67	11.77	12.85	-4.52	11.72	20.45
<i>RMSPE</i>	15.43	0.92	24.53	9.53	7.78	3.12	26.76	13.18

¹ deviations from historical data in billion pound sterling

key:

M3S — money supply (sterling M3)

PSBR — public sector borrowing requirement

SBLPRIVS — nominal stock of bank lending

SGDETPRI — nominal stock of bond sales

WEALPC — real stock of wealth

RALLTAX — real total tax revenues

RSBLPR — real stock of bank lending

RSGD — real stock of bond sales

Table 6.4: Tracking performance — oil sub-model
% deviations from historical data

year	<i>DWOCA</i>	<i>SOPEC</i>	<i>SNA</i>	<i>SONOUK</i>	<i>POILD</i>	<i>CU</i>
1975	0.32	0.31	1.43	-2.24	-11.18	0.77
1976	-2.06	-2.64	0.48	-3.66	-11.67	-10.13
1977	-2.69	-3.42	-0.08	-3.50	-14.49	-15.24
1978	-3.26	-3.15	-3.22	-4.40	-6.91	-13.31
1979	-3.27	-2.69	-3.96	-4.54	-14.61	-26.33
1980	-0.28	3.20	-4.36	-5.83	-22.26	34.91
1981	1.68	6.01	-3.63	-2.15	-15.20	33.00
1982	1.52	5.83	-3.11	-1.15	-7.10	15.75
1983	1.61	6.93	-2.46	-2.45	5.11	15.55
1984	2.18	10.78	-4.30	-4.06	6.56	25.74
1985	3.27	14.22	-5.09	-2.79	6.72	29.40
<i>RMSPE</i>	2.26	6.62	3.31	3.58	12.15	22.42

key: *DWOCA* — world oil demand outside communist areas

SOPEC — OPEC supply of oil

SNA — North American supply of oil

SONOUK — supply of oil of other non-OPEC-non-UK countries

POILD — dollar oil price

CU — OPEC capacity utilisation

slightly higher oil supply figures — as demand schedules are usually better understood and hence modelled. The residual OPEC supply variable, *SOPEC*, has a higher *RMSPE* value of 6.62. The crucial variable in this sub-model and the model altogether, the dollar oil price *POILD*, has an *RMSPE* value of 12.15. This can be considered a reasonable achievement given the simplistic formula that is applied to compute it. The variable upon which *POILD* depends, the degree of OPEC capacity utilisation *CU*, has a larger percentage deviation than *POILD* with a value of 22.42.

Looking at the tracking record in more detail and considering the causal relationships in the sub-model, the tracking performance of the individual variables can be explained better. Since the supply schedules for North America and Non-OPEC-non-UK, *SNA* and *SONOUK*, consistently underestimate their actual values, the residual OPEC supply scheme, *SOPEC*, would tend to overestimate its actual path, and indeed it does so after 1980. Yet, since the demand variable *DWOCA* also underestimates the first half of its actual path, the underprediction of *SNA* and *SONOUK* is not counteracted and hence *SOPEC*, too, underestimates that part of the simulation period. This pattern of underestimation first and overestimation later is also reflected in *CU* and finally the oil price schedule, *POILD*.

6.4 DYNAMIC PROPERTIES

After establishing that the complete model is able to track historical data fairly well, we discuss in this section the dynamic properties of the model. An analysis of the dynamic properties is commonly used⁵ as an additional test of the validity and adequacy of the model and involves the study of the dynamic multipliers of the model. These record changes of the model caused by unit step changes in various exogenous variables and are then compared with those of other models and with *a priori* reasoning. We consider here changes in the major policy variables of the UK government (interest rates, government expenditure, and UK oil production), as well as an OPEC policy variable (its rate of capacity utilisation), and finally changes in the foreign price level.

⁵see *inter alia* the comparison of UK macroeconometric models in Wallis *et al.* (1984, 1985).

6.4.1 A change in interest rates

In this section, we discuss the effects that a percentage point increase in the treasury bill rate has on the rest of the model. The reactions of the various variables are recorded in Tables 6.5 – 6.7. An interest rate rise propagates through various channels in the model. It affects the price and exchange rate sector, the real sector and the monetary sector. Its greatest influence, of course, is in the monetary sector, where the treasury bill rate determines bank lending, bond sales and, ultimately, the money supply. But the treasury bill rate also influences portfolio decisions of national as well as international investors. By changing the level of interest rates, the government as the ultimate economic policy maker can influence the real interest rate differential between the UK and international capital markets. This determines the flow of international funds — whether they leave the country or are invested in the UK capital market — and hence the exchange rate and the balance of payments. Another channel through which the economy is affected by changes in interest rates is the influence on consumption and investment. The influence on consumption reflects the consumer's choice in the model, to either spend his money or to save it. In the case of investment, interest rates proxy the price of money and therefore the availability of funds that can be used to add to the capital stock or replace parts of it.

The demand effect on the economy is negative. After the 11-year simulation period, the level of *GDPE* has been reduced by an average of 0.64% with respect to the base simulation. In its profile, the reduction starts slowly and reaches a minimum of 0.82% below the base values in its fifth year of adjustment; thereafter *GDPE* recovers steadily until it reaches its long term value of around 0.72% below the base path. The profile of the adjustment process of consumption is similar: it also falls to a low point in its fifth year and recovers thereafter. However, after its low point GDP rises again to a long term value that is relatively closer to its pre-shock value than that of consumption. This is mainly due to the effect of the interest rate on consumption. In our model, the consumer is faced with two choices: he can spend his money or he can save it. Evidently, a higher interest rate level has tempted him to save more of his income; he therefore spends less on consumption.

**Table 6.5: A 1 per cent increase in interest rates —
effects on real variables
% deviations from base run**

year	<i>GDPE</i>	<i>CON</i>	<i>INV</i>	<i>IMP</i>	<i>IM</i>	<i>X</i>	<i>XOX</i>
1975	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1976	-0.16	-0.25	-0.54	-0.31	-0.31	-0.02	0.00
1977	-0.45	-0.57	-0.94	-0.51	-0.54	-0.33	-0.26
1978	-0.60	-0.73	-1.16	-0.78	-0.86	-0.64	-0.47
1979	-0.80	-0.89	-1.38	-0.90	-1.03	-0.96	-0.72
1980	-0.82	-0.89	-1.42	-1.03	-1.15	-1.08	-0.86
1981	-0.77	-0.85	-1.34	-1.03	-1.14	-1.08	-0.86
1982	-0.73	-0.81	-1.23	-0.97	-1.09	-1.06	-0.82
1983	-0.71	-0.79	-1.15	-0.92	-1.05	-1.05	-0.78
1984	-0.70	-0.77	-1.09	-0.87	-0.99	-1.04	-0.79
1985	-0.72	-0.78	-1.05	-0.85	-0.98	-1.07	-0.81
<i>RMSPE</i>	0.64	0.72	1.10	0.81	0.91	0.86	0.66

key: *GDPE* — GDP at 1980 prices
CON — consumers' expenditure at 1980 prices
INV — investment at 1980 prices
IMP — total imports at 1980 prices
IM — non-oil imports at 1980 prices
X — total exports at 1980 prices
XOX — non-oil exports at 1980 prices

The profiles for the other real variables are similar to those of GDP and consumption. A low point of adjustment is generally achieved in 1980, the fifth year of the adjustment process. From then on until the end of the simulation period all variable paths rise again towards their base paths. They differ in their ratio of lowest value and final value of deviations. For example, investment drops to a low of 1.42 per cent below base and ends up 1.05 per cent below base; the difference for non-oil is slighter — a low value of 0.86 below base and a final value of 0.81 per cent below base. The greater response of investment reflects the direct influence that interest rates have on it; interest rates affect exports only indirectly via changes in the real exchange rate.

The effects on prices and the exchange rate are shown Table 6.6. In comparison to the real variables, prices react more strongly to the change in interest rates. But their profiles look different from those of the real variables. Instead of showing a clear decline, peak and recovery, prices fall gently during the whole simulation period. The profile for the real exchange rate differs: it reaches a clear peak in 1979, the fourth year of adjustment, declines but picks up again in the last two time periods. The nominal exchange rate's profile is similar to those of the price variables: it rises gently, reflecting the influence of prices that are used to compute the nominal exchange rate in our model.

**Table 6.6: A 1 per cent increase in interest rates —
effects on price variables and exchange rates**
% deviations from base run

year	<i>PC</i>	<i>PIMO</i>	<i>WHR</i>	<i>PEX</i>	<i>PM</i>	<i>REXRAT</i>	<i>EXRAT</i>	<i>BAL</i> ¹
1975	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1976	-0.09	-0.13	-0.07	-0.33	-0.93	1.31	1.44	0.32
1977	-0.26	-0.53	-0.39	-0.79	-1.61	1.85	2.39	0.35
1978	-0.61	-1.12	-1.04	-1.50	-2.63	2.66	3.82	0.59
1979	-0.99	-1.78	-1.72	-2.16	-3.34	2.85	4.71	0.55
1980	-1.42	-2.39	-2.48	-2.74	-3.76	2.58	5.09	0.32
1981	-1.80	-2.84	-3.06	-3.16	-4.09	2.38	5.37	0.19
1982	-2.13	-3.16	-3.48	-3.47	-4.37	2.26	5.60	0.19
1983	-2.42	-3.41	-3.81	-3.74	-4.72	2.36	5.98	0.37
1984	-2.70	-3.66	-4.11	-4.00	-5.06	2.47	6.36	0.51
1985	-2.95	-3.90	-4.40	-4.26	-5.42	2.61	6.78	0.71
<i>RMSPE</i>	1.73	2.50	2.74	2.78	3.68	2.26	4.79	0.42

¹ deviations from historical data in billion pound sterling

key:

PC — consumer price index

PM — import price index

PIMO — producer price index

REXRAT — real exchange rate index

WHR — hourly wage rate index

EXRAT — nominal exchange index

UNLC — index of unit labour cost

BAL — balance of payments

PEX — export price index

**Table 6.7: A 1 per cent increase in interest rates —
effects on monetary variables**
deviations from base run in billion pound sterling

year	<i>DM3S</i>	<i>DSBLPRIV</i>	<i>DSGDETPR</i>	<i>PSBR</i>	<i>WEALPC</i>
1975	0.00	0.00	0.00	0.00	0.00
1976	-0.53	-0.47	0.10	0.04	0.62
1977	-0.59	-0.26	0.44	0.11	1.33
1978	-0.93	-0.57	0.50	0.13	2.36
1979	-0.91	-0.43	0.63	0.15	3.36
1980	-1.25	-0.67	0.66	0.07	4.13
1981	-1.40	-1.01	0.57	0.18	4.83
1982	-2.27	-1.93	0.60	0.25	5.49
1983	-2.09	-1.70	0.48	0.08	6.28
1984	-2.85	-2.38	0.56	0.10	7.19
1985	-3.57	-2.96	0.72	0.11	8.13
<i>RMSE</i>	1.81	1.46	0.53	0.13	4.74

key: *DM3S*— change in money supply (sterling M3)

DSBLPRIV— change in bank lending

DSGDETPR— change in bond sales

PSBR— public sector borrowing requirement

WEALPC— real wealth

The way the monetary sector is affected by the change in interest rates is shown in Table 6.7. Two phenomena are evident: the strong sensitivity of bank lending to the change in interest rates on the one hand, and the relatively immobile response of bond sales on the other. This reflects the direct influence of the treasury bill rate on bank lending; bond sales are only influenced by the treasury bill rate via the consol rate.

The overall results show that the interest rate can be successfully used by the government as an anti-inflation policy instrument. An increase in interest rates lowers inflation and diverts funds from spending towards higher savings. The consequence is lower consumption and total output. A further anti-inflationary impact is shown by the increase in the exchange rate. Somewhat surprising is the overall increase in the balance of payments. This can, however, be explained by the strong influence of income on imports, which therefore decline.

6.4.2 A change in government expenditure

In this section, we discuss the response of the model to a change in government expenditure. Even though different macromodels of a particular country all model the same economy, they usually consider a different number of variables and parameters; they may also differ in the disaggregation of various sectors and whether a particular variable is endogenous or exogenous to the model. Yet most macromodels have one feature in common: government expenditure is taken to be a policy variable under control of the government and hence exogenous to the model. For this reason, it is possible and a standard feature of comparative model analysis to compare with other models the response of each of them to an increase in government expenditure. Model comparisons used to be done by increasing government expenditure alone. But more recently, the question — how would the government finance the increase in expenditure? — has been considered. Generally, two broad ways of financing government expenditure are open to the monetary authorities: by printing more money (money-finance), or by selling bonds to the public (bond-finance). Both ways require the monetary authorities to change the level of interest rates. In the case of money-finance, interest rates will be lowered to facilitate the expansion of the necessary bank lending. In the opposite case of bond-finance, interest rates will be increased to provide a sufficiently attractive rate of return

for investors to lend money to the government. Of course, both forms of finance have different impacts on the economy. The reduced level of interest under money-finance will give an additional boost to economic development, whereas higher interest rates dampen economic development. Hence, the choice between the two usually depends on the condition of the economy. If growth threatens to become excessive, the mode of finance may be switched to bond-finance, while a slowdown in growth may be reversed or at least softened by a switch to money-finance.

In the following, we consider three cases of a 3.25% annual increase in government expenditure⁶. In the first case, the financing of it has been disregarded, mainly in order to judge the size and plausibility of the model's reaction to a change in one variable only. In cases two and three, the expansion is financed by money and bonds respectively, with according changes in interest rates.

Before turning to the discussion of the results, we consider the ways through which government expenditure affects the rest of the economy. Higher government expenditure is transmitted through two channels — total final expenditure and the public sector borrowing requirement. Higher total final expenditure leads to a larger gross domestic product which, in turn, will boost other real variables that are determined among other factors by income terms; imports, investment and consumption are all expected to grow after an increase in government expenditure. This growth in gross domestic product is, however, not expected to continue forever. As expanding production reaches full capacity utilisation, extra demand in the short term can only be dampened by an increase in goods prices since additional production facilities take more time to build. The increase in inflation will erode to some extent the benefits of higher growth in gross domestic product.

The second channel through which higher government expenditure affects the economy is the public sector borrowing requirement. A larger level of government expenditure will increase the borrowing requirement which in turn will lead to higher growth in the money supply. However, these developments in the monetary sector do not feed back directly into the real side of the economy in our model, since the only link between the monetary sector and the real economy is through interest rates. Interest rates therefore provide

⁶This increase corresponds to tests that have been carried out with major UK macromodels, the LBS, NIESR, CUBS. The results of these are reported in Wallis (1984, 1985).

an indirect feedback in the the real economy as they reflect the government's economic policy objectives and reactions. In the case of a money-financed increase in government expenditure, interest rates will fall to accommodate the increase in the money supply. This movement in the interest rate, of course, causes additional, expansionary effects whose workings have been described in the previous section.

We start the discussion of the results with Table 6.8a, which shows the demand side variables' reaction to the expansion in government expenditure in isolation of any financing question. The real variables react strongly and positively to the policy measure. GDP, consumption and investment all reach a peak in the fifth year of adjustment, and then decline steadily for the rest of the simulation period. The foreign trade variables are affected with a time lag of one year, and they therefore reach a peak in 1980. This time lag arises because effects of a changed exchange rate and prices take more time to work through the economic system. Tables 6.8b and 6.8c show the demand side's reaction under money- and bond-financing schemes. The profile of adjustment under bond-finance is similar to that of Table 6.8a, where financing questions are ignored. That is, the variables expand and reach relative peaks in the same year as the variables in Table 6.8a. The difference, however, lies in the magnitude of the adjustment. As predicted above, the increase in interest rates (see Table 6.10c⁷) that is necessary to implement the bond-financed expansion of government expenditure has reduced the overall addition to economic activity. For example, GDP's peak expansion of 2.23 per cent above base has here been reduced to a 1.82 per cent increase. Moreover, the model also declines more strongly after 1980 and ends up only 0.84 per cent higher under bond-finance, compared with a figure of 1.63 per cent in the other case.

The model's reaction under a money-finance scheme (Table 6.8b) runs the opposite way with increased economic activity in comparison to the case of Table 6.8a, where the financing of the deficit is ignored. But the figures in Table 6.8b also show that the induced expansion is so strong that the variables' adjustment profiles are changed. Because of the additional expansionary effects that the reduction of the interest rate (see Table 6.10b) have induced, GDP, consumption and investment reach a peak in 1980, a year later than in the other two cases. The profiles of the foreign trade variables, imports and exports, have changed even more. Imports now reach a peak in 1982, two years after GDP, and exports continue rising throughout the simulation period.

⁷on page 21.

**Table 6.8a: Increase in government expenditure —
effects on real variables
% deviations from base run**

year	<i>GDPE</i>	<i>CON</i>	<i>INV</i>	<i>IMP</i>	<i>IM</i>	<i>X</i>	<i>XOX</i>
1975	1.05	0.92	1.14	1.89	1.89	0.00	0.00
1976	1.33	1.30	1.68	2.31	2.33	0.51	0.45
1977	1.82	1.83	2.26	2.71	2.79	1.23	1.05
1978	1.95	1.93	2.42	3.06	3.24	1.79	1.36
1979	2.23	2.13	2.67	3.07	3.32	2.33	1.76
1980	2.14	1.98	2.55	3.24	3.44	2.37	1.90
1981	1.94	1.81	2.22	3.13	3.30	2.18	1.75
1982	1.79	1.68	1.90	2.92	3.09	1.99	1.55
1983	1.68	1.59	1.65	2.73	2.91	1.88	1.39
1984	1.62	1.51	1.47	2.53	2.71	1.80	1.34
1985	1.63	1.53	1.39	2.46	2.65	1.84	1.37
<i>RMSPE</i>	1.77	1.69	2.00	2.76	2.91	1.78	1.38

key: *GDPE* — GDP at 1980 prices
CON — consumers' expenditure at 1980 prices
INV — investment at 1980 prices
IMP — total imports at 1980 prices
IM — non-oil imports at 1980 prices
X — total exports at 1980 prices
XOX — non-oil exports at 1980 prices

**Table 6.8b: Money-financed increase in government expenditure —
effects on real variables
% deviations from base run**

year	<i>GDPE</i>	<i>CON</i>	<i>INV</i>	<i>IMP</i>	<i>IM</i>	<i>X</i>	<i>XOX</i>
1975	1.05	0.92	1.14	1.89	1.89	0.00	0.00
1976	1.34	1.30	1.68	2.31	2.33	0.51	0.45
1977	1.87	1.91	2.41	2.80	2.88	1.25	1.05
1978	2.06	2.06	2.63	3.18	3.38	1.89	1.42
1979	2.50	2.44	3.25	3.42	3.72	2.58	1.89
1980	2.71	2.65	3.80	3.97	4.27	2.90	2.20
1981	2.70	2.67	3.70	4.07	4.36	3.01	2.33
1982	2.68	2.70	3.63	4.11	4.42	3.07	2.30
1983	2.69	2.72	3.42	3.99	4.37	3.21	2.30
1984	2.57	2.52	2.90	3.64	4.00	3.22	2.41
1985	2.55	2.49	2.74	3.56	3.94	3.28	2.44
<i>RMSPE</i>	2.32	2.29	2.96	3.43	3.69	2.53	1.90

key: see Table 6.8a

**Table 6.8c: Bond-financed increase in government expenditure —
effects on real variables
% deviations from base run**

year	<i>GDPE</i>	<i>CON</i>	<i>INV</i>	<i>IMP</i>	<i>IM</i>	<i>X</i>	<i>XOX</i>
1975	1.05	0.92	1.14	1.89	1.89	0.00	0.00
1976	1.19	1.09	1.21	2.04	2.05	0.50	0.45
1977	1.50	1.47	1.74	2.46	2.51	0.93	0.79
1978	1.61	1.54	1.82	2.62	2.74	1.34	1.02
1979	1.82	1.70	2.06	2.67	2.85	1.74	1.30
1980	1.76	1.59	1.92	2.75	2.89	1.79	1.43
1981	1.55	1.40	1.53	2.62	2.73	1.62	1.31
1982	1.31	1.14	0.97	2.28	2.36	1.37	1.11
1983	1.06	0.89	0.50	1.94	2.00	1.11	0.88
1984	0.89	0.70	0.19	1.64	1.68	0.87	0.69
1985	0.84	0.66	0.14	1.54	1.57	0.73	0.57
<i>RMSPE</i>	1.37	1.24	1.37	2.26	2.34	1.21	0.96

key: see Table 6.8a

Again, this change is due to price and exchange rate effects, which will be discussed more fully below. A second feature and result of the specific monetary policy measure in this case is that the relative decline in GDP after 1980 is relatively minor — a peak expansion of 2.71 per cent in 1980 compares with an expansion of 2.55 per cent in 1985. This is in stark contrast to the comparable figures of 2.23 per cent and 1.63 per cent in the ‘neutral-finance’ case.

The responses of prices and exchange rates are shown in Table 6.9. Overall, prices increase in comparison to the base run. This is because of the pressure of higher demand for goods and higher labour costs. The adjustment of prices differs to that of the real variables in that here there is no clear-cut peak followed by a declining phase. Instead, prices rise throughout the simulation period, with a growth rate that is slowing down towards the end of the simulation period. These figures suggest that the economy reaches a new steady-state inflation rate. Closer inspection of the price rises reveals the strong dependence of the real exchange rate on the growth rates of export and import prices. The two prices determine the balance of payments, which in turn, is the main determining factor of the real exchange rate. *Ceteris paribus*, when import prices grow faster than export prices, the balance of payments worsens, and vice versa. In Table 6.9a, import prices are pushed down more than export prices throughout the simulation period, hence the worsened position of the balance of payments with respect to the base run. But while the export price index reacts smoothly to the increase in government

expenditure — with a marked slow-down after 1980 — there are stronger fluctuations around the adjustment path of the import price index, and it is those that determine the changes in the balance of payments and finally in the real exchange rate. The more rapid growth of import prices (in comparison to export prices) until 1978 worsens the balance of payments. Then there is a period until 1982, where import prices grow relatively more slowly, resulting in an improvement of the balance of payments. But from 1983 onwards, the growth gap is widening again, and this leads to a renewed deterioration in the balance of payments and simultaneously in the real exchange rate.

Table 6.9a: Increase in government expenditure —
effects on price variables and exchange rates
% deviations from base run

year	<i>PC</i>	<i>PIMO</i>	<i>WHR</i>	<i>PEX</i>	<i>PM</i>	<i>REXRAT</i>	<i>EXRAT</i>	<i>BAL</i> ¹
1975	-0.03	0.17	-0.02	0.52	1.60	-2.23	-2.40	-0.91
1976	0.57	1.28	1.44	1.94	3.83	-4.17	-5.39	-1.40
1977	1.24	2.57	2.81	3.24	5.24	-4.48	-6.88	-1.25
1978	2.20	4.01	4.57	4.92	7.49	-5.75	-9.39	-1.89
1979	3.12	5.42	6.08	6.29	8.81	-5.63	-10.48	-1.69
1980	4.03	6.59	7.64	7.33	9.33	-4.67	-10.57	-1.13
1981	4.79	7.32	8.73	7.97	9.68	-4.02	-10.56	-0.86
1982	5.38	7.73	9.37	8.33	9.96	-3.65	-10.56	-0.97
1983	5.86	8.00	9.81	8.63	10.44	-3.76	-10.89	-1.48
1984	6.29	8.27	10.18	8.94	10.96	-3.96	-11.30	-1.86
1985	6.68	8.57	10.54	9.29	11.56	-4.24	-11.80	-2.38
<i>RMSPE</i>	4.30	6.15	7.39	6.78	8.64	4.33	9.54	1.51

¹ deviations from historical data in billion pound sterling

key:

PC — consumer price index

PIMO — producer price index

WHR — hourly wage rate index

PEX — export price index

PM — import price index

REXRAT — real exchange rate index

EXRAT — nominal exchange index

BAL — balance of payments

The reactions of the price and exchange rate sector to the increase in government expenditure under money- and bond-finance are tabulated in Tables 6.9b and 6.9c. As with the discussion of Tables 6.8, the series in Tables 6.9b and 6.9c show the same profile of adjustment as those in Table 6.9a, but with different magnitudes. That is, in the case of money-finance (Table 6.9b), prices rise faster than compared with Table 6.9a; and in the case of bond-finance (Table 6.9c), the rise is slower. The different levels of growth rates in the price indices cause corresponding reactions in the balance of payments and in the real exchange rate.

**Table 6.9b: Money-financed increase in government expenditure —
effects on price variables and exchange rates
% deviations from base run**

year	<i>PC</i>	<i>PIMO</i>	<i>WHR</i>	<i>PEX</i>	<i>PM</i>	<i>REXRAT</i>	<i>EXRAT</i>	<i>BAL</i> ¹
1975	-0.03	0.17	-0.02	0.52	1.60	-2.23	-2.40	-0.91
1976	0.57	1.29	1.44	1.94	3.85	-4.20	-5.41	-1.41
1977	1.26	2.61	2.83	3.33	5.48	-4.79	-7.20	-1.34
1978	2.28	4.16	4.69	5.15	7.98	-6.24	-9.98	-2.03
1979	3.32	5.79	6.39	6.86	10.01	-6.78	-11.89	-2.09
1980	4.47	7.43	8.38	8.52	11.65	-6.77	-13.21	-1.85
1981	5.60	8.84	10.23	9.90	12.87	-6.42	-14.02	-1.53
1982	6.65	9.99	11.74	11.08	14.18	-6.48	-14.97	-1.77
1983	7.66	11.04	13.08	12.23	15.74	-6.95	-16.20	-2.49
1984	8.64	12.05	14.34	13.23	16.83	-6.87	-16.89	-2.69
1985	9.54	12.92	15.39	14.19	18.18	-7.27	-17.89	-3.51
<i>RMSPE</i>	5.54	8.13	9.53	9.09	11.97	6.09	12.76	2.08

key: see Table 6.9a

**Table 6.9c: Bond-financed increase in government expenditure —
effects on price variables and exchange rates
% deviations from base run**

year	<i>PC</i>	<i>PIMO</i>	<i>WHR</i>	<i>PEX</i>	<i>PM</i>	<i>REXRAT</i>	<i>EXRAT</i>	<i>BAL</i> ¹
1975	-0.03	0.17	-0.02	0.52	1.60	-2.23	-2.40	-0.91
1976	0.48	1.15	1.37	1.61	2.90	-2.96	-4.07	-1.08
1977	1.02	2.11	2.48	2.62	4.07	-3.39	-5.39	-1.07
1978	1.74	3.18	3.77	3.85	5.67	-4.27	-7.22	-1.52
1979	2.45	4.22	4.91	4.89	6.76	-4.33	-8.21	-1.46
1980	3.14	5.11	6.07	5.65	7.10	-3.52	-8.21	-0.99
1981	3.71	5.63	6.89	6.08	7.20	-2.82	-8.00	-0.72
1982	4.09	5.81	7.27	6.15	6.97	-2.07	-7.45	-0.60
1983	4.32	5.75	7.33	6.03	6.73	-1.64	-6.98	-0.80
1984	4.42	5.54	7.16	5.78	6.47	-1.39	-6.57	-0.95
1985	4.43	5.31	6.91	5.56	6.35	-1.42	-6.39	-1.31
<i>RMSPE</i>	3.14	4.44	5.53	4.82	5.91	2.92	6.68	1.07

key: see Table 6.9a

The results for the monetary sector reflect the use of the policy instrument that is available to the government in this simulation exercise. It shows that the general increase in the money supply is caused by the expansion in bank lending; bond sales are immobile. The PSBR is also higher than during the base simulation which implies that the increased government expenditure is achieved by additional borrowing. Higher bank lending is made possible by the government instrument, the treasury bill rate, which is generally lower than during the base simulation.

Tables 6.10 show how the monetary policy objective has been achieved: The expansion of government spending increased the public sector borrowing requirement, *PSBR*, and the money was raised by driving up bond sales. Bank lending and the money supply, *M3S*, remain largely at base values.

Table 6.10a: Increase in government expenditure —
effects on monetary variables
deviations from base run in billion pound sterling

year	<i>DM3S</i>	<i>PSBR</i>	<i>DSBLPRIV</i>	<i>DSGDETPR</i>	<i>WEALPC</i>
1975	0.69	0.58	-0.01	-0.11	-0.59
1976	0.47	0.66	-0.25	-0.06	-1.85
1977	0.09	0.68	-0.53	0.05	-2.79
1978	0.31	0.82	-0.39	0.12	-4.32
1979	0.08	1.02	-0.75	0.20	-5.54
1980	0.47	1.49	-0.45	0.57	-6.14
1981	0.83	1.36	0.39	0.92	-6.55
1982	2.10	1.32	1.65	0.86	-6.90
1983	2.25	1.80	1.33	0.88	-7.51
1984	2.70	1.82	1.54	0.66	-8.37
1985	2.77	1.84	1.45	0.52	-9.33
<i>RMSE</i>	1.54	1.30	0.97	0.56	6.05

key: *DM3S*— change in money supply (sterling M3)
DSBLPRIV— change in bank lending
DSGDETPR— change in bond sales
PSBR— public sector borrowing requirement
WEALPC— real wealth

These results show that the use of government expenditure as a policy variable produces well-known results: total output and all of its constituents rise, as do prices. Because of the rise in inflation the real interest rate differential between the domestic economy and overseas deteriorates, and the exchange rate declines as a consequence. The strong influence of income on imports that is particular to the UK economy also leads to a deterioration of the balance of payments. The government as the policy maker therefore has to balance desirable effects (expansion of output) against undesirable ones (increase in inflation, decline in the exchange rate, and decline in the balance of payments). When choosing an appropriate method of financing an expansion of government expenditure, a bond-financed expansion seems preferable to a money-financed expansion, as the increase in interest rates that is necessary to sell more bonds limits the undesirable effects on the price level, the exchange rate, and the balance of payments.

Table 6.10b: Money-financed increase in government expenditure — effects on monetary variables
deviations from base run in billion pound sterling

year	<i>DM3S</i>	<i>PSBR</i>	<i>DSBLPRIV</i>	<i>DSGDETPR</i>	<i>WEALPC</i>	<i>TREBILL</i>
1975	0.69	0.58	-0.01	-0.11	-0.59	-0.01
1976	0.48	0.66	-0.25	-0.06	-1.86	-0.27
1977	0.26	0.66	-0.38	0.02	-2.95	-0.17
1978	0.48	0.79	-0.33	-0.01	-4.70	-0.69
1979	0.76	0.94	-0.19	-0.01	-6.46	-1.40
1980	2.09	1.31	0.75	-0.03	-8.01	-1.19
1981	1.99	1.06	0.89	-0.04	-9.38	-1.42
1982	4.36	0.90	3.42	-0.04	-10.84	-1.24
1983	4.18	1.45	2.67	-0.06	-12.73	-0.63
1984	3.88	1.53	2.29	-0.06	-14.68	-0.87
1985	5.84	1.59	4.29	0.03	-16.79	-0.86
<i>RMSE</i>	2.95	1.10	2.00	0.05	9.56	0.92

key: *DM3S*— change in money supply (sterling M3)
DSBLPRIV— change in bank lending
DSGDETPR— change in bond sales
PSBR— public sector borrowing requirement
WEALPC— real wealth
TREBILL— treasury bill rate

Table 6.10c: Bond-financed increase in government expenditure — effects on monetary variables
deviations from base run in billion pound sterling

year	<i>DM3S</i>	<i>PSBR</i>	<i>DSBLPRIV</i>	<i>DSGDETPR</i>	<i>WEALPC</i>	<i>TREBILL</i>
1975	0.69	0.58	-0.01	-0.11	-0.59	0.86
1976	0.00	0.69	-0.66	0.03	-1.24	0.28
1977	0.00	0.74	-0.35	0.39	-1.81	0.44
1978	0.00	0.88	-0.58	0.30	-2.76	0.25
1979	0.00	1.07	-0.58	0.49	-3.57	0.43
1980	0.00	1.47	-0.68	0.78	-3.84	0.61
1981	0.01	1.43	-0.21	1.21	-3.88	1.03
1982	-0.01	1.49	-0.16	1.34	-3.64	1.16
1983	0.00	1.95	-0.35	1.59	-3.38	1.16
1984	0.00	2.03	-0.54	1.48	-3.14	0.94
1985	0.00	2.07	-0.69	1.38	-2.97	0.85
<i>RMSE</i>	0.21	1.41	0.49	1.00	3.00	0.80

key: *DM3S*— change in money supply (sterling M3)
DSBLPRIV— change in bank lending
DSGDETPR— change in bond sales
PSBR— public sector borrowing requirement
WEALPC— real wealth
TREBILL— treasury bill rate

6.4.3 A change in UK oil production

We now discuss the model's response to an increase in UK oil production. The model was subjected to a 10 per cent increase of its annual oil production.

The increase of domestic oil production will be transmitted through three channels — the domestic economy, the exchange rate, and the international oil market. On the domestic front, a higher level of domestic oil production raises the level of GDP created in the oil sector of the economy. This translates into larger oil exports and import savings of oil. Through higher total exports, the effects of an increase in UK oil production then feed into the demand side and the price and exchange rate sector of the economy. The demand effects are similar to other types of expansion — e.g. increased government expenditure levels that were discussed above — leading to more growth and more inflation. However, the exchange rate effects may differ. Since interest rates are assumed to remain constant, a depreciating factor is absent and the exchange rate will be boosted by a higher surplus of the balance of payments. This appreciation in the exchange rate will ease inflationary pressures from the world economy as raw materials and other imports become cheaper.

The increase in domestic oil production also has reverberations in the international oil market. Since OPEC is assumed to be the swing producer, i.e. the producer who adjusts his own supply to equilibrate the world oil market, the initial reaction of OPEC to an increase in UK oil production will be a drop in OPEC output. This however will have implications on the level of the dollar oil price that is modelled here to be determined by levels of OPEC capacity utilisation. A lower oil price will then tend to reduce oil supply from North American and other non-OPEC-non-UK producers, but it will also lower domestic prices further. Overall, thus, the reduction in price pressures may offset the inflationary pressures caused by the secondary and expansionary demand effects that follow an increase in oil production.

The effect on the demand side is positive throughout as can be seen in Table 6.11. Over the total simulation period, *GDPE* is 0.4% higher than without the boost in oil production. Consumption, investment and imports all follow suit as do total exports, bolstered by the increase in *XOIL*. Non-oil exports, however, show the familiar signs of Dutch Disease problems: they decline steadily and lie on average about 0.06% below their base paths. The

profile of the adjustment paths shows an increase up to a peak in 1979 after which the onsetting decline is superseded by a second wave of expansion that carries through until the end of the simulation period. This strong second wave can be explained by the steady rise of actual oil production, which increased more than 11 fold from 0.08 mby (million barrels per year) to 0.93 mby in 1985.

Table 6.11: Increase in UK oil production —
effects on real variables
% deviations from base run

year	<i>GDPE</i>	<i>CON</i>	<i>INV</i>	<i>IMP</i>	<i>IM</i>	<i>X</i>	<i>XOX</i>
1975	0.01	0.01	0.01	0.01	0.01	0.02	0.00
1976	0.09	0.08	0.11	0.06	0.13	0.13	-0.00
1977	0.23	0.24	0.31	0.20	0.40	0.33	-0.02
1978	0.37	0.39	0.54	0.39	0.70	0.54	-0.05
1979	0.39	0.44	0.67	0.51	0.84	0.55	-0.10
1980	0.37	0.43	0.71	0.52	0.80	0.45	-0.11
1981	0.41	0.47	0.78	0.54	0.83	0.50	-0.08
1982	0.47	0.52	0.88	0.60	0.92	0.61	-0.06
1983	0.53	0.58	0.98	0.68	1.04	0.72	-0.03
1984	0.53	0.57	1.00	0.71	1.05	0.72	-0.02
1985	0.56	0.60	1.04	0.72	1.09	0.78	0.00
<i>RMSPE</i>	0.40	0.44	0.72	0.51	0.79	0.54	0.06

key: *GDPE* — GDP at 1980 prices

CON — consumers' expenditure at 1980 prices

INV — investment at 1980 prices

IMP — total imports at 1980 prices

IM — non-oil imports at 1980 prices

X — total exports at 1980 prices

XOX — non-oil exports at 1980 prices

Prices and the exchange rates in Table 6.12 are of course an important transmitter of the effects caused by the increase in oil production. As discussed above, there are pressures on prices pointing in opposite directions — upward pressure from extra domestic activity, and downward pressure from an appreciated exchange rate added to a likely fall in the dollar oil price. The combined effect cannot be predicted on theoretical grounds and thus depends on the strength of each component. In our case, domestic prices fall compared with their base paths; the overall decrease is less than 1 per cent. This is achieved partly by the strengthened real exchange rate, which rises to a peak in 1978 of 0.39% above its base path. From then up to the end of the simulation period, the real exchange rate declines and finishes 1 per cent below its base path. The continued fall in prices therefore must come from another direction.

Indeed, in Table 6.14, the dollar oil price is shown to fall by about 2 per cent during the simulation period. Its effect on the producer and consumer prices in the domestic economy together with the exchange rate effects outweigh inflationary trends in the domestic economy.

Table 6.12: Increase in UK oil production — effects on price variables and exchange rates
% deviations from base run

<i>year</i>	<i>PC</i>	<i>PIMO</i>	<i>WHR</i>	<i>PEX</i>	<i>PM</i>	<i>REXRAT</i>	<i>EXRAT</i>	<i>BAL</i> ¹
1975	0.00	0.00	0.00	0.00	-0.01	0.01	0.01	0.00
1976	-0.03	-0.02	-0.02	-0.03	-0.06	0.08	0.10	0.03
1977	-0.10	-0.07	-0.01	-0.10	-0.18	0.20	0.27	0.09
1978	-0.19	-0.13	0.07	-0.19	-0.36	0.39	0.53	0.15
1979	-0.37	-0.34	0.10	-0.40	-0.50	0.35	0.69	0.08
1980	-0.57	-0.62	-0.01	-0.67	-0.61	0.19	0.81	-0.09
1981	-0.75	-0.84	-0.19	-0.89	-0.73	0.10	0.96	-0.16
1982	-0.89	-0.99	-0.32	-1.03	-0.83	0.05	1.05	-0.17
1983	-1.00	-1.08	-0.39	-1.11	-0.89	0.02	1.10	-0.15
1984	-1.04	-1.08	-0.37	-1.10	-0.89	-0.04	1.05	-0.17
1985	-1.04	-1.04	-0.37	-1.04	-0.83	-0.11	0.94	-0.14
<i>RMSPE</i>	0.68	0.71	0.23	0.74	0.62	0.19	0.78	0.12

¹ deviations from historical data in billion pound sterling

key:

PC — consumer price index

PM — import price index

PIMO — producer price index

REXRAT — real exchange rate index

WHR — hourly wage rate index

EXRAT — nominal exchange index

UNLC — index of unit labour cost

BAL — balance of payments

PEX — export price index

Table 6.13 shows the accompanying effects of increased economic activity on the monetary sector. The pattern of the balance of payments — from surplus into deficit — is reflected in the real stock of wealth. It too rises but then declines after 1979. The decline is exacerbated by the fall in prices. This fall in wealth affects bank lending, bond sales and ultimately the demand for money. All these variables decline with respect to their base paths.

The effects of an annual 10 per cent increase in UK oil production on the international oil market can be seen in Table 6.14. The crucial responses have already been mentioned above, namely the overall fall in the dollar oil price, which is caused by the changes in OPEC's oil supply. Initially, OPEC supply declines; this depresses the oil price and with it production in North America and other non-OPEC countries. North American supply moves very little; it is inelastic to changes in prices. The other non-OPEC producers, however, respond more quickly to the fall in price by cutting their own output. But

their decline in supply also slows down more quickly than that of North America as the oil price levels out in response to increased OPEC oil output.

Table 6.13: Increase in UK oil production —
effects on monetary variables
deviations from base run in billion pound sterling

year	<i>DM3S</i>	<i>DSBLPRIV</i>	<i>DSGDETPR</i>	<i>PSBR</i>	<i>WEALPC</i>
1975	-0.00	-0.00	-0.00	-0.00	0.00
1976	-0.02	-0.01	-0.01	-0.02	0.03
1977	-0.06	-0.02	-0.02	-0.06	0.07
1978	-0.14	-0.06	-0.04	-0.12	0.13
1979	-0.18	-0.14	-0.15	-0.19	0.05
1980	-0.53	-0.54	-0.28	-0.26	-0.18
1981	-0.86	-0.96	-0.37	-0.27	-0.45
1982	-1.04	-1.15	-0.38	-0.28	-0.73
1983	-1.09	-1.09	-0.39	-0.39	-1.04
1984	-1.15	-1.07	-0.31	-0.39	-1.36
1985	-1.15	-1.03	-0.29	-0.41	-1.70
<i>RMSE</i>	0.74	0.74	0.26	0.26	0.78

key: *DM3S*— change in money supply (sterling M3)

DSBLPRIV— change in bank lending

DSGDETPR— change in bond sales

PSBR— public sector borrowing requirement

WEALPC— real wealth

Table 6.14: Increase in UK oil production —
effects on oil sub-model
% deviations from base run

year	<i>DWOCA</i>	<i>SOPEC</i>	<i>SNA</i>	<i>SONOUK</i>	<i>POILD</i>	<i>CU</i>
1975	0.00	-0.01	0.00	0.00	-0.00	-0.02
1976	0.00	-0.07	0.00	-0.00	-0.07	-0.27
1977	0.01	-0.22	0.00	-0.01	-0.31	-0.96
1978	0.03	-0.30	-0.00	-0.04	-0.61	-1.21
1979	0.10	-0.32	-0.00	-0.09	-2.07	-2.94
1980	0.20	-0.15	-0.02	-0.28	-3.00	-1.61
1981	0.29	0.05	-0.05	-0.52	-2.92	0.27
1982	0.38	0.25	-0.14	-0.68	-2.79	0.71
1983	0.47	0.50	-0.29	-0.77	-2.59	1.22
1984	0.54	0.69	-0.43	-0.82	-2.28	1.85
1985	0.60	0.95	-0.56	-0.82	-1.91	2.30
<i>RMSPE</i>	0.32	0.42	0.23	0.50	2.04	1.49

key: *DWOCA* — world oil demand outside communist areas

SOPEC — OPEC supply of oil

SNA — North American supply of oil

SONOUK — supply of oil of other non-OPEC-non-UK countries

POILD — dollar oil price

CU — OPEC capacity utilisation

Apart from affecting the supply of oil, the change in the dollar oil price also influences world demand for oil, which rises in proportion to the fall in the price of oil. This effect also sheds light on the working of the Dutch Disease phenomena. The theory predicts that when oil production goes up the exchange rate appreciates and squeezes the manufacturing sector sufficiently for it to decline in real terms. Eventually when the oil has run out, the country is faced with an increased balance of payments deficit. For, added to the imports of manufacturing goods which the economy previously produced itself now come extra imports of oil. These theoretical considerations can be found implemented in many econometric models that feature the UK oil sector in some detail. All assume a direct influence of oil on the exchange rate. Atkinson *et al.* (1983) include the real value of North Sea oil reserves in their exchange rate equation. In Bond and Knöbl (1982) the discounted present value of future earnings from North Sea oil is one of the explanatory variables in the exchange rate system. The effective exchange rate in Motamen (1983) is wholly determined by the value of UK oil production. Given this influence, strong responses to any change in the oil sector are passed on to the real side of the economy, of which consequently the manufacturing part will decline relative to total output.

However, our results suggest that first the appreciation of the exchange rate may have been exaggerated and that second the negative effects may not materialise — or if they do occur, they may not occur with the same severity. To investigate this claim further our model has been subjected to the same 10 per cent expansion in UK oil output as in the above exercise, but now the dollar oil price has been exogenised and thus any feedback that expanding UK oil production would have on the domestic economy has been disregarded. In Table 6.15, the percentage responses of the main variables in the model have been compiled from the two simulations. The figures in the exogenous column basically correspond to a conventional model type discussed above, where there is no feedback of the events in the UK oil sector on the whole economy via the international oil market. The figures in the endogenous column are taken from Tables 6.11 – 6.14 of this section.

The comparison shows that the variables still move in the same direction in response to an annual 10 per cent expansion of UK oil output. But the magnitude of that change differs for the crucial variables: the real exchange rate, non-oil exports, the balance of payments and prices. The real exchange rate, for example, appreciates more than three times more when the dollar oil

price is exogenous. The same ratio is passed on to export prices and eventually to non-oil exports, which — while still displaying Dutch Disease symptoms — fall by only a third of the decline when the dollar oil price is exogenous. So the trading sector seems considerably better off when the repercussions of UK oil production on the international oil market are considered in the analysis.

Table 6.15: Endogenous vs exogenous oil price
% deviations from base run

	endogenous	exogenous
GDP	0.40	0.42
Consumption	0.44	0.48
Investment	0.72	0.69
Non-oil imports	0.79	0.93
Total imports	0.51	0.55
Non-oil exports	-0.06	-0.18
Oil exports	8.11	9.50
Total exports	0.54	0.61
Real wealth	-0.68	0.54
Consumer prices	-0.68	-0.18
Wholesale prices	-0.71	-0.16
Wages	-0.23	0.42
Export prices	-0.74	-0.22
Import prices	-0.62	-0.59
Real exchange rate	0.19	0.59
Balance of payments	-0.048	0.304
Dollar oil price	-0.204	0

The difference between the movements of the import prices is marginal; this points to the strong influence of domestic prices on export prices. Indeed, all domestic price indices are more than three times lower when the dollar oil price is endogenous, wholesale prices even four times. This shows the considerable benefits the domestic economy reaps from the excess supply of oil in the international oil market and the consequent fall in the dollar oil price — 2 per cent in our simulation compared with no change when the oil price is exogenous.

The fall in the oil price has an important effect on wholesale and consumer prices where it strengthens a reduction in both indices. But the influence on the wage rate index is even greater: where under an exogenous dollar oil price the wage rate index increases in response to the expansion in oil output, now wage rates fall in response to the same shock. The reason for this lies partly in the increased impact of the consumer price index on wages, but also in the reduced influence of the demand-pull factor on the wage rate index.

Indeed, real variables generally grow more when the dollar oil price is exogenous; the exception is investment which responds positively to a reduction in inflation.

The sector which fares worst when the dollar oil price is endogenous is the foreign sector with the balance of payments and the stock of wealth. Both variables decline, even though the decline in the balance of payments is slight. This reduction in the balance of payments can be explained by two factors — a price factor and an income factor. Even if traded volumes had remained constant, the balance of payments would have been lower because the reduction in import and export prices diminishes the value of imports and exports alike. But because a lower dollar oil price has reduced the income generated through oil exports, the volume of total exports is affected as well and it is down more than that of imports. A reduction in the balance of payments is the longer term result.

6.4.4 A change in OPEC production capacity

So far, we have dealt with changes in policy variables that are under the control of the UK government. However, since the next chapter analyses the interaction of UK oil supply with that of the rest of the western world, we now turn to the analysis of a policy variable under the control of OPEC, the main market force in the international oil market. We discuss the effects of a 10 per cent reduction in the oil production capacity of OPEC.

In Chapter 4 we argued that the international oil price is set by OPEC, and more specifically that it depends on the extent to which OPEC production capacity is utilised. It was also argued that OPEC's oil policy is to act as a *swing* producer, that is to produce as much (or as little) as is required to clear the international oil market. This is largely a passive role, requiring OPEC to adjust its own output in response to production from independent producers. Since the early 1980s this has meant that OPEC has had to reduce its production levels. From OPEC's point of view, this begs the question of how this affects its oil revenues, which constitute the main source of foreign exchange for most member countries. In turn, this is related to the oil price, which OPEC generally determines by adjusting its level of production. As long as OPEC acts as the swing producer, a way for it to influence the level of the international oil price is either by changing its target value of capacity

utilisation, or by changing its production capacity. Since the target value of capacity utilisation represents profitability and cost considerations, a changed 'view' of a target value might just result as uneconomic. A rather more realistic option seems therefore a change in the production facilities themselves. When reduced, they would relieve OPEC from a fixed cost burden and would allow to maintain a constant profit margin, even with falling oil prices. On the other hand, if production facilities are expanded, OPEC will be able to take advantage of a possibly higher oil price by increasing its own production levels. Changes in production facilities take time. But since our model is geared towards an analysis of longer term developments, the analysis of changes in production capacities seems justified in the context of our model. The results of this simulation exercise are listed in Tables 6.16 – 6.19.

We begin with an analysis of the effects on the oil sub-model, shown in Table 6.16. The figures show the oil price to have increased, on average by 27 per cent. But the increase is not uniform: there is a distinct peak in 1979 after which the increase with respect to the base run diminishes constantly. From the structure of the model we know that the oil price depends on the degree of OPEC capacity utilisation, *CU*. The changes in this variable — values above the base path until 1979, followed by values below the base path thereafter — explain the pattern of the changes in the dollar oil price path in this simulation exercise. The degree of capacity utilisation, in turn, is determined by two variables: OPEC production potential (*OPECPOT*) and OPEC production levels (*SOPEC*). The first of these has been set exogenously at 10 per cent below its base value, but the second — OPEC oil supply — is endogenously determined as the difference between world oil demand, *DWOCA*, and the accumulated supply of the other world oil producers. As shown in Table 6.16, the higher oil price has reduced world oil demand by about 4.7 per cent, but it has at the same time induced the non-OPEC producers to increase their production levels throughout. North American output is up by 5.24 per cent, that of other non-OPEC producers by 6.8 per cent. Given the assumption that OPEC acts as the *swing* producer in the world oil market, its supply necessarily declined — on average by 15.4 per cent.

How did all this affect OPEC's oil wealth? The consequences of a higher oil price and a lower production has meant that OPEC's oil revenues, *OPECWLTH*, go up until 1979, but decline from 1980 onwards. This pattern is mainly due to the particular coincidence of opposing shifts in the variables, where a low reduction in oil production is coupled with a high increase in the oil

price (until 1979), and a large downwards shift of oil production coincides with a declining increase in the oil price.

Table 6.16: A reduction in OPEC production capacity —
effects on oil sub-model
% deviations from base run

year	<i>POILD</i>	<i>DWOCA</i>	<i>SNA</i>	<i>SONOUK</i>	<i>SOPEC</i>	<i>CU</i>	<i>OPECWLTH</i>
1975	6.25	-0.20	0.00	0.00	-0.32	36.26	5.91
1976	20.66	-0.81	0.00	0.64	-1.35	55.87	19.03
1977	36.13	-1.79	0.00	2.45	-3.27	47.31	31.67
1978	43.48	-2.93	0.29	5.07	-6.13	21.43	34.69
1979	52.10	-4.23	1.18	7.56	-9.02	11.51	38.37
1980	32.15	-5.07	2.66	10.02	-12.50	-23.82	15.64
1981	20.10	-5.60	4.42	10.15	-16.36	-29.14	0.45
1982	14.56	-5.98	6.50	9.15	-20.73	-25.42	-9.19
1983	9.76	-6.22	7.91	7.91	-23.28	-26.13	-15.78
1984	4.57	-6.31	8.85	6.56	-23.00	-27.63	-19.48
1985	0.20	-6.28	9.55	5.09	-23.68	-26.41	-23.53
<i>RMSPE</i>	27.21	4.68	5.24	6.80	15.42	32.29	22.54

key:

POILD — dollar oil price

DWOCA — world oil demand

outside communist areas

SNA — North American supply of oil

SONOUK — supply of oil of other

non-OPEC-non-UK countries

SOPEC — OPEC supply of oil

CU — OPEC capacity utilisation

OPEC POT — OPEC production capacity

OPECWLTH — OPEC oil wealth

OPEC's wealth, as recorded by the rather simplistic measure of revenues, could therefore have been higher — on average by 7.1 per cent. This is, of course, a conservative estimate, since it is based on the unrealistic assumption that OPEC lowered its capacity in each time period. It would have been more realistic and more profitable for OPEC, had it lowered its capacity in the early part of the simulation period and then increased it in order to keep the rise in the oil price below the barrier beyond which additional supply from other producers becomes profitable. A more careful determination of installed capacity will be one of the results of the analysis in the next chapter where optimal policies for OPEC as well as the UK will be designed.

Here, we continue by considering how the UK economy is affected in this simulation exercise. The consequences of a reduction in potential OPEC production are channelled into the UK economy through the same variable as is used to channel them into the international oil market, namely the dollar oil price. In the oil market, a changed oil price causes shifts in demand and

**Table 6.17: A reduction in OPEC production capacity —
effects on real variables
% deviations from base run**

year	<i>GDPE</i>	<i>CON</i>	<i>INV</i>	<i>IMP</i>	<i>IM</i>	<i>X</i>	<i>XOX</i>
1975	-0.07	-0.11	-0.23	-0.14	-0.14	0.01	0.00
1976	-0.15	-0.29	-0.72	-0.40	-0.26	0.15	-0.10
1977	0.13	-0.10	-0.88	-0.45	0.27	0.81	-0.40
1978	0.55	0.35	-0.64	-0.09	1.23	1.59	-0.82
1979	0.76	0.68	-0.58	0.43	2.37	2.09	-1.61
1980	-0.56	-0.13	-1.84	0.03	1.13	-0.30	-2.49
1981	-0.83	-0.19	-2.37	-0.71	-0.09	-1.38	-2.68
1982	-0.88	-0.14	-2.45	-0.67	-0.28	-1.61	-2.53
1983	-0.94	-0.12	-2.39	-0.61	-0.43	-1.82	-2.33
1984	-1.06	-0.16	-2.33	-0.60	-0.66	-2.10	-2.13
1985	-1.04	-0.15	-2.11	-0.61	-0.85	-2.19	-1.84
<i>RMSPE</i>	0.73	0.27	1.72	0.49	0.95	1.50	1.82

key: *GDPE* — GDP at 1980 prices

CON — consumers' expenditure at 1980 prices

INV — investment at 1980 prices

IMP — total imports at 1980 prices

IM — non-oil imports at 1980 prices

X — total exports at 1980 prices

XOX — non-oil exports at 1980 prices

**Table 6.18: A reduction in OPEC production capacity —
effects on price and exchange rate variables
% deviations from base run**

year	<i>PC</i>	<i>PIMO</i>	<i>WHR</i>	<i>PEX</i>	<i>PM</i>	<i>REXRAT</i>	<i>EXRAT</i>	<i>BAL</i> ¹
1975	0.56	0.62	0.47	0.61	0.08	0.50	-0.12	0.19
1976	2.08	2.39	1.76	2.36	0.37	1.83	-0.55	0.85
1977	4.18	5.06	3.74	4.99	1.12	3.35	-1.63	2.12
1978	6.14	7.68	6.14	7.25	0.78	6.62	-0.98	3.84
1979	8.24	10.10	9.03	9.37	0.42	9.67	-0.39	6.01
1980	8.99	10.41	10.80	9.75	1.15	8.75	-1.50	5.41
1981	8.57	9.05	9.74	8.35	1.15	7.50	-1.42	4.60
1982	7.86	7.50	8.49	6.83	0.73	6.72	-0.72	3.73
1983	6.88	5.88	7.21	5.24	0.12	6.08	0.19	2.94
1984	5.66	4.15	5.75	3.60	-0.34	4.98	0.80	1.92
1985	4.25	2.37	4.03	1.87	-0.98	4.07	1.66	1.03
<i>RMSPE</i>	6.33	6.72	6.88	6.23	0.77	6.09	1.06	3.49

¹ deviations from historical data in billion pound sterling

key:

PC — consumer price index

PIMO — producer price index

WHR — hourly wage rate index

UNLC — index of unit labour cost

PEX — export price index

PM — import price index

REXRAT — real exchange rate index

EXRAT — nominal exchange index

BAL — balance of payments

supply patterns; in the UK economy, the change in the oil price causes changes in the level of UK inflation and changes in the levels of oil wealth that is derived from domestic oil production. Details of the mechanism through which the economy is affected have already been discussed above in the section on the effects of an expansion of UK oil production. We can therefore concentrate on the results that are shown in Tables 6.17 – 6.19.

Two basic effects are at work. The stronger of the two, the inflationary impact, is reflected in the price variables (which are up) in Table 6.18 and in the real variables (which are down) in Table 6.17. The oil wealth impact, on the other hand, appears only briefly — between 1977 and 1979 — and affects total exports and imports first, and filters then through to the other real variables. This short ‘flicker’ can be explained by the size of the oil price increase that occurs between 1977 and 1979: Table 6.16 shows this to be between 36 and 52 per cent.

**Table 6.19: A reduction in OPEC production capacity —
effects on monetary variables**
deviations from base run in billion pound sterling

year	<i>DM3S</i>	<i>PSBR</i>	<i>DSBLPRIV</i>	<i>DSGDETPR</i>	<i>WEALPC</i>
1975	-0.05	0.07	0.13	0.25	0.43
1976	0.24	0.25	0.93	0.94	1.98
1977	1.68	0.28	3.31	1.92	4.80
1978	6.30	0.49	8.68	2.87	9.47
1979	10.96	0.86	14.46	4.36	15.49
1980	19.23	1.74	21.74	4.26	20.14
1981	16.18	0.96	18.61	3.38	23.57
1982	7.46	0.53	9.24	2.32	26.26
1983	3.29	0.94	3.53	1.19	28.43
1984	-1.08	0.77	-1.77	0.08	29.89
1985	-4.35	0.58	-5.56	-0.62	30.81
<i>RMSE</i>	8.95	0.81	10.65	2.50	20.58

key: *DM3S*— change in money supply (sterling M3)
DSBLPRIV— change in bank lending
DSGDETPR— change in bond sales
PSBR— public sector borrowing requirement
WEALPC— real wealth

Table 6.19 shows the effects caused in the monetary sector of the economy. Notable is the increase in real wealth, which is up by about 20 per cent with respect to the base simulation. This pattern is due to the constant balance of payments surplus that is shown in Table 6.18, which in turn is due to the large increase of total exports.

6.4.5 A change in world wholesale prices

The last type of shock we discuss is that of an increase in the world wholesale price index *INWWPI*. In this simulation exercise, *INWWPI* has been increased by 5% in each time period.

The world wholesale price index in our model stands for the general price level in the world economy and therefore affects the domestic part of the model as well as the international oil market.

In the domestic economy the wholesale price index, as a proxy for world inflation, influences the real sector, the price sector and the exchange rate. The fundamental effect of an increase in the level of world prices is an appreciation of the effective exchange rate index; this effect then filters into two main areas of the economy. The first is the price sector. Through the higher exchange rate some downward pressure is exerted on the domestic price level. As a consequence, consumption and investment will rise and so will total output, GDP. The second area the appreciated exchange rate affects is foreign trade. The improved exchange rate lowers sterling revenues of exports, especially oil exports. This works in the opposite direction of the effect that affects the price sector and reduces GDP.

In the oil sub-model, the world wholesale price index serves as a price deflator for the dollar oil price. The consequences of a higher price level are a lower real price of oil. In the first instance, demand for oil will thus tend to rise, whereas supply of oil will drop.

In the simulation exercise, these effects work, of course, simultaneously. We start with the discussion of the effects on the real variables; these are shown in Table 6.20. The first impression one gets from Table 6.20 is that all variables move in unison. Initially, there is a slight rise, which in 1977 is followed by a strong movement downwards. The variables then rise from this low point to a peak around 1981/82 after which a decline sets in again. This time, however, with reduced amplitude. The fluctuations in the model's response show a complex interaction of several effects, and we use the above described sub-effects to disentangle the variables' movements. The results suggest that the repercussions of the price sector, the trade sector, and the oil sector alternate. At first, reduced prices (see Table 6.21) help GDP to grow slightly. In the third year, however, the improved exchange rate has had its

**Table 6.20: An increase in world prices —
effects on real variables
% deviations from base run**

year	<i>GDPE</i>	<i>CON</i>	<i>INV</i>	<i>IMP</i>	<i>IM</i>	<i>X</i>	<i>XOX</i>
1975	0.05	0.09	0.18	0.11	0.11	-0.01	0.00
1976	0.11	0.18	0.42	0.23	0.17	-0.03	0.08
1977	-0.71	-0.59	-0.45	0.14	0.01	-0.93	-0.74
1978	-0.34	-0.32	-0.25	-0.52	-0.65	-0.88	-0.67
1979	-0.10	-0.16	-0.03	-0.24	-0.16	-0.27	-0.43
1980	0.15	0.03	0.21	-0.05	0.24	0.22	-0.32
1981	0.15	0.07	0.22	0.07	0.37	0.28	-0.30
1982	0.16	0.12	0.20	0.11	0.41	0.29	-0.30
1983	0.11	0.11	0.11	0.13	0.40	0.22	-0.34
1984	-0.03	0.03	-0.08	0.07	0.25	-0.01	-0.41
1985	-0.12	-0.03	-0.23	-0.03	0.09	-0.20	-0.46
<i>RMSPE</i>	0.26	0.22	0.25	0.20	0.31	0.43	0.42

key: *GDPE* — GDP at 1980 prices
CON — consumers' expenditure at 1980 prices
INV — investment at 1980 prices
IMP — total imports at 1980 prices
IM — non-oil imports at 1980 prices
X — total exports at 1980 prices
XOX — non-oil exports at 1980 prices

**Table 6.21: An increase in world prices —
effects on prices and exchange rates
% deviations from base run**

year	<i>PC</i>	<i>PIMO</i>	<i>WHR</i>	<i>PEX</i>	<i>PM</i>	<i>REXRAT</i>	<i>EXRAT</i>	<i>BAL</i> ¹
1975	-0.44	-0.48	-0.37	-0.48	-0.05	-0.40	5.09	-0.15
1976	-1.10	-1.28	-0.95	-1.94	-3.32	3.95	10.56	0.45
1977	-1.37	-2.16	-1.26	-2.38	-2.89	1.84	9.30	-0.29
1978	-1.82	-2.74	-2.47	-2.89	-2.79	0.80	8.82	-0.20
1979	-1.62	-2.33	-2.41	-2.41	-2.58	0.72	8.28	0.03
1980	-1.09	-1.41	-1.77	-1.44	-2.11	0.83	7.39	0.47
1981	-0.58	-0.52	-0.93	-0.55	-1.57	0.91	6.51	0.74
1982	-0.14	0.13	-0.28	0.07	-1.21	1.09	6.01	1.00
1983	0.21	0.56	0.23	0.45	-1.04	1.36	5.84	1.18
1984	0.44	0.73	0.53	0.60	-0.94	1.49	5.79	1.18
1985	0.50	0.67	0.55	0.51	-1.02	1.64	6.00	1.15
<i>RMSPE</i>	1.01	1.45	1.32	1.57	2.03	1.65	7.43	0.75

¹ deviations from historical data in billion pound sterling

key:

PC — consumer price index
PIMO — producer price index
WHR — hourly wage rate index
UNLC — index of unit labour cost
PEX — export price index
PM — import price index
REXRAT — real exchange rate index
EXRAT — nominal exchange index
BAL — balance of payments

negative effect on exports, and thus GDP is pushed down strongly below its base path. The withering-away of this effect is then reinforced by repercussions from the international oil market, which — through a higher dollar oil price — increases domestic prices and also oil revenues and therefore total exports. As a result, GDP, the balance of payments and, eventually, the real exchange rate improve. The end of the simulation sees GDP declining again, but as mentioned above with a dampened amplitude showing that the economic system has approached a new steady-state equilibrium. This decline is caused by the renewed strengthening of the exchange rate index with its negative effects on exports and the balance of payments.

As shown in Table 6.22, the effects of an increase in world wholesale prices on the monetary sector are small. Driven by the movement in the balance of payments, the stock of real wealth changes. This affects bank lending more than bond sales and so, ultimately, the money supply *M3S* moves in the same direction as bank lending.

Table 6.22: An increase in world prices —
effects on monetary variables
deviations from base run in billion pound sterling

year	<i>DM3S</i>	<i>DSBLPRIV</i>	<i>DSGDETPR</i>	<i>PSBR</i>	<i>WEALPC</i>
1975	0.04	-0.10	-0.20	-0.06	-0.34
1976	-0.58	-0.59	-0.14	-0.14	0.34
1977	0.21	-0.08	-0.24	0.05	0.18
1978	-0.60	-0.91	-0.40	-0.09	-0.02
1979	-1.10	-0.94	-0.00	-0.17	0.09
1980	-0.17	0.43	0.38	-0.22	0.61
1981	1.31	1.99	0.59	-0.09	1.30
1982	1.86	2.69	0.77	-0.06	2.10
1983	2.20	3.06	0.83	-0.03	3.01
1984	2.42	3.15	0.77	0.04	3.92
1985	2.33	2.90	0.64	0.07	4.84
<i>RMSE</i>	1.45	1.93	0.53	0.11	2.23

key: *DM3S*— change in money supply (sterling M3)
DSBLPRIV— change in bank lending
DSGDETPR— change in bond sales
PSBR— public sector borrowing requirement
WEALPC— real wealth

Finally, we turn to the discussion of the effects of an increase in *INWWPI* on the international oil market. As before, the movement in real variables is much smaller than in price variables. *INWWPI* affects the real dollar oil price, which in turn drives demand and all the supply functions, one

of which, *SOPEC*, eventually determines *POILD*. The general observation to make is that *POILD* continuously rises to a peak of 12.22% above its base value in 1980, after which the positive difference between the shocked path and the base path narrows. After some delay, the rise in *POILD* begins to bite, and world demand and OPEC supply of oil decline during the second half of the simulation period. The induced changes in the supply from North American and non-OPEC-non-UK countries reflect the supply conditions. North American supply does not change much because accumulated total production has already exceeded the peak in possible total extraction; whereas the non-OPEC-non-UK countries still have ample oil reserves and are therefore able to take advantage of the higher world oil price by pushing up their supply.

Table 6.23: An increase in world prices —
effects on oil sub-model
% deviations from base run

year	<i>DWOCA</i>	<i>SOPEC</i>	<i>SNA</i>	<i>SONOUK</i>	<i>POILD</i>	<i>CU</i>
1975	0.16	0.25	0.00	0.00	0.11	0.63
1976	0.30	0.54	0.00	-0.50	0.58	2.07
1977	0.40	0.79	0.00	-0.80	1.48	3.51
1978	0.48	1.09	-0.22	-0.92	2.65	4.66
1979	0.38	0.98	-0.43	-0.89	8.11	10.24
1980	0.15	0.57	-0.59	-0.32	12.61	6.91
1981	-0.08	-0.02	-0.69	0.51	12.56	-0.14
1982	-0.29	-0.85	-0.56	1.09	12.06	-2.37
1983	-0.48	-1.77	-0.23	1.46	11.32	-4.08
1984	-0.63	-2.41	0.10	1.65	10.16	-5.99
1985	-0.75	-3.03	0.41	1.67	8.97	-6.68
<i>RMSPE</i>	0.42	1.42	0.38	1.03	8.79	5.17

key: *DWOCA* — world oil demand outside communist areas
SOPEC — OPEC supply of oil
SNA — North American supply of oil
SONOUK — supply of oil of other non-OPEC-non-UK countries
POILD — dollar oil price
CU — OPEC capacity utilisation

6.5 CONCLUSIONS

The aim of this chapter has been twofold. First, to establish that the complete model is a realistic representation of the UK economy and the international oil

market so that it can be used for policy simulation exercises. The second aim has been to analyse the dynamic properties of the complete model as an additional test of its validity and adequacy. We have shown that the model tracks history closely, and that it reacts plausibly to shocks in exogenous variables.

As part of the analysis of the model's dynamic properties, we have considered shocks to UK policy variables (interest rates, government expenditure, and the UK rate of oil extraction), to the rate of OPEC capacity utilisation (an OPEC policy variable), and to the international wholesale price index. The dynamic response to shocks to the domestic fiscal and monetary variables have been fairly standard. The interest rate's main policy use is shown as countering inflation and excessive growth, as a rise in interest rates leads to lower inflation and lower total output. An expansion of government expenditure, instead, produces diametrically opposite results in that both inflation and output increase. This is also true for the real exchange rate and the balance of payments. The results of both exercises confirm in addition the particularly strong impact of income on imports as the main influence on the balance of payments.

The model's dynamic response to a shock to variables that affect the international oil market (i.e. the UK rate of oil extraction, the international wholesale price index, and OPEC's capacity utilisation index) has shown that the inclusion of the dollar oil price as an endogenous variable leads to qualitatively new results, especially as far as the discussion of Dutch Disease phenomena is concerned. That is, whether or not the discovery of a natural resource will necessarily harm the manufacturing sector of the economy. Our results suggest, for example, that an expansion of UK oil output will indeed lead to an appreciation of the exchange rate (thus confirming predictions by the Dutch Disease literature), but it will also lead to a decline in the international dollar oil price. This second effect depends largely on the working of the international oil market, but given an initial market equilibrium extra oil supply causes excess supply in the market, which will force a reduction in the international oil price. This, of course, helps to reduce inflation levels in the UK economy and hence to diminish the differential between domestic and international prices, i.e. the exchange rate. Ultimately, therefore, the negative effects on the manufacturing sector are reduced.

The analysis of the model's dynamic multipliers caused by a change in OPEC's capacity utilisation index shows that OPEC could have increased its wealth by more than 7 per cent, had it lowered its production capacity by 10 per cent throughout the simulation period. The main consequence of the reduction in capacity was an increase in the oil price of more than 20 per cent, which in turn dampened demand for oil internationally and induced non-OPEC oil supply to increase. Given the swing producer assumption this meant that OPEC's own output was pushed increasingly down. It was pointed out that by using optimal control methods, OPEC could have achieved a larger increase in wealth, because the unwelcome consequence of the rise in the oil price — the expansion of non-OPEC output — would have been kept at bay. The effects on the UK economy are channelled through the oil price and are thus similar to the case of an expansion in UK oil production, which was also considered.

Chapter 7

Games and Policy Optimisation

7.1 INTRODUCTION

In the previous chapter we verified that the complete model is a valid and adequate representation of actual economic processes. The chapter also established that substantial interactions exist between the UK oil sector and the international oil market. This pointed to the need to include such interactions in an analysis of the macroeconomic effects of UK oil production on the UK economy. For the UK economy was shown to suffer less severe Dutch Disease phenomena because of increased oil production when the interactions with the international oil market were included in the analysis. Apart from demonstrating the potential ‘benefits’ to the UK economy of a wider analytical framework, OPEC too was shown to benefit if it adjusted its policy variable in the model — its maximum oil production capacity. Such a situation of gain that is in part mutually exclusive strongly invites an application of game theory to the analysis in order to investigate more thoroughly the size and limits of any benefits that each ‘player’ attempts to reap in a complex and interdependent environment. It is therefore the application of game theory combined with optimal control methods that is the task of this chapter.

Specifically, we consider in the next two sub-sections the outcomes of single player games, where each player’s welfare — to be defined below — is maximised using optimal control methods. This will first of all establish an ‘optimal’ policy mix that is designed to achieve the given economic targets. The obtained paths of the policy variables can then be compared with actual paths, and conclusions about the appropriateness of economic policies can be drawn. Whereas this insight is of particular practical relevance to policy makers, the results will be similarly useful to theoreticians, as the outcomes can be compared with those of 2-player games. This comparison allows conclusions to be drawn about the adequacy of game theoretic models when applied to real

life data. We analyse two multi-player games in Sections 3.3 and 3.4, one featuring a competitively played game the other a harmoniously played one. Conclusions of this chapter follow in Section 4.

7.2 OPTIMAL CONTROL

Control theory is widely used in engineering to control the functioning of a system, where the system is viewed as a group of relationships emphasising links between input and output variables. This system can be viewed as a reduced form or a final form of a structural macroeconomic model in our context. The control of the system is achieved by influencing the input variables, also termed as control variables. This theoretical framework has been adopted by economists¹ for policy recommendations. The reason is that the economy can be viewed as a system of dynamic relationships, and control variables as instruments under the control of the policy maker. Tax rates, interest rates and levels of government expenditure are typically regarded as policy instruments.

Optimal control theory is then concerned with the optimal functioning of the system, which may be constrained. In the engineering world, optimality can be defined unambiguously in terms of the laws of physics. In economics, however, the equivalent of the physical laws of nature do not exist. What exists is a multitude of theories which often conflict with one another. This notwithstanding, in practical applications economists usually define optimality in terms of some welfare function, whose overall value is maximised by minimising an equivalent loss function, or typically the objective function. Any definition of optimality is therefore subjective and ambiguous, in so far as it depends on the specific choice of a welfare function.

Before deciding upon the exact form of the objective function, some further questions have to be clarified. The first of these concern the scope of the objective function. Put differently, it has to be agreed *whose* welfare is to be maximised and *what* affects it. The answer to this is related to the definition of the system that is to be controlled. Whereas in engineering such a

¹The first and classical application of control theory to economics is Phillips (1954); but see also Pindyck (1973).

definition is fairly clear-cut, in economics this is less so. At a practical level, however, the definition of a system is related to the specification of the econometric model. For example, we have argued that the links between the international oil market and the UK economy are strong enough to warrant their inclusion into a model that purports to analyse the influence of the UK oil sector on the rest of the economy. Previous studies defined their systems more narrowly.

Apart from the domain to which the optimisation is applied, another subjective issue concerning the objective function is the determination of optimal (desired) trajectories. Since economic theory is vague on this point, in practice the determination of desired values usually involves an iterative process of specification and simulation, which stops when the modeller's objectives are met².

Another example of ambiguity is the functional form of the chosen objective function. This is again an arbitrary choice because, as mentioned in Chapter 4, economic theory is vague about the specific way the economy works. However, a quadratic functional form is most commonly adopted partly because a quadratic function may be defined conceptually as a second-order Taylor-series expansion of the true nonlinear objective function about its unconstrained optimum. Hence, a quadratic welfare loss function can be defined as³

$$J(Y, U) = \frac{1}{2}[Y - Y^d]^T Q_y [Y - Y^d] + \frac{1}{2}[U - U^d]^T Q_u [U - U^d], \quad (7.1)$$

where

$$Y = [y_1^T, \dots, y_K^T]^T$$

is the matrix of endogenous variables throughout the optimisation period $[1, K]$,

$$U = [u_1^T, \dots, u_K^T]^T$$

is the matrix of policy instruments, and d denotes desired values. The matrices Q_y and Q_u represent the weight structure that is attached to the targets and instruments by the policy maker. This weight structure reflects the policy maker's different degrees of importance (weights) on achieving each

²see Westcott *et al.* (1979) for an elaboration.

³see Westcott *et al.* (1982).

of them. In other words, he will have a ranking of preferences. It is this ranking that signifies another normative issue and a weakness of this type of objective function since the policy maker has to translate his preferences into cardinal numbers that reflect the importance he attaches to marginal deviations of the targets from their desired values.

The policy optimisation problem may be formulated as

$$\min \{J(\mathbf{Y}, \mathbf{U}) \mid F(\mathbf{Y}, \mathbf{U}) = \mathbf{0}\} \quad (7.2)$$

which can be thought of as finding $\mathbf{Y}$ and $\mathbf{U}$ such that the objective function J is minimised subject to the equations of the econometric model throughout the time period $[1, K]$. (7.1) is minimised by some optimisation algorithm, of which the Newton type⁴ that has been used in this thesis is the most common⁵.

7.3 CONTROL RESULTS

In this section, we discuss the results of the method of optimal control to our estimated model. As mentioned in the previous section, there is a choice as to whose welfare is maximised. In our framework, there are two obvious options. The first is to maximise the welfare of the UK economy — and this is done in exercise 1; the second is to maximise OPEC's welfare — which follows in exercise 2.

Before discussing the results of the various control exercises in detail, we refer briefly to Table 7.1, which lists the weights and desired trajectories that are used in the following sections. The values in the column named 'targets' are added to (or subtracted from) the base paths of the respective variables. The values in the column named 'weights' are those values that enter the weighting matrices $\mathbf{Q}_y$ and $\mathbf{Q}_u$ in (7.1) and refer to the importance that the policy maker attaches to achieving the respective target.

The endogenous variables all have the same weight, *viz.* unity, attached to them. The weight on the policy variables, 0.000001, is to some extent arbitrary as it depends on the implementation of the optimisation algorithm.

⁴see Chapter 6 of Rustem (1981).

⁵see Rustem and Zarrop (1979, 1981).

It is meant to convey maximum freedom to the movement of the various policy instruments.

Table 7.1: Target variables — their desired trajectories and weight structure

1. endogenous variables		
	desired trajectories	weights
<i>DELGDPE</i> ^{1,3,4}	+2%	1
<i>DELPC</i> ^{1,3,4}	−5%	1
<i>DM3S</i> ^{1,3,4}	base	1
<i>OPECWLTH</i> ^{2,3,4}	+10%	1
<i>ANNCOST</i> ^{1,3,4}	+10%	8
2. policy variables		
	desired trajectories	weights
<i>GOV</i> ^{1,3,4}	base	0.000001
<i>TREBILL</i> ^{1,3,4}	base	0.000001
<i>SUKB</i> ^{1,3,4}	base	0.000001
<i>OPEC POT</i> ^{2,3,4}	base	0.000001

Note: superscripts indicate the exercise in which the variable is used.

7.3.1 Control exercise 1: Single-player optimisation — UK

The government's objective is to reduce inflation, to increase growth of GDP, and in order to maintain monetary stability to keep monetary growth stable. To achieve these aims the government uses the following policy instruments: the treasury bill rate, the level of government expenditure, and the rate of oil extraction. The justification for regarding these instruments as policy variables of the government is simple — all three variables are determined by government policy. The degree of control over the variables though differs. Out of the three instruments, the government has the most direct control over interest rates, as these are set by the Bank of England, which in turn executes monetary policies that are decided by the Treasury. Changes in interest rates can therefore be implemented in the very short term. Government expendi-

ture is again determined by the government, traditionally once a year as part of the budget. The annual nature of the model is therefore suited to allow the use of government expenditure as a free control variable. Control over the third policy variable — the rate of oil extraction — is less direct than that over interest rates or government expenditure but by no means non-existent. Decisions about production rates are essentially made by the oil companies on economic grounds. The government's influence on extraction rates in the short term is therefore restricted to influencing the economic environment of the operations, and this is done by the taxation of profits and revenues. In the medium to long term, the government has a more powerful instrument: the granting of exploration and drilling rights. Through these mechanisms the government can broadly define the lifetime extraction profile of the resource.⁶

Tables 7.2 – 7.6 show the changes that government policy induced. In Table 7.2 the two target variables and the government policy instruments are shown. GDP-growth (*DELGDPE*) is generally higher and inflation (*DELPC*) generally lower.

This result was achieved by increasing the oil extraction rate, and lowering both the interest rate and government expenditure. From the previous chapter, we recall that the influences of the three instruments in isolation work in opposite directions for some variables. GDP, for example, is lowered by higher interest rates but increased when oil extraction or government expenditure are increased. Hence the combined effects are uncertain. In our case, the extra GDP-growth is achieved by higher oil extraction and lower interest rates. Higher oil extraction leads to higher total exports (Table 7.3); a resulting higher level of GDP stimulates the other real aggregates: consumption, investment and imports. The results of the previous chapter show that the effect of higher oil extraction on GDP peters out in time. This is avoided here by the decrease in the level of interest which encourages spending and investment rather than saving. The lowering of government expenditure seems more directed at achieving the inflationary target, since as we know from Chapter 6 it decreases GDP.

The major impact of the increased oil production is on the inflationary front via the changes in the international oil market (Table 7.6). The feedback variable is the dollar oil price (*POILD*) which is pushed down. Combined with a higher nominal exchange rate, this means that the sterling price of oil is

⁶The use of the rate of oil extraction as a control variable is also adopted by Motamen (1983).

reduced even further. Given the influence of the oil price in the economy (as a measure of costs for industry and households, and as a measure of the value of oil exports), this represents a strong downward push for the price variables in the model (Table 7.2 and 7.4).

With respect to the Dutch Disease question, the effect on the real exchange rate has been kept low (Table 7.4), and hence there is hardly any reduction (a fall of 0.25 per cent) in non-oil exports in comparison to the base run. This is mainly because of the relatively small increase in oil production, and Dutch Disease effects — of a manufacturing sector squeezed out by a increased real exchange rate — have been kept at bay.

**Table 7.2: Control exercise 1 —
effects on target variables.
deviations from base run**

year	<i>DELGDPE</i> ¹	<i>DELPC</i> ¹	<i>OPECWLTH</i> ²	<i>SUKB</i> ³	<i>TREBILL</i> ¹	<i>GOV</i> ⁴
1975	0.22	-0.12	-0.34	0.02	-3.62	-0.11
1976	-0.03	-0.26	-2.76	0.17	2.51	-3.06
1977	0.29	-0.36	-1.06	0.01	-0.78	1.32
1978	0.23	-0.34	-2.72	0.12	-0.40	-0.39
1979	-0.11	-0.41	-4.69	0.12	-1.05	-0.35
1980	0.17	-0.53	-6.33	0.14	-2.01	-0.51
1981	0.05	-0.42	-7.17	0.21	-1.18	-1.69
1982	0.08	-0.36	-6.48	0.21	-1.74	-1.31
1983	0.15	-0.31	-6.06	0.26	-1.78	-1.67
1984	-0.02	-0.19	-5.33	0.29	-0.76	-1.76
1985	0.23	-0.22	-4.14	0.30	0.91	-1.15
mean	0.11	-0.32	-4.28	0.17	-0.90	-0.97

¹ deviations from base run in percentage points

² deviations from base run in per cent

³ deviations from base run in billion barrels

⁴ deviations from base run in billion pound sterling

key: *DELGDPE* — GDP growth rate in per cent

DELPC — consumer price inflation rate in per cent

OPEC POT — OPEC production capacity

SUKB — UK oil production

GOV — government expenditure at 1980 prices

TREBILL — treasury bill rate

The effects on the monetary sector are shown in Table 7.5. The target of stable monetary growth is broadly achieved. The negative public sector borrowing requirement implies that the government is able to repay part of the national debt. This, of course, implies that the private sector holds a lower level of financial assets, which is reflected in a lower level of real private wealth, *WEALTH*.⁷

**Table 7.3: Control exercise 1 —
effects on real variables.
% deviations from base run**

year	<i>GDPE</i>	<i>CON</i>	<i>INV</i>	<i>IMP</i>	<i>IM</i>	<i>X</i>	<i>XOX</i>
1975	0.22	0.20	0.27	0.04	0.29	0.45	0.00
1976	0.20	0.61	1.79	-1.41	0.03	2.44	-0.08
1977	0.49	0.47	0.09	1.29	1.24	-0.34	-0.32
1978	0.71	0.82	1.34	0.68	1.59	1.26	-0.44
1979	0.60	0.79	1.43	0.74	1.42	0.88	-0.47
1980	0.77	1.01	1.95	0.86	1.59	1.04	-0.39
1981	0.82	1.20	2.55	0.32	1.39	1.80	-0.17
1982	0.90	1.24	2.49	0.62	1.58	1.79	-0.06
1983	1.05	1.40	2.90	0.68	1.85	2.26	-0.04
1984	1.03	1.38	3.01	0.74	1.87	2.21	-0.05
1985	1.26	1.48	2.91	1.12	2.25	2.28	-0.05
<i>RMSPE</i>	0.80	1.04	2.12	0.86	1.51	1.69	0.25

key: *GDPE* — GDP at 1980 prices
CON — consumers' expenditure at 1980 prices
INV — investment at 1980 prices
IMP — total imports at 1980 prices
IM — non-oil imports at 1980 prices
X — total exports at 1980 prices
XOX — non-oil exports at 1980 prices

**Table 7.4: Control exercise 1 —
effects on prices and exchange rates
% deviations from base run**

year	<i>PC</i>	<i>PIMO</i>	<i>WHR</i>	<i>PEX</i>	<i>PM</i>	<i>REXRAT</i>	<i>EXRAT</i>	<i>BAL</i> ¹
1975	-0.10	-0.07	-0.08	-0.13	-0.30	0.40	0.47	0.16
1976	-0.33	-0.34	-0.09	-0.56	-1.18	1.45	1.80	1.54
1977	-0.64	-0.77	-0.33	-0.98	-1.61	1.53	2.32	-0.40
1978	-0.95	-1.12	-0.37	-1.32	-1.89	1.44	2.59	0.54
1979	-1.29	-1.54	-0.43	-1.70	-1.97	0.97	2.56	0.21
1980	-1.75	-2.06	-0.87	-2.12	-1.80	0.05	2.15	-0.16
1981	-2.12	-2.41	-1.14	-2.49	-2.02	-0.02	2.45	0.54
1982	-2.45	-2.72	-1.42	-2.82	-2.34	0.09	2.89	0.35
1983	-2.74	-2.98	-1.66	-3.08	-2.61	0.16	3.23	0.72
1984	-2.92	-3.12	-1.74	-3.21	-2.76	0.15	3.37	0.73
1985	-3.13	-3.24	-1.93	-3.37	-3.08	0.43	3.79	0.69
<i>RMSPE</i>	1.97	2.15	1.13	2.25	2.09	0.85	2.65	0.66

¹ deviations from base run in billion pound sterling

key:

PC — consumer price index

PIMO — producer price index

WHR — hourly wage rate index

PEX — export price index

PM — import price index

REXRAT — real exchange rate index

EXRAT — nominal exchange index

BAL — balance of payments

⁷On the relationship between the PSBR and the stock of private wealth, see Artis (1984, pp.154ff).

**Table 7.5: Control exercise 1 —
effects on monetary variables.**
deviations from base run in billion pounds sterling

year	<i>DM3S</i>	<i>PSBR</i>	<i>DSBLPRIV</i>	<i>DSGDETPR</i>	<i>WEALPC</i>
1975	-0.12	-0.10	-0.02	-0.01	0.13
1976	0.00	-1.90	1.68	-0.22	-0.52
1977	-0.05	0.74	-2.03	-1.25	0.07
1978	-0.38	-0.59	0.80	0.59	0.09
1979	0.01	-0.71	-0.08	-0.81	-0.29
1980	-0.12	-1.18	-0.10	-1.17	-1.25
1981	-0.57	-2.49	0.01	-1.91	-2.70
1982	-1.71	-2.16	-2.07	-2.51	-3.99
1983	-1.53	-2.93	-0.72	-2.12	-5.43
1984	-0.95	-3.10	-0.26	-2.41	-6.97
1985	-2.25	-2.48	-2.25	-2.49	-8.10
<i>RMSE</i>	1.03	1.95	1.26	1.66	3.92

key: *DM3S*— change in money supply (sterling M3)
DSBLPRIV— change in bank lending
DSGDETPR— change in bond sales
PSBR— public sector borrowing requirement
WEALPC— real wealth

**Table 7.6: Control exercise 1 —
effects on oil sub-model.**
% deviations from base run

year	<i>DWOCA</i>	<i>SOPEC</i>	<i>SNA</i>	<i>SONOUK</i>	<i>POILD</i>	<i>CU</i>
1975	0.00	-0.24	0.00	0.00	-0.10	-0.59
1976	0.05	-1.49	0.00	-0.01	-1.29	-5.26
1977	0.08	0.11	0.00	-0.14	-1.17	0.47
1978	0.15	-0.80	-0.00	-0.22	-1.94	-3.18
1979	0.29	-0.51	-0.07	-0.36	-4.20	-4.61
1980	0.49	-0.30	-0.12	-0.71	-6.04	-3.29
1981	0.72	-0.42	-0.21	-1.15	-6.78	-2.40
1982	0.94	0.21	-0.41	-1.54	-6.67	0.61
1983	1.15	0.47	-0.71	-1.80	-6.50	1.15
1984	1.35	0.84	-1.03	-1.97	-6.12	2.28
1985	1.53	1.51	-1.36	-2.05	-5.56	3.69
<i>RMSPE</i>	0.81	0.78	0.58	1.20	4.88	2.96

key: *DWOCA* — world oil demand outside communist areas
SOPEC — OPEC supply of oil
SNA — North American supply of oil
SONOUK — supply of oil of other non-OPEC-non-UK countries
POILD — dollar oil price
CU — OPEC capacity utilisation

The effects on the international oil market are essentially similar to those discussed in Section 4.3 in Chapter 6. The increase in UK oil production causes a fall in the oil price, which increases world demand for oil, but lowers the production of oil in other non-OPEC areas. OPEC oil production changes little, but the drop in the oil price is substantial enough to cause a fall in its revenues, as discussed above.

7.3.2 Control exercise 2: Single-player optimisation — OPEC

This section reports the results of an exercise where the wealth of OPEC alone has been maximised. The outcome of this are — as one would expect — overall gains for OPEC and a worse position of the UK economy in comparison to the base run. This is shown in Tables 7.7 – 7.11. The first of these shows the target variables. OPEC revenues (*OPECWLTH*) are increased, even if only by a relatively small margin. This is achieved by a reduction throughout of OPEC production capacity, *OPECPOT*. As explained in the previous chapter, the economic mechanism behind these changes works through the oil price reaction function as follows. The oil price depends inversely on the maximum capacity of OPEC oil production. For a given level of oil demand

Table 7.7: Control exercise 2 —
effects on target variables.
% differences from base run

year	<i>OPECWLTH</i>	<i>DELGDPE</i> ¹	<i>DELPC</i> ¹	<i>OPECPOT</i>
1975	0.05	0.00	0.01	−0.02
1976	0.05	0.00	0.00	0.00
1977	0.08	0.00	0.01	−0.01
1978	0.11	0.00	0.01	−0.01
1979	1.30	0.05	0.12	−0.04
1980	3.11	0.05	0.28	−0.07
1981	2.06	−0.08	0.16	−0.03
1982	1.30	−0.01	0.09	−0.04
1983	0.79	−0.02	0.06	−0.12
1984	0.91	−0.01	0.08	−0.26
1985	0.67	−0.02	0.06	−0.26
mean	0.95	−0.00	0.08	−0.08

¹ deviations from base run in percentage points

key: *OPECWLTH* — OPEC oil wealth

DELGDPE — GDP growth rate in per cent

DELPC — consumer price inflation rate in per cent

OPECPOT — OPEC production capacity

therefore, a lower *utilised* level of production capacity will cause excess demand and thus to a rise in oil prices. This is essentially what happened, as Table 7.8 shows a 2 per cent rise in oil prices during the simulation period.

An alternative rationale for cuts in installed production capacity may be offered by an appreciation of the situation leading to the oil price rises in the 1970s. It is arguable that the relationship between prices and the capacity utilisation rate of OPEC is only an approximation to the true data generating process, since political factors in 1973/4 and 1978/9 were almost certainly decisive in pushing up oil prices in either period. Only then did OPEC change its installed production capacity. Why was this change economically sensible? The higher oil prices in the 1970s generally led to a situation of excess supply in the international oil market, because they stimulated oil supply mainly from non-OPEC producers but stifled world oil demand. Reacting as the swing producer in the international oil market, OPEC's response more often than not has been to reduce its production in order to keep prices steady. This, however, has meant that its capacity utilisation falls and fixed costs rise relative to profits. It therefore makes economic sense to reduce oil production capacity thereby easing a fixed cost burden.

**Table 7.8: Control exercise 2 —
effects on oil sub-model.
% deviations from base run**

year	<i>POILD</i>	<i>DWOCA</i>	<i>SNA</i>	<i>SONOUK</i>	<i>SOPEC</i>	<i>CU</i>	<i>OPECPOT</i>
1975	0.05	-0.00	0.00	0.00	-0.00	0.28	-0.12
1976	0.06	-0.00	0.00	0.00	-0.01	0.06	-0.02
1977	0.09	-0.01	0.00	0.01	-0.01	0.12	-0.04
1978	0.13	-0.01	0.00	0.02	-0.02	0.15	-0.06
1979	1.40	-0.06	0.01	0.03	-0.10	2.49	-0.35
1980	3.45	-0.17	0.01	0.16	-0.33	3.40	-0.62
1981	2.74	-0.25	0.02	0.47	-0.66	-2.12	-0.29
1982	2.37	-0.33	0.08	0.62	-1.04	-1.94	-0.35
1983	2.25	-0.40	0.24	0.68	-1.43	-0.71	-1.14
1984	2.65	-0.48	0.37	0.72	-1.69	2.25	-2.50
1985	2.84	-0.57	0.48	0.78	-2.10	1.11	-2.56
<i>RMSPE</i>	2.07	0.29	0.20	0.45	1.00	1.73	1.16

key:

POILD — dollar oil price

DWOCA — world oil demand outside communist areas

SNA — North American supply of oil

SONOUK — supply of oil of other
non-OPEC-non-UK countries

SOPEC — OPEC supply of oil

CU — OPEC capacity utilisation

OPECPOT — OPEC production capacity

Table 7.8 shows the effects on the oil sub-model in detail. OPEC is able to increase its revenues purely because of a higher oil price, since its production, *SOPEC*, has been reduced. The higher oil price has meant that production of independent producers in North America and elsewhere (*SNA* and *SONOUK*) is increased, which consequently leaves OPEC's own production diminished.

The effects of this exercise on the UK economy are relatively small, since there is only one variable linking the oil market and the UK economy — the price of oil. With an increase in the oil price, it is expected to see higher inflation levels in the UK economy. This is confirmed by Table 7.7, which shows consumer price inflation, *DELPC*, up by 0.08 percentage points. GDP-growth is not affected at all on average, although there are minute movements throughout the optimisation period. Tables 7.9 – 7.11 record for the sake of completeness the effects on the UK economy in more detail. Prices and the real exchange rate go up; but since producer prices rise faster than the real exchange rate between 1981 and 1985, the nominal exchange rate, *EXRAT*, declines marginally in that time period. The balance of payments improves because of the greater rise of exports and their price index over the equivalent import variables.

Table 7.9: Control exercise 2 —
effects on real variables.
% deviations from base run

year	<i>GDPE</i>	<i>CON</i>	<i>INV</i>	<i>IMP</i>	<i>IM</i>	<i>X</i>	<i>XOX</i>
1975	-0.00	-0.00	-0.00	-0.00	-0.00	0.00	0.00
1976	-0.00	-0.00	-0.00	-0.00	-0.00	-0.00	-0.00
1977	-0.00	-0.00	-0.00	-0.00	-0.00	0.00	-0.00
1978	0.00	0.00	-0.00	-0.00	0.00	0.00	-0.00
1979	0.05	0.04	0.02	0.01	0.07	0.10	-0.01
1980	0.11	0.08	0.04	0.05	0.20	0.22	-0.04
1981	0.03	0.03	-0.03	0.05	0.16	0.11	-0.11
1982	0.02	0.04	-0.07	0.01	0.11	0.06	-0.14
1983	0.00	0.03	-0.10	0.01	0.10	0.03	-0.16
1984	-0.01	0.03	-0.14	-0.00	0.10	0.02	-0.19
1985	-0.03	0.01	-0.18	-0.01	0.08	-0.02	-0.23
<i>RMSPE</i>	0.04	0.03	0.08	0.02	0.10	0.08	0.12

key: *GDPE* — GDP at 1980 prices
CON — consumers' expenditure at 1980 prices
INV — investment at 1980 prices
IMP — total imports at 1980 prices
IM — non-oil imports at 1980 prices
X — total exports at 1980 prices
XOX — non-oil exports at 1980 prices

**Table 7.10: Control exercise 2 —
effects on prices and exchange rates
% deviations from base run**

year	<i>PC</i>	<i>PIMO</i>	<i>WHR</i>	<i>PEX</i>	<i>PM</i>	<i>REXRAT</i>	<i>EXRAT</i>	<i>BAL</i> ¹
1975	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1976	0.01	0.01	0.01	0.01	0.00	0.01	0.00	0.00
1977	0.01	0.02	0.01	0.02	0.00	0.01	0.00	0.01
1978	0.02	0.02	0.02	0.02	0.00	0.02	0.00	0.01
1979	0.12	0.15	0.11	0.13	-0.03	0.20	0.05	0.14
1980	0.36	0.45	0.37	0.43	-0.01	0.46	0.01	0.40
1981	0.51	0.64	0.62	0.63	0.11	0.47	-0.17	0.42
1982	0.59	0.72	0.70	0.68	0.13	0.53	-0.19	0.46
1983	0.65	0.75	0.77	0.70	0.09	0.63	-0.11	0.49
1984	0.73	0.79	0.83	0.73	0.05	0.74	-0.05	0.58
1985	0.79	0.81	0.88	0.73	-0.04	0.90	0.09	0.66
<i>RMSPE</i>	0.46	0.52	0.53	0.49	0.06	0.48	0.09	0.38

¹ deviations from base run in billion pound sterling

key:

PC — consumer price index

PM — import price index

PIMO — producer price index

REXRAT — real exchange rate index

WHR — hourly wage rate index

EXRAT — nominal exchange index

PEX — export price index

BAL — balance of payments

**Table 7.11: Control exercise 2 —
effects on monetary variables.
deviations in from base run in billion pounds sterling**

year	<i>DM3S</i>	<i>PSBR</i>	<i>DSBLPRIV</i>	<i>DSGDETPR</i>	<i>WEALPC</i>
1975	-0.00	0.00	0.00	0.00	0.00
1976	0.00	0.00	0.01	0.00	0.01
1977	0.01	0.00	0.01	0.01	0.02
1978	0.02	0.00	0.03	0.01	0.04
1979	-0.01	0.00	0.09	0.11	0.18
1980	0.27	0.04	0.56	0.33	0.53
1981	0.95	0.04	1.26	0.35	0.86
1982	0.86	0.01	1.17	0.32	1.20
1983	0.78	0.06	1.05	0.33	1.57
1984	0.80	0.07	1.12	0.38	1.99
1985	1.02	0.07	1.38	0.43	2.50
<i>RMSE</i>	0.60	0.04	0.83	0.27	1.17

key: *DM3S*— change in money supply (sterling M3)

DSBLPRIV— change in bank lending

DSGDETPR— change in bond sales

PSBR— public sector borrowing requirement

WEALPC— real wealth

7.3.3 Control exercise 3: A non-cooperative game — UK vs OPEC

In this section we consider the results of a non-cooperative game played between the UK economy and OPEC. Başar and Olsder (1982) and Başar (1987) show that a Nash equilibrium in this type of game can be obtained through repeated optimisation.

Before discussing the economic results in detail, we describe briefly the iterative optimisation process by which a Nash equilibrium was achieved. As in the single player optimisation, the model here is optimised repeatedly until no further cost reduction is achieved. The processes though differ in that in the 2-player game the model is optimised for each player in alternation. The objective functions are those that were used in the previous two sections — one stating the objectives of the UK economy, the other those of OPEC. As a general rule, the calculated output trajectories of a particular stage of the iterative process are used as the input or starting trajectories of the consecutive stage. Table 7.12 shows the reduction in cost that was achieved at each stage of the optimisation process. The figure of 2.04, for example, was obtained during iteration 2 when the model was optimised to achieve UK targets, and it implies that a 104 per cent cost reduction was achieved. The profile of the figures makes it clear that during iteration 2 the maximum in cost reduction was achieved for both players. It is also evident that the figures for OPEC are larger than those for the UK at every iteration. This implies that it is generally easier for OPEC to achieve the given objectives than it is for the UK economy. The iteration process stopped at iteration 6 when no further cost reduction was possible.

Table 7.12: Reduction in cost functions

iteration	UK	OPEC
1	1.09204	3.36248
2	2.04893	12.1873
3	1.30411	2.32249
4	1.01211	1.51919
5	1.00229	1.44230

We now turn to the economic interpretation of the results, which are tabulated in Tables 7.13 – 7.17. In Table 7.13, the effects on the target

variables are recorded. The mean values show that OPEC's target of raising its oil wealth has at least been qualitatively achieved, because the results show an average increase of 4.19 per cent, which is nevertheless short of the target of a 10 per cent increase. The results for the UK economy are more mixed. Of the two main targets, GDP growth and consumer price inflation (*DELGDPE* and *DELPC*), only *DELGDPE* has moved into the desired direction with an increase of 0.85 percentage points. This is equivalent to 42.3 per cent of the desired target of a 2 percentage point increase over the simulation period, and thus a slightly better achievement rate than that of OPEC. Yet the inflation outcome is disappointing for the UK economy. Instead of a desired reduction in inflation, the results of the Nash game show a slight increase of 0.29 percentage points. This is despite the movements of interest rates (*TREBILL*) and government expenditure (*GOV*) in directions that would normally guarantee a reduction in economic activity and therefore inflation.

Table 7.13: Control exercise 3 —
effects on target variables.
deviations from base run

year	<i>OPECWLTH</i> ²	<i>DELGDPE</i> ¹	<i>DELPC</i> ¹	<i>OPEC POT</i> ²	<i>SUKB</i> ³	<i>GOV</i> ⁴	<i>TREBILL</i> ¹
1975	6.56	1.03	0.30	-1.85	0.13	-0.72	-12.94
1976	1.63	-0.67	0.08	-1.19	0.70	-12.50	9.43
1977	3.47	2.57	-1.53	-0.06	0.18	5.38	-4.41
1978	1.33	-0.38	-0.11	-1.30	0.57	-3.68	-0.50
1979	-2.56	0.18	-1.00	-0.93	0.60	-2.03	-6.14
1980	8.10	1.24	0.26	-1.55	0.82	-6.72	-0.24
1981	2.20	0.09	0.12	-1.52	0.76	-2.24	1.28
1982	5.47	1.22	0.73	-3.36	0.93	-3.36	3.68
1983	5.44	1.26	0.98	-4.07	1.01	-1.42	6.48
1984	3.37	-1.11	1.57	-4.34	1.10	0.13	5.47
1985	11.11	3.95	1.84	-6.06	1.28	-0.54	2.48
mean	4.19	0.85	0.29	-2.38	0.73	-2.52	0.42

¹ deviations from base run in percentage points

² deviations from base run in per cent

³ deviations from base run in billion barrels

⁴ deviations from base run in billion pound sterling

key: *OPECWLTH* — OPEC oil wealth

DELGDPE — GDP growth rate in per cent

DELPC — consumer price inflation rate in per cent

OPEC POT — OPEC production capacity

SUKB — UK oil production

GOV — government expenditure at 1980 prices

TREBILL — treasury bill rate

The reason for this undesired increase lies in the interaction of OPEC and the UK economy. We know from Chapter 6 that an increase in UK oil production leads *inter alia* to a reduction in the international oil price, which in turn lowers domestic inflation rates. It is therefore economically sensible for the UK economic authorities to push up the domestic production of oil, and this is what happens as Table 7.13 shows: UK oil production (*SUKB*) is increased by 0.73 billion barrels on average. That this has not worked to the overall advantage of the UK economy is because the other player in the game, OPEC, reacted to its own advantage by reducing its production capacity — on average by 2.28 billion barrels. Recall that this leads to an increase in the oil price, which as Table 7.14 confirms, is increased by 45 per cent over the optimisation period. OPEC's own production is reduced, not only because the UK expanded its production, but also because the increase in the oil price stimulated oil production from other areas. Another consequence of the higher oil price is an average reduction in world demand for oil of 3.79 per cent.

Table 7.14: Control exercise 3 —
effects on oil sub-model.
% deviations from base run

year	<i>POILD</i>	<i>DWOCA</i>	<i>SNA</i>	<i>SONOUK</i>	<i>SOPEC</i>	<i>CU</i>	<i>OPECPOT</i>
1975	8.40	-0.26	0.00	0.00	-1.70	48.26	-13.13
1976	9.65	-0.56	0.00	0.85	-7.31	5.00	-8.48
1977	6.80	-0.77	0.00	1.58	-3.12	-10.31	-0.46
1978	9.68	-1.06	0.38	1.81	-7.61	10.83	-9.76
1979	6.16	-1.25	0.82	2.26	-8.22	-6.42	-7.55
1980	23.23	-1.91	1.13	2.23	-12.27	25.25	-13.81
1981	20.67	-2.50	1.57	3.82	-15.31	-6.38	-14.31
1982	36.71	-3.47	1.86	4.73	-22.85	67.18	-32.36
1983	51.39	-4.74	2.86	6.77	-30.35	62.35	-39.96
1984	61.80	-6.19	3.78	9.39	-36.11	37.93	-42.13
1985	115.00	-8.46	5.32	12.07	-48.32	175.73	-59.31
<i>RMSPE</i>	45.07	3.79	2.31	5.50	22.68	63.26	28.17

key:

POILD — dollar oil price

SOPEC — OPEC supply of oil

DWOCA — world oil demand outside communist areas

SNA — North American supply of oil

CU — OPEC capacity utilisation

SONOUK — supply of oil of other

OPECPOT — OPEC production capacity

non-OPEC-non-UK countries

Table 7.15 shows the effects on the real sector of the economy in more detail. We see the signs — familiar from Chapter 6 — of an increase in domestic oil production. GDP and all its aggregate constituents are increased,

**Table 7.15: Control exercise 3 —
effects on real variables.
% deviations from base run**

year	<i>GDPE</i>	<i>CON</i>	<i>INV</i>	<i>IMP</i>	<i>IM</i>	<i>X</i>	<i>XOX</i>
1975	1.04	0.89	1.05	-0.09	1.27	2.48	0.00
1976	0.38	1.85	5.88	-6.47	-0.41	10.07	-0.59
1977	2.94	2.74	1.09	5.72	6.93	0.27	-2.04
1978	2.56	3.30	5.41	1.61	6.59	6.57	-2.64
1979	2.74	3.52	5.12	2.65	6.97	5.05	-3.35
1980	4.04	5.19	8.65	1.31	8.58	9.78	-3.74
1981	4.13	5.18	7.25	4.53	10.39	7.12	-4.26
1982	5.41	6.10	7.57	4.10	11.90	10.94	-4.44
1983	6.70	7.13	8.08	7.10	15.90	12.87	-5.29
1984	5.54	5.90	5.66	7.60	15.89	10.83	-6.58
1985	9.68	9.52	9.59	10.02	22.55	18.38	-7.79
<i>RMSPE</i>	4.82	5.24	6.51	5.49	11.59	9.83	4.33

key: *GDPE* — GDP at 1980 prices

CON — consumers' expenditure at 1980 prices

INV — investment at 1980 prices

IMP — total imports at 1980 prices

IM — non-oil imports at 1980 prices

X — total exports at 1980 prices

XOX — non-oil exports at 1980 prices

**Table 7.16: Control exercise 3 —
effects on prices and exchange rates
% deviations from base run**

year	<i>PC</i>	<i>PIMO</i>	<i>WHR</i>	<i>PEX</i>	<i>PM</i>	<i>REXRAT</i>	<i>EXRAT</i>	<i>BAL</i> ¹
1975	0.25	0.49	0.21	0.13	-1.58	2.98	2.48	1.19
1976	0.32	0.52	1.28	-0.64	-5.56	9.49	8.93	7.27
1977	-0.99	-1.12	0.02	-2.22	-7.05	9.52	10.76	-0.13
1978	-1.09	-1.42	1.97	-2.74	-9.13	12.21	13.83	5.30
1979	-1.95	-2.73	1.75	-4.12	-10.72	12.80	15.97	4.90
1980	-1.73	-2.61	2.15	-4.10	-12.18	14.88	17.96	9.86
1981	-1.63	-2.32	3.58	-3.71	-12.39	14.72	17.44	7.50
1982	-0.96	-1.33	4.86	-3.22	-14.46	19.51	21.12	12.66
1983	-0.02	0.03	7.33	-2.36	-16.85	25.60	25.56	15.86
1984	1.51	1.43	10.85	-1.30	-18.60	30.36	28.52	17.61
1985	3.31	3.66	12.62	0.05	-21.88	40.58	35.62	27.94
<i>RMSPE</i>	1.54	1.92	5.88	2.66	13.15	20.33	20.13	12.66

¹ deviations from base run in billion pound sterling

key:

PC — consumer price index

PIMO — producer price index

WHR — hourly wage rate index

PEX — export price index

PM — import price index

REXRAT — real exchange rate index

EXRAT — nominal exchange index

BAL — balance of payments

but non-oil exports are markedly lower. These symptoms of the Dutch Disease result from the strong rise in the real exchange rate (shown in Table 7.16), which has also left a strong imprint on wages and import prices. The fall in import prices reflects the dominant influence of foreign prices, whereas export prices, down by much less than import prices, are mainly driven by domestic wholesale prices which fall only slightly. The relative change of import and export prices also determines the value of imports and exports, and because of the stronger fall in import prices the balance of payments (Table 7.16) improves strongly. This of course leads to an overall improvement of the stock of real wealth, as shown Table 7.17, which in turn feeds back into the real side of the economy by affecting consumers' expenditure.

**Table 7.17: Control exercise 3 —
effects on monetary variables.**
deviations from base run in billion pounds sterling

year	<i>DM3S</i>	<i>PSBR</i>	<i>DSBLPRIV</i>	<i>DSGDETPR</i>	<i>WEALPC</i>
1975	-0.75	-0.50	0.06	0.31	1.30
1976	0.52	-7.54	7.97	-0.09	0.50
1977	0.31	2.90	-6.42	-3.83	4.77
1978	1.75	-3.66	8.99	3.58	6.98
1979	3.24	-3.05	4.67	-1.63	9.53
1980	6.97	-8.72	15.89	0.20	11.22
1981	4.95	-4.66	7.29	-2.32	14.25
1982	-2.91	-6.68	6.23	2.46	19.70
1983	-4.04	-5.14	6.81	5.70	28.71
1984	-5.92	-2.70	6.68	9.90	40.50
1985	-3.95	-5.67	17.59	15.87	57.44
<i>RMSE</i>	3.85	5.19	9.30	6.21	24.58

key: *DM3S*— change in money supply (sterling M3)
DSBLPRIV— change in bank lending
DSGDETPR— change in bond sales
PSBR— public sector borrowing requirement
WEALPC— real wealth

We conclude this section with a discussion of the game theoretic aspects of the control exercises so far. How has each player fared, and who has done best overall? Above, we discussed these issues in a rather qualitative manner but now we turn to Table 7.18, which records the total cost that each player incurs in the various games that were played. The first four rows show the partial costs of each target variable, and the last three rows record the total costs — incurred individually by the UK and OPEC, and taken together in the last row. Column 1 shows the costs incurred at the start of the control

exercises. We compare these numbers with those of the other columns. Since the particular optimisation algorithm aims to minimise the value of the cost function, a number that is smaller than its equivalent base-value is considered a gain.

Table 7.18: Comparison of costs in three different game situations

	Base	UK	OPEC	UK vs OPEC*
<i>DELGDPE</i>	2,200	1,965	2,207	1,813
<i>DELPC</i>	13,750	12,052	14,192	15,914
<i>DM3S</i>	0	585	200	8,149
<i>OPECWLTH</i>	1,937,080	4,823,520	1,450,230	809,252
Σ UK	15,950	14,600	16,599	28,329
Σ OPEC	1,937,080	4,823,520	1,450,230	809,252
Σ all	1,953,030	4,838,120	1,466,829	837,581

¹ Nash game

Equipped with this information we can conclude that it is very dangerous for the UK economy to engage in a fully-blown 'economic war' over oil production with OPEC. For it is the UK economy that loses and OPEC that gains. The total cost figures shows this clearly: the cost of 28,329 for the UK as the outcome of the competitive Nash game is nearly double the cost of 15,590, the figure of the base simulation. OPEC gains instead: it more than halves its cost from 1,937,080 to 809,252. As discussed above, the differences occur because OPEC clearly manages to improve its oil wealth and because the UK suffers from much higher inflation and a worse position of the money supply.

As a consistency check of the optimisation outcomes, we can compare the total cost figures of the four cases with what game theory predicts for each case. It is clear that compared with the base case of no optimisation, the single player outcome, where the model is optimised such that only one player's targets are achieved, should produce lower total cost figures. That is, the particular player's outcome should move closer to his targets. Indeed, this is the case both for the UK and for OPEC. But again, the UK's gains are much less than those of OPEC with a reduction of around 9 per cent against a reduction of 25 per cent for OPEC.

Conversely, if one assumes a near zero-sum game outcome, where one player's gain is the other's loss, an OPEC gain should be accompanied by a loss for the UK and vice versa. Again, this is borne out by the total cost figures. When the model is optimised to achieve the UK's targets, the relatively moderate gain for the UK leaves OPEC in a position $2\frac{1}{2}$ times worse compared with the base simulation. This is of course because OPEC is not allowed to react to the UK's increase in oil production by adjusting its own policy variable. The result is a reduction in OPEC oil production and oil price, and consequently much lower oil revenues for OPEC. Optimising the model to reach OPEC's targets leaves the UK about 4 per cent worse off, caused by the rise in oil prices that OPEC is able to achieve.

7.3.4 Control exercise 4: A cooperative game — UK and OPEC

After having considered in the previous section a game dominated by confrontation between the two players, we now analyse the outcome of a game in which both players' targets are pursued simultaneously. The solution of such a game is said to be Pareto efficient.⁸ First, we will consider the economic outcome of this type of game and compare the obtained results with those of the Nash game and the single player games of the previous sections.

As in the previous exercises, the economic targets for the UK economy have been to increase GDP growth by 2 per cent in each year, to lower consumer price inflation by 5 per cent per annum, and to maintain stable money supply conditions. In addition, OPEC is assumed to maximise its oil wealth by aiming to increase its oil revenues by 10 per cent in each time period. In order to make meaningful comparisons with the results of previous exercises possible, the weight structure that is imposed on the deviations of target variables from their desired values has been kept unchanged at the values listed in Table 7.1.

The results are shown in Tables 7.19 – 7.24. Table 7.19 shows the effects on the target variables and the movement of the control variables. Overall, the results show that OPEC's oil revenues increase in each time period. The UK economy instead succeeds to increase GDP growth in 8 out of 11 periods; and, even worse, achieves its target of lowering inflation in 3 out of 11 periods. These qualitative differences are reflected in the quantitative results.

⁸see the discussion in Chapter 2.

OPEC is able to push its oil revenues up by 3.96 per cent (equivalent to about 40% of its desired value of 10 per cent); the UK only achieves an increase in GDP growth of 0.03 per cent (0.15% of the desired value of 2 per cent), while overall consumer price inflation increases by 0.3 per cent.

**Table 7.19: Control exercise 4 —
effects on target variables.
deviations from base run**

year	<i>OPECWLTH</i> ²	<i>DELGDPE</i> ¹	<i>DELPC</i> ¹	<i>OPEC POT</i> ²	<i>SUKB</i> ³	<i>GOV</i> ⁴	<i>TREBILL</i> ¹
1975	0.23	0.03	0.01	-0.11	0.01	-0.05	-0.37
1976	0.59	0.00	0.04	-0.13	0.02	-0.36	0.29
1977	0.38	0.04	-0.04	0.00	0.01	0.07	0.29
1978	0.92	0.10	-0.01	-0.14	0.02	0.13	0.41
1979	1.04	-0.05	0.02	-0.07	0.02	0.23	-0.57
1980	8.34	0.40	0.66	-0.28	0.06	-0.56	0.22
1981	11.04	0.03	0.88	-0.45	0.04	-0.01	-0.15
1982	8.78	0.04	0.67	-0.56	0.07	-0.34	0.53
1983	5.84	-0.08	0.46	-0.45	0.05	0.25	-0.49
1984	3.59	-0.28	0.39	-0.94	0.10	-0.72	0.24
1985	2.64	0.05	0.22	-1.36	0.09	-0.13	0.03
mean	3.94	0.03	0.30	-0.41	0.04	-0.14	0.04

¹ deviations from base run in percentage points

² deviations from base run in per cent

³ deviations from base run in billion barrels

⁴ deviations from base run in billion pound sterling

key: *OPECWLTH* — OPEC oil wealth

DELGDPE — GDP growth rate in per cent

DELPC — consumer price inflation rate in per cent

OPEC POT — OPEC production capacity

SUKB — UK oil production

GOV — government expenditure at 1980 prices

TREBILL — treasury bill rate

The increase in OPEC oil revenues was achieved through a combination of lowering its production capacity by about 0.41 per cent (i.e. the dismantling of oil rigs), shown in Table 7.19, and a reduction of its own output by 4.95 per cent, as shown in Table 7.20. The general effect of this policy combination has been an average increase of nearly 10 per cent in the dollar oil price. This in turn depressed world oil demand by just less than 1 per cent but stimulated the non-OPEC oil producers in North America, the UK and other areas to increase their production levels. Since OPEC is assumed in the oil model to act as a *swing* producer that clears the market, OPEC's production resulted in a decline. However, the results shows that despite a decline in output, OPEC's oil revenues can still be higher than the base simulation path if it manages to

reduce excess production capacity since this is translated into an eventual increase of the oil price.

**Table 7.20: Control exercise 4 —
effects on oil sub-model.
% deviations from base run**

year	<i>POILD</i>	<i>DWOCA</i>	<i>SNA</i>	<i>SONOUK</i>	<i>SOPEC</i>	<i>CU</i>	<i>OPEC POT</i>
1975	0.30	-0.01	0.00	0.00	-0.07	1.81	-0.79
1976	0.87	-0.04	0.00	0.03	-0.28	2.50	-0.93
1977	0.61	-0.06	0.00	0.11	-0.23	-1.02	0.01
1978	1.32	-0.10	0.01	0.14	-0.39	2.87	-1.07
1979	1.54	-0.15	0.06	0.24	-0.50	0.43	-0.54
1980	9.94	-0.46	0.08	0.33	-1.45	13.46	-2.48
1981	14.04	-0.88	0.15	1.23	-2.63	11.15	-4.28
1982	14.36	-1.31	0.22	2.27	-4.88	1.52	-5.38
1983	13.38	-1.70	0.67	3.04	-6.64	-5.28	-4.42
1984	13.57	-2.10	1.29	3.49	-8.78	0.96	-9.11
1985	14.98	-2.53	1.93	3.83	-10.73	7.63	-13.33
<i>RMSPE</i>	9.98	1.22	0.73	1.98	4.95	6.13	5.53

key:

POILD — dollar oil price

SOPEC — OPEC supply of oil

DWOCA — world oil demand outside communist areas

SNA — North American supply of oil

CU — OPEC capacity utilisation

SONOUK — supply of oil of other

OPEC POT — OPEC production capacity

non-OPEC-non-UK countries

We now turn to the movement of the control variables (instruments) — UK oil production, government expenditure and the treasury bill rate — that are assumed to be under the control of the UK government. The percentage changes as listed in Table 7.19 reveal a fairly minimal movement of the instruments. UK oil production is pushed up; government expenditure and interest rates show a slight cyclical pattern around their base paths. Comparing the average changes of this exercise with those of the previous ones helps to further the understanding of the movement of the control variables. The oil extraction rate essentially seems to dictate corrective movements in the other two variables, government expenditure and the treasury bill rate. In the Nash game of exercise 3, oil extraction was constantly and by a wide margin above the base simulation path (on average by 0.73 bn barrels); hence the induced changes in the economy required relatively large manoeuvring with government expenditure and interest rates. This is in contrast to the outcome of exercise 1 and this exercise, where UK oil production rises only very little above the base path. As a consequence, the movement in the other two

instruments remains slight too. All this explains on a superficial level the under-achievement of the UK's economic targets, *viz.* a reduction in inflation and an increase in GDP growth.

A more fundamental explanation of the under-achievement of UK economic targets is given by the relative movements of the dollar oil price index. It was mentioned in the previous chapter that an important benefit arising from additional oil extraction is a reduction in the international oil price and a consequent reduction in domestic inflation levels. The scenario in exercise 1, however, assumed OPEC to remain passive in the wake of additional UK oil exports. In the other exercises, this assumption has instead been replaced by the assumption that OPEC itself is pursuing an optimal policy which resulted in an increase in its oil revenues in each of the other optimisation exercises. The mean deviations of the oil price index from its base path reveal that in the Nash game as well as in the Pareto game strong increases are achieved. Indeed, the oil price stays continuously above the base simulation path in either game, whereas under the regime of exercise 1 it stays below the base path. The underlying reason for the under-achievement of UK economic targets is therefore that it is no longer profitable for the UK to expand oil production further since a major beneficial effect — a reduction in the international oil price — has been reversed by counteracting OPEC oil policies.

The target that suffered most from this has been inflation, as Table 7.19 shows. Whereas in exercise 1 the inflation target was achieved throughout (Table 7.2), in this exercise economic policies were unable to halt an increase in inflation in every time period, with a resulting higher price level that at the end of the simulation period is about 3.09 per cent higher than the base value (Table 7.23). This compares to a price profile of exercise 1, which is lower than the base value for most of the optimisation period and only in the last two periods shows an increase. The outcome for the UK output growth target is also far from desired. Even though in absolute terms output growth is higher overall, the increase is very slight and is interrupted twice by falls in growth relative to the base simulation path.

This leads to the analysis of relative achievement under the regimes of the four control exercises. We mentioned in the last section that this can be done by comparing total cost figures that are obtained from the minimisation of the respective cost functions. Table 7.21 records these values. It is a replica

Table 7.21: Comparison of costs in four different game situations

	Base	UK	OPEC	UK vs OPEC ¹	UK and OPEC ²
<i>DELGDPE</i>	2,200	1,965	2,207	1,813	2,159
<i>DELPC</i>	1,375	12,052	14,192	15,914	15,507
<i>DM3S</i>	0	585	200	8,149	3,902
<i>OPECWLTH</i>	1,937,080	4,823,520	1,450,230	809,252	618,688
Σ UK	15,950	14,600	16,599	28,329	21,567
Σ OPEC	1,937,080	4,823,520	1,450,230	809,252	618,688
Σ all	1,953,030	4,838,120	1,466,829	837,581	640,255

¹ Nash game

² Pareto game

of Table 7.18 except for the last column, which lists the cost figures obtained in the Pareto game of this exercise. First of all, the comparison of the overall costs incurred by both players shows that the Pareto outcome is indeed the best outcome for the system as a whole. Yet when split up into subtotals, the figures show the UK again as the loser. This is despite total UK costs of 21,567 in the Pareto game being less than the costs of 28,329 in the Nash game. But compared with the base case or the UK single player optimisation, or even with the OPEC optimisation case, the UK always fares worse. This is surprising and would point to some inconsistency in the setup of the games played were it not for the strong gains of OPEC. We have already seen the gain that OPEC achieves in the Nash game, and the cost of 618,688 in the Pareto game is lower than that of the Nash game. Overall consistency in the results is therefore preserved.

Nevertheless, another puzzling feature remains. This concerns the huge changes in OPEC costs relative to the UK's costs. OPEC's worst cost outcome is $7\frac{1}{2}$ times its best; for the UK the multiple is less than 2. One reason for this lies certainly in the simplicity of the OPEC cost function, which contains only one target. And this target in turn is determined by only two variables, one of which is the oil price. Since there is a very immediate link between movements in both the oil price and OPEC production rates, large fluctuations in oil revenues (OPEC's target variable) are expected. In contrast to this, the two main UK targets — inflation and GDP growth — are difficult to achieve simultaneously. Indeed, part of the Phillips curve literature maintains that the one can only be obtained at the cost of the other. Furthermore, they are

affected by a variety of influences, which for the most part are not immediate at all. The consequence is a more moderate change in economic performance, reflecting thus the complexity of the economic system and of the transmission mechanisms involved.

Another reason for the large changes in the OPEC cost function is that its target variable, oil revenues, is denominated in nominal terms. UK output growth, instead, is measured in real terms. A price deflator for oil revenues was omitted, as was explained above, because international prices are exogenous to the model. An inclusion of a term deflating oil revenues would constitute therefore only a scaling factor, unresponsive to any development in the model.

Table 7.22: Control exercise 4 —
effects on real variables.
% deviations from base run

year	<i>GDPE</i>	<i>CON</i>	<i>INV</i>	<i>IMP</i>	<i>IM</i>	<i>X</i>	<i>XOX</i>
1975	0.03	0.03	0.03	-0.03	0.03	0.11	0.00
1976	0.04	0.08	0.19	-0.17	0.04	0.34	-0.03
1977	0.07	0.07	0.02	0.10	0.20	0.08	-0.10
1978	0.17	0.15	0.09	0.19	0.39	0.22	-0.15
1979	0.12	0.10	0.02	0.28	0.46	0.12	-0.25
1980	0.53	0.50	0.65	0.01	0.87	1.26	-0.32
1981	0.56	0.52	0.43	0.53	1.38	1.08	-0.55
1982	0.60	0.64	0.52	0.39	1.46	1.35	-0.76
1983	0.51	0.60	0.16	0.73	1.58	0.84	-0.96
1984	0.24	0.49	0.12	0.11	1.15	0.99	-1.16
1985	0.29	0.53	-0.16	0.35	1.30	0.64	-1.38
<i>RMSPE</i>	0.36	0.41	0.30	0.34	0.99	0.79	0.69

key: *GDPE* — GDP at 1980 prices
CON — consumers' expenditure at 1980 prices
INV — investment at 1980 prices
IMP — total imports at 1980 prices
IM — non-oil imports at 1980 prices
X — total exports at 1980 prices
XOX — non-oil exports at 1980 prices

The more detailed effects that were caused in the domestic economy are listed in Tables 7.22 – 7.24. A general comparison of the effects in this exercise with those of the previous exercises shows them to be in line with what has already been established. That is, the overall magnitude of the effects differs greatly from exercise to exercise. They are largest in the Nash games, then followed by the Pareto game and the two single control exercises. The underlying reasons for this have been discussed above. We simply note here

**Table 7.23: Control exercise 4 —
effects on prices and exchange rates
% deviations from base run**

year	<i>PC</i>	<i>PIMO</i>	<i>WHR</i>	<i>PEX</i>	<i>PM</i>	<i>REXRAT</i>	<i>EXRAT</i>	<i>BAL</i> ¹
1975	0.01	0.01	0.01	-0.01	-0.09	0.16	0.14	0.06
1976	0.04	0.05	0.06	0.00	-0.27	0.45	0.40	0.27
1977	0.01	0.00	0.06	-0.06	-0.39	0.55	0.55	0.12
1978	0.00	-0.01	0.09	-0.12	-0.66	0.93	0.94	0.27
1979	0.02	-0.01	0.22	-0.13	-0.81	1.08	1.09	0.28
1980	0.59	0.66	0.69	0.49	-1.07	2.11	1.44	1.75
1981	1.39	1.71	1.85	1.54	-0.83	2.71	0.98	2.07
1982	2.02	2.52	2.77	2.28	-0.71	3.30	0.76	2.92
1983	2.47	2.98	3.48	2.65	-0.81	3.93	0.92	2.79
1984	2.87	3.21	3.97	2.78	-1.13	4.66	1.40	3.96
1985	3.09	3.22	4.03	2.66	-1.80	5.71	2.41	4.11
<i>RMSPE</i>	1.66	1.89	2.25	1.64	0.90	2.94	1.16	2.27

¹ deviations from base run in billion pound sterling

key:

PC — consumer price index

PM — import price index

PIMO — producer price index

REXRAT — real exchange rate index

WHR — hourly wage rate index

EXRAT — nominal exchange index

PEX — export price index

BAL — balance of payments

**Table 7.24: Control exercise 4 —
effects on monetary variables.
deviations from base run in billion pounds sterling**

year	<i>DM3S</i>	<i>PSBR</i>	<i>DSBLPRIV</i>	<i>DSGDETPR</i>	<i>WEALPC</i>
1975	-0.04	-0.03	0.00	0.01	0.06
1976	-0.03	-0.22	0.22	0.03	0.13
1977	0.05	0.03	-0.06	-0.08	0.35
1978	-0.13	0.06	0.02	0.21	0.77
1979	0.03	0.17	0.19	0.33	1.29
1980	0.40	-0.64	2.10	1.06	2.27
1981	2.08	-0.11	3.46	1.26	3.80
1982	3.73	-0.61	6.19	1.85	5.52
1983	3.55	0.31	5.01	1.77	7.67
1984	5.28	-0.86	8.33	2.19	9.75
1985	4.38	-0.14	6.34	1.82	12.56
<i>RMSE</i>	2.66	0.40	4.15	1.26	5.75

key: *DM3S*— change in money supply (sterling M3)

DSBLPRIV— change in bank lending

DSGDETPR— change in bond sales

PSBR— public sector borrowing requirement

WEALPC— real wealth

that with respect to Dutch Disease phenomena, the outcome of the Nash game is therefore worst for the UK economy. Non-oil exports decline by 4.25 per cent. Their decline in the other games is rather slight, with magnitudes of less than $\frac{1}{2}$ per cent in the single optimisation cases and 0.69 per cent in the Pareto case (Table 7.22). We have seen that this is essentially due to the rise in the real exchange rate, which in this exercise is increased by about 3 per cent.

7.4 CONCLUSIONS

The sensitivity analyses of the previous chapter suggested that the interactions between the UK economy — its oil sector in particular — and the international oil market could be profitably investigated by applying game theoretical concepts to the analysis. Such an application of game theory would throw light on the problem of what economic policies the two identified players — the UK economy and OPEC — should pursue and what the consequences of these policies would be to each of them. This, in part, has been the purpose of this chapter. The additional use of control theory has ensured that the suggested policies are optimal, in the sense that they are designed to steer the economies towards reaching desired economic targets.

In order to establish the particular gains and losses in games with up to two players, we have considered 4 cases. In the first two, optimal policies are designed for each player by disregarding any influence of the other player. These single-player outcomes are contrasted with those of two-player games. Exercise 3 presents results of a competitive game whose solution is shown to be a Nash equilibrium. In exercise 4, a game with a Pareto efficient solution is played. The overall results are shown to be consistent with *a priori* theoretical expectations. In the single-player games, for instance, one player's gain coincides with the other's loss, thus confirming zero-sum game phenomena expected in such an interdependent environment. In addition, the Pareto efficient outcome is shown to be 'better' than the Nash game for both players. This agrees with common sense in that it is better to cooperate than to fight.

The chosen economic targets for each player have been the same in each exercise. The aims for the UK economy have been to increase GDP growth, to reduce consumer price inflation, and to maintain stable money supply conditions. As control instruments, the interest rate, the level of government expenditure, and the annual rate of oil production have been used. OPEC's

economic target has been to increase its oil revenues; its control or policy variable has been chosen to be its maximum capacity of oil production.

The results show that in the single-player control exercise the UK economy is able to improve its position only moderately. Output is generally higher, and inflation is lower in each time period. The change in the money supply is also kept small, as desired. OPEC, on the other hand, suffers a decline in wealth, as measured by its oil revenues. These changes have been brought about by increasing UK oil production, and by lowering both the level of interest rates and of government expenditure. It is argued that the increase in oil production is mainly responsible for higher growth in output. But it also has beneficial effects on inflation levels, for the increase in UK oil production causes excess supply of oil in the world oil market and a consequent drop in the oil price. This, as was shown in Chapter 6, leads to lower domestic inflation levels. Another effect of the increase in oil production is an appreciation of the real exchange rate, which by reducing the cost imported goods dampens inflation levels. An interesting outcome is the suggested mix of expenditure and monetary policy variables. The obtained reduction in interest rates implies their ineffectiveness at combating inflation, and suggests them to be used more beneficially at propping up any faltering growth in the economy. Additional reduction in inflation, the results suggest, is obtained by lowering the level of government expenditure. This appears to be at odds with the economic policies of the UK government, which relies on interest rates to reduce inflation.

The gains that OPEC obtains in the second single-player control exercise are larger than those for the UK economy in the first exercise. The results are similar to those discussed in Chapter 6. An overall reduction of OPEC's production capacity pushes up the oil price. Even though this leads to a reduced supply of OPEC oil — since non-OPEC oil production is stimulated — the increase outweighs the loss in production, and OPEC's oil revenues are increased throughout the optimisation period. The effects on the UK economy are small, with virtually unchanged growth in output and slight increases in inflation levels.

The main result of the third control exercise — the 2-players Nash game — is a strong warning to the UK policy makers. The results show the UK as the clear loser in an 'economic war' with OPEC over oil production. OPEC needs not fear such a confrontation: it gains easily. That is, UK output growth

is higher, but at the cost of an undesired increase in inflation and a worse position of the money supply. OPEC's oil revenues, however, are increased in most time periods. These changes have mainly been brought about by a strong increase in UK oil production, to which OPEC reacts by reducing part of its oil production capacity. Chapter 6 showed it economically sensible for the UK to push up its oil production in order to stimulate growth and yet benefit at the same time from lower international oil prices, which the increase in production causes. OPEC, however, keen to reach its own economic target, responds to this excess in oil supply by cutting idle production capacity in order to produce near full capacity with a consequent rise in the oil price.

The results of the Pareto game are similar to those of the Nash game: compared with the base simulation, OPEC gains and the UK loses. If, however, the comparison is made with the Nash outcome, both players gain. Several reasons were given for the relatively bad performance of the UK and the strong gains of OPEC. The first concerns the simplistic formulation of OPEC's cost function and the rather more complex formulation of the UK's cost function. OPEC has only one economic target that can be relatively easily achieved by changing only one policy variable. The UK, however, has three targets to achieve, which are difficult — if not impossible — to reach simultaneously. Another reason may be that OPEC's target — its oil revenues — are formulated in nominal terms. Changes in *OPECWLTH* would have been reduced, if the variable had been deflated. A price deflator is however not used since foreign prices are exogenous in the model.

The obtained results have to be qualified by recalling that the games were played in a deterministic world. Here economic or political shocks are not shocks, because any required adjustments in economic management would have already been fully anticipated. This, of course, is unrealistic as economic policy makers are able to make decisions in a risk-free environment. In our context this implies, for example, that OPEC is able to freely adjust its built-up production capacity in order to maximise revenues by cutting unnecessary fixed cost components. The political instability of the Middle East in particular and the importance of oil to the world mean that it may be necessary to increase oil production rapidly. A prudent decision maker would have to take this requirement into account and would be reluctant to reduce oil production capacity too drastically in pursuit of short term revenue maximisation. Rather, he would take a more long term view and consider not only economic factors but political ones as well.

From a short term viewpoint, on the other hand, it could be argued that a cut in production capacity is desirable since at the outbreak of any crisis involving world oil supplies, fear of medium to long term disruptions in oil supplies would push up the international price of oil. This increase in the oil price in such a case is likely to outweigh any preceding reduction in production caused by dismantling idle production capacity. Oil revenues would therefore rise and satisfy the target of short-term-revenue maximisation. However, as many oil producing countries increasingly invest a great part of their wealth in industrialised countries, any disruption to the world economy caused by a man-made oil crisis would eventually rebound and hit the very countries that allowed — in part — a shortage of oil supply to occur because of excessive cuts in production capacity. This interdependence and the importance of a risk factor in decision making are recognised but have not been fully investigated here. Such an analysis would be properly conducted by considering stochastic elements. We leave this for future work.

Chapter 8

Conclusions and Suggestions for Future Work

This thesis set out to analyse the macroeconomic effects of UK oil production on the UK economy. If one considers the importance of oil to the economy and the size of production, it comes as no surprise 15 years after production started in earnest to find that several studies have dealt with this problem already. Papers of a theoretical nature, for instance, are surveyed extensively in Corden (1984), and applied work can be found in Atkinson *et al.* (1983), Bond *et al.* (1982), or Bean (1986). The drawback of the research in this part of the literature is its purely isolationist framework, which disregards any interaction of the UK economy with other economic agents within the greater whole of the world economy. Instead we have argued that a proper analysis of the UK oil sector and its impact on the economy should also feature its relationship with the international oil market. The novelty of this study then has been the extension of the 'narrow' conventional analytical framework to incorporate the interactions of the UK economy and the international oil market. The analysis has been conducted with two macroeconometric models — one featuring the UK economy the other relating to the international oil market. The models have been combined and solved as an interdependent system. The implicit contention that there is an interaction between the two independent models has of course been tested and established. This has provided new results as far as the macroeconomic effects are concerned, and it has also opened the door for the application of game theoretic concepts to the analysis. Within this generalised framework optimal economic policies have been designed both for the UK and for OPEC — the dominant force in the international oil market — first in isolation by disregarding any interaction with others and then by considering two multi-player games, of which one has been a non-cooperative Nash game and the other a cooperative Pareto game.

This as an outline; our main results can be summarised as follows. The multiplier analysis in Chapter 6 has shown that the inclusion of an endogenous

international oil price variable — that is provided here by the sub-model of the international oil market — has led to different results compared to models with an exogenous oil price. This relates especially to the undesired phenomenon of de-industrialisation — i.e. a shrinking manufacturing sector — that often follows the discovery and exploitation of a natural resource.¹ The economy's manufacturing or trading sector declines because added oil production — as in the case of the UK — leads to an appreciation of the real exchange rate and thereby makes domestic exports less competitive. Our results suggest, an appreciation of the exchange rate still occurs, but the appreciation is about three times less than in the case where the UK oil impacts are analysed without considering the interaction with the international oil market. A second important consequence of analysing the multiplier effects of an increase in domestic oil production within a more general analytical framework has been a reduction in the international oil price. It has been argued in this thesis that given an initial equilibrium in the international oil market, added UK oil production would lead to an excess supply of oil, and eventually to a drop in the oil price. These two results in combination have shown that the undesired effects on the economy of oil discovery and exploitation are less severe. First, because the reduced appreciation of the real exchange rate has caused a smaller decline of the manufacturing sector; and second because the reduction in the international oil price has dampened the inflationary impacts that have been caused by spending part of the larger stock of wealth to which higher oil exports have added.

The application of optimal control within a game theoretic framework has provided new insight into the possibilities of UK and OPEC oil production policies in particular. We have found that it is undesirable for UK economic policy makers to engage in an economic 'war' over oil production with OPEC, for it is the UK that loses and OPEC that gains in such a conflict.² This situation has been brought about because UK policy makers have expanded domestic oil production. It was indicated as part of the multiplier analysis in Chapter 6 and shown in a single-player optimisation game in Section 3.1 in Chapter 7 that an expansion of UK oil production would benefit the UK economy by increasing output growth and reducing inflation levels.³ Yet the outcome of the non-cooperative Nash game has shown that OPEC responds to

¹A 10 per cent increase in UK oil production has been considered in Section 4.3 of Chapter 6.

²refer to Section 3.3 of Chapter 7, where a non-cooperative Nash game is considered.

this increase of UK oil production by reducing its own production and by cutting idle production plants. As a result, OPEC is shown to produce near full capacity, and able to raise the international price of oil, which increases OPEC oil revenues but reinforces the inflationary impacts of added UK oil production.

The above findings differ significantly enough from those of other studies to suggest the following conclusions. First, a proper planning of UK oil policies should be done within a game theoretic framework, for the international oil market has been shown too important a factor to ignore. Second, the overall UK economic policy management ought to be analysed as a policy optimisation problem in order to combine most effectively and to the greatest benefit the determination of key government policy variables.

These overall findings have been obtained by using two macro-econometric models, of the UK economy and the international oil market respectively. The theoretical underpinning of the UK model is an extension of the Dornbusch (1976) model of exchange rate determination.⁴ This model type has been widely used in the analysis of the so called Dutch Disease phenomena, which, as has been pointed out, refer to the decline of the Dutch manufacturing sector after considerable gas resources had been discovered and exploited in the early 1970s. We have pointed out that the Dornbusch model and all its derivatives used in the Dutch Disease literature lack a feedback mechanism from trade flows onto the rest of the model and the exchange rate in particular. Without such a mechanism an economy is permitted, for example, to run indefinite current account deficits without ever experiencing a depreciation of its currency. In Chapter 3 we have amended an essentially Dornbusch-type model by incorporating such a feedback mechanism and adapted it to the UK economy and its oil sector by adding oil production as an exogenous variable. This novel feature has been shown to affect the model's long term behaviour. An increase in oil production, for example, leads to an appreciation of the nominal exchange rate, and to an increase in the domestic price level. While the exchange rate appreciation is a standard outcome of this model type, that of an increased price level is not. In fact, it was shown to result from the inclusion of the feedback mechanism. A recession — equivalent to a drop in

³The complete set of economic objectives for the UK has been to achieve an increase in output growth, a reduction in consumer price inflation, and to maintain stable monetary growth conditions. OPEC has been assumed to strive for an increase in its oil revenues. For details, see Chapter 7.

⁴refer to Chapter 3.

the price level — does not occur in the model because the expansionary spending effect has been reinforced by an additional wealth effect that originates from the current account and that is absent from conventional Dutch Disease models.

The econometric specification of the UK model as well as that of the international oil market model has been based on recent advances in econometric methodology.⁵ These refer to the use of error correction methods (ECM) and cointegrating vectors in the specification of long run economic relationships as suggested by economic theory.⁶ The methodology places the econometric specification process within a probabilistic framework and thus allows and requires the testing of all statistical assumptions that underlie an obtained econometric model. Particular emphasis is furthermore put on the data series; these determine the short term dynamics of econometric models. Long run economic relationships between economic variables, instead, are captured by ECMs or cointegrating vectors.

The estimation methodology has been successfully applied to the UK macroeconometric model, whose structure has been adopted from the theoretical model of Chapter 3. Output is demand determined in the model, and its main constituents have been fully estimated. In order to trace better the effects of oil production on the economy, exports and imports are disaggregated into a non-oil part and an oil part. Oil production is assumed to be a UK policy control variable, as are the treasury bill rate and the level of government expenditure. Oil production increases total output and thus affects the demand side of the economy; oil exports increase the stock of wealth and — via the current balance — have an indirect effect of the real exchange rate. A direct effect of oil on the real exchange rate was not substantiated by the data. This thesis has shown that the international oil price exerts an important influence on the UK economy. The effects of the oil price variable in the macroeconometric model are twofold. First, it enters the determination of the value of UK oil production; second, it affects domestic inflation levels by influencing wholesale and consumer prices. Prices then feed *inter alia* into the determination of private consumption and investment and thus affect the demand side of the economy.

⁵refer to Chapters 4 and 5.

⁶The seminal contributions in these research areas are Hendry and Richards (1982, 1983), and Engle and Granger (1987).

The model of the international oil market is essentially an adaptation of Baldwin and Prosser (1987). In character, the model is a demand and supply model; its equilibrium condition determines the international oil price. Supply and demand are equilibrated through adjustments of OPEC production, ie. OPEC is assumed to be a swing producer. The oil price depends on the level of utilisation of OPEC oil production capacity.

This thesis has not said much in detail about OPEC; indeed OPEC's economic objectives were kept simple, and only one control variable was reserved for its economic decision making. This simplicity was justified by pointing out that for many OPEC countries, oil production is the only important wealth creating industrial sector and therefore the only source of foreign currency, which is used — in part — to pay for imported goods. While this is arguably a reasonably realistic assumption, it was also mentioned that the assumption of perfect foresight should be relaxed to incorporate random disturbances in the analysis. This means to assume more realistically that economic agents do not operate within a risk-free environment. An extension of the work in this thesis would therefore be to study the interactions of the UK economy and the international oil market within a non-deterministic framework. It is expected that such an analysis would restrict OPEC in its use of changing its oil producing capacity.

We also noted that the long-lasting prosperity has enabled many OPEC countries, notably Kuwait, to invest large parts of their oil wealth in the industrialised countries. Through this OPEC wishes to transform the temporary oil wealth into a source of wealth that will not dry up when the oil runs out. But at the same time it has made OPEC countries more dependent upon the prosperity of the industrialised countries. Unemployment, inflation and recessions now matter for OPEC too. In order to extend the analysis of this thesis further, these features could be incorporated by endogenising the international price level, and by considering a block of industrialised countries, probably led by the US economy.

Appendix A

Listing of Econometric Model Equations

UK economy: real sector

Identities and unestimated behavioural relationships

$$GDPOIL = \frac{POILS}{PC} \cdot SUKB \cdot SUKBAD \quad (A.1)$$

$$XOIL = 0.60 \cdot GDPOIL \quad (A.2)$$

$$IMSAV = GDPOIL - XOIL \quad (A.3)$$

$$X = XOX + XOIL \quad (A.4)$$

$$IMP = IM - IMSAV \quad (A.5)$$

$$TFE = CON + INV + GOV + X + \Delta 1STOCKS \quad (A.6)$$

$$GDPE = TFE - IMP - REXPTAX \quad (A.7)$$

$$RPDI = GDPE - RINCTAX - RINCTAD \quad (A.8)$$

$$REXPTAX = 0.222 \cdot CON \quad (A.9)$$

$$RINCTAX = 0.0379 \cdot GDPE \quad (A.10)$$

$$GDPT = 100.78676 + 4.28916 \cdot TREND - 1.11716 \cdot TR70 \quad (A.11)$$

$$GDPOX = GDPE - GDPOIL \quad (A.12)$$

$$GDPGDPT = \frac{GDPE}{GDPT} \quad (A.13)$$

$$AFCGDPE = \frac{AFC}{GDPE} \quad (A.14)$$

Estimated relationships

$$\begin{aligned} \Delta \ln CON = & \frac{-0.012}{(2.55)} + \frac{0.715}{(9.35)} \cdot \Delta \ln RPDI - \frac{0.085}{(2.13)} \cdot \Delta \ln PC \\ & - \frac{0.482}{(2.06)} \cdot (\ln CON - \{0.087 - 0.002 \cdot TREBILL \\ & + 0.929 \cdot \ln RPDI + 0.037 \cdot \ln WEALPC\})_{t-1} \end{aligned} \quad (A.15)$$

$$\begin{aligned} \Delta \ln INV = & \frac{0.018}{(0.86)} + \frac{1.083}{(3.26)} \cdot \Delta \ln GDPE - \frac{0.285}{(1.76)} \cdot \Delta \ln PC \\ & - \frac{0.793}{(2.63)} \cdot (\ln INV - \{-4.465 + 1.557 \cdot \ln GDPE \\ & - 0.005 \cdot TREBILL - 0.167 \cdot \ln PC\})_{t-1} \end{aligned} \quad (A.16)$$

$$\begin{aligned} \Delta \ln XOX = & \frac{0.565}{(12.82)} \cdot \Delta \ln XWM - \frac{0.590}{(4.98)} \cdot (\ln XOX - \{4.019 \\ & + 0.572 \cdot \ln XWM - 0.340 \cdot \ln REXRAT\})_{t-1} \end{aligned} \quad (A.17)$$

$$\begin{aligned} \Delta \ln IM = & \frac{0.005}{(1.31)} + \frac{1.577}{(13.08)} \cdot \Delta \ln TFE - \frac{1.300}{(6.13)} \cdot (\ln IM \\ & - \{-6.214 + 1.827 \cdot \ln TFE + 0.158 \cdot \ln REXRAT\})_{t-1} \end{aligned} \quad (A.18)$$

**UK economy: Price sector, balance of payments
and exchange rates**

Identities

$$POILS = \frac{POILD}{100} \cdot DOLLEXR \quad (A.19)$$

$$WWPIS = \frac{INWWPI}{EXRAT} \quad (A.20)$$

$$BAL = PEX \cdot X - PM \cdot IMP + ADBAL \quad (A.21)$$

$$DOMRTB = \frac{TREBILL}{100} - \Delta \ln PC \quad (A.22)$$

$$FORRSW = \frac{RSW}{100} - \Delta \ln INWWPI \quad (A.23)$$

$$RINTDIF = DOMRTB - FORRSW \quad (A.24)$$

$$EXRAT = REXRAT \cdot \frac{INWWPI}{PIMO} \quad (A.25)$$

$$DOLLEXR = \frac{EXRAT}{EXRAT_{t-1}} \cdot DOLLEXR_{t-1} \quad (A.26)$$

Estimated price and exchange rate relationships

$$\Delta \ln WHR = \underset{(2.90)}{0.031} + \underset{(8.06)}{0.829} \cdot \Delta \ln PC - \underset{(3.12)}{0.334} \cdot \Delta \ln AVH \quad (A.27)$$

$$\begin{aligned} & - \underset{(10.00)}{0.568} \cdot \ln WHR_{t-1} + \underset{(9.83)}{0.663} \cdot \ln PC_{t-1} \\ & - \underset{(2.82)}{0.412} \cdot \ln AVH_{t-1} + \underset{(6.66)}{0.926} \cdot \ln GDPGDPT_{t-1} \end{aligned}$$

$$\Delta \ln PC = \underset{(5.46)}{0.030} + \underset{(6.50)}{0.355} \cdot \Delta \ln PIMO + \underset{(7.53)}{0.053} \cdot \Delta \ln POILS \quad (A.28)$$

$$\begin{aligned} & + \underset{(14.57)}{0.212} \cdot \Delta \ln AFCGDPE - \underset{(4.32)}{0.214} \cdot \ln PC_{t-1} \\ & + \underset{(3.07)}{0.150} \cdot \ln PIMO_{t-1} + \underset{(3.74)}{0.030} \cdot \ln POILS_{t-1} \end{aligned}$$

$$\Delta \ln PIMO = \underset{(10.37)}{0.038} + \underset{(9.57)}{0.327} \cdot \Delta \ln WHR + \underset{(9.63)}{0.075} \cdot \Delta \ln POILS \quad (A.29)$$

$$\begin{aligned} & + \underset{(4.81)}{0.025} \cdot D77 - \underset{(11.81)}{0.413} \cdot \ln PIMO_{t-1} \\ & + \underset{(3.70)}{0.114} \cdot \ln WHR_{t-1} + \underset{(7.34)}{0.106} \cdot \ln WWPIS_{t-1} \\ & + \underset{(10.78)}{0.087} \cdot \ln POILS_{t-1} \end{aligned}$$

$$\Delta \ln PEX = \underset{(3.10)}{-0.021} + \underset{(16.96)}{0.971} \cdot \Delta \ln PIMO + \underset{(4.01)}{0.143} \cdot \Delta \ln WWPIS \quad (A.30)$$

$$\begin{aligned} & - \underset{(6.10)}{1.037} \cdot \ln PEX_{t-1} + \underset{(6.00)}{0.951} \cdot \ln PIMO_{t-1} \\ & + \underset{(3.63)}{0.107} \cdot \ln WWPIS_{t-1} \end{aligned}$$

$$\Delta \ln PM = \underset{(8.21)}{0.652} \cdot \Delta \ln WWPIS - \underset{(3.01)}{0.222} \cdot \ln PM_{t-1} \quad (A.31)$$

$$+ \underset{(2.77)}{0.206} \cdot \ln WWPIS_{t-1} + \underset{(4.46)}{0.155} \cdot D74$$

$$REXRAT = \underset{(3.40)}{0.402} + \underset{(2.45)}{0.010} \cdot \frac{BAL}{PIMO} + \underset{(3.82)}{0.533} \cdot REXRAT_{t-1} \quad (A.32)$$

$$+ \underset{(1.96)}{0.452} \cdot RINTDIF_{t-1}$$

UK economy: monetary sector

Identities

$$RALLTAX = REXPTAX + RINCTAX \quad (A.33)$$

$$RPSBR = GOV - RALLTAX + RPSBRAD \quad (A.34)$$

$$PSBR = RPSBR \cdot PC \quad (A.35)$$

$$WEALPC = WEALPC_{t-1} + RPSBR + \frac{BAL}{PIMO} + ADRWEL \quad (A.36)$$

$$WEALTH = WEALPC \cdot PC \quad (A.37)$$

$$RCNSL = \frac{TREBILL}{TREBILL_{t-1}} \cdot RCNSL_{t-1} \quad (A.38)$$

$$SBLPRIVS = RSBLPR \cdot PC \quad (A.39)$$

$$SGDETPRI = RSGD \cdot PC \quad (A.40)$$

$$\Delta M3S = PSBR - \Delta SGDETPRI + \Delta SBLPRIVS + EFC - NNDL \quad (A.41)$$

Estimated relationships

$$\Delta RSGD = -3.179 + 0.360 \cdot \Delta WEALPC + 0.375 \cdot RCNSL_{t-2} \quad (A.42)$$

(2.18) (5.39) (2.80)

$$\Delta \ln RSBLPR = 1.924 \cdot \Delta \ln WEALTH_{t-1} - 0.019 \cdot TREBILL_{t-1} \quad (A.43)$$

(2.89) (2.59)

$$+ 0.096 \cdot \ln \left(\frac{WEALTH}{SBLPRIVS} \right)_{t-1} + 0.336 \cdot \ln C7173$$

(3.79) (5.55)

International oil market

Identities

$$\text{if } (SUKB > LIMPROD) \text{ } ANNCOST = PRODDIF \cdot PRODDIF \quad (\text{A.44})$$

$$\text{if } (SUKB \leq LIMPROD) \text{ } ANNCOST = 0 \quad (\text{A.45})$$

$$PRODDIF = SUKB - LIMPROD \quad (\text{A.46})$$

$$LIMPROD = \alpha \cdot SUKB_{BASE} \quad (\text{A.47})$$

$$SOPEC = DWOCA - (SNA + SONOUK + SUKB + XCPE) + OILSTOCK \quad (\text{A.48})$$

$$OPECWLTH = POILD \cdot SOPEC \quad (\text{A.49})$$

$$OPECPER = \frac{SOPEC}{OPEC POT} \quad (\text{A.50})$$

$$CU = \frac{1}{1 - OPECPER} \quad (\text{A.51})$$

$$OPI = \frac{POILD}{INWWPI} \quad (\text{A.52})$$

Estimated relationships

$$\ln \frac{DWOCA}{WOCAGDP} = \underset{(9.10)}{-0.036} \cdot \ln OPI + \underset{(2.37)}{0.129} + \underset{(27.04)}{0.996} \cdot \ln \left(\frac{DWOCA}{WOCAGDP} \right)_{t-1} \quad (\text{A.53})$$

$$\Delta \ln \frac{SNA}{GSNA} = \underset{(9.15)}{-0.234} + \underset{(9.39)}{0.060} \cdot \ln OPI_{t-3} \quad (\text{A.54})$$

$$\ln \frac{SONOUK}{GSONOUK} = \underset{(11.94)}{0.707} \cdot \ln \left(\frac{SONOUK}{GSONOUK} \right)_{t-1} - \underset{(4.65)}{0.406} + \underset{(5.04)}{0.105} \cdot \ln OPI_{t-1} \quad (\text{A.55})$$

$$\Delta \ln POILD = \underset{(2.75)}{-0.184} + \underset{(4.67)}{0.048} \frac{1}{1 - CU} \quad (\text{A.56})$$

Appendix B

Variable Definitions and Data Sources

Variable name	Description	Source	Units
<i>ADBAL</i>	Adjustment factor for current account identity		£bn /transformed
<i>ADRWEL</i>	Adjustment factor for real wealth identity		£bn 1980 /transformed
<i>AFC</i>	Adjustment to factor cost	CSO	£bn /transformed
<i>ANNCOST</i>	Squared deviation of UK oil production from desired target		
<i>AVH</i>	Average hours worked per operative in manufacturing	CSO	1980=1.0
<i>BAL</i>	Current balance	CSO	£bn
<i>CON</i>	Real consumers' expenditure	CSO	£bn 1980
<i>DOLLEXR</i>	US dollar exchange rate (£/\$)	CSO	1980=1.0 /transformed
<i>DOMRTB</i>	UK real interest rate		%
<i>DWOCA</i>	Demand for oil in WOCA	BP	bn bbl
<i>EFC</i>	External and foreign currency counterparts	CSO	£bn
<i>EXRAT</i>	Effective sterling exchange rate	CSO	1980=1.0 /transformed
<i>FACO</i>	Stock of financial assets, company sector	NIER	£bn /transformed
<i>FAPER</i>	Stock of financial assets, persons	NIER	£bn /transformed
<i>FORRSW</i>	Overseas real interest rate		%
<i>GDPE</i>	GDP at factor cost - expenditure based	CSO	£bn 1980
<i>GDPOIL</i>	North Sea oil contribution to GDP	C.E.F.	£bn 1980 /transformed
<i>GDPOX</i>	GDP excluding North Sea oil	C.E.F.	£bn 1980 /transformed
<i>GDPT</i>	GDP trend	C.E.F.	£bn 1980 /transformed
<i>GOV</i>	General government consumption	CSO	£bn 1980
<i>GSNA</i>	Geological oil supply in NA	BP	bn bbl
<i>GSONOUK</i>	Geological oil supply in ONOUK	BP	bn bbl
<i>IM</i>	Imports, incl. oil import savings	C.E.F.	£bn 1980 /transformed
<i>IMP</i>	Imports of goods and services	CSO	£bn 1980
<i>IMSAV</i>	North-Sea oil imports savings	C.E.F.	£bn 1980 /transformed

<i>INV</i>	Gross fixed investment	CSO	£bn 1980
<i>INWWPI</i>	World wholesale prices	C.E.F.	1980=1.0 /transformed
<i>LIMPROD</i>	UK oil production limit, used in optimisation		bn bbl
<i>M3S</i>	Money stock, sterling M3	CSO	£bn
<i>NNDL</i>	Non-deposit sterling liabilities	CSO	£bn
<i>OILSTOCK</i>	Adjustment factor in oil supply identity	BP	bn bbl
<i>OPEC POT</i>	Maximum OPEC oil production capacity	BP	bn bbl
<i>OPECWLTH</i>	OPEC oil revenues		index
<i>OPI</i>	Real international oil price		1980=1.0/transformed
<i>PC</i>	Price of private consumption	CSO	1980=1.0 /transformed
<i>PEX</i>	Price of exports	CSO	1980=1.0/transformed
<i>PIMO</i>	Producer price home sales of manufacturing output	CSO	1980=1.0
<i>PM</i>	Price of imports	CSO	1980=1.0/transformed
<i>POILD</i>	US dollar price of North Sea oil (\$/bbl.)		1980=1.0 /transformed
<i>POILS</i>	Sterling oil price		1980=1.0/transformed
<i>PSBR</i>	Public sector borrowing requirement	CSO	£bn
<i>RALLTAX</i>	Total real tax take	CSO	£bn 1980 /transformed
<i>RCNSL</i>	Yield on 2% consols	FS	%
<i>REXPTAX</i>	Expenditure tax in real terms		£bn 1980 /transformed
<i>REXRAT</i>	Real effective sterling exchange rate	C.E.F.	1980=1.0 /transformed
<i>RINCTAD</i>	Adjustment factor for real disposable income		£bn 1980 /transformed
<i>RINCTAX</i>	Income tax in real terms	CSO	£bn 1980 /transformed
<i>RINTDIF</i>	Real interest differential between UK and overseas		%
<i>RPDI</i>	Real personal disposable income	CSO	£bn 1980
<i>RPSBRAD</i>	Adjustment factor for real <i>PSBR</i>		£bn 1980 /transformed
<i>RPSBR</i>	Real <i>PSBR</i>		£bn 1980 /transformed
<i>RSBLPR</i>	Stock of bank lending in real terms		£bn 1980 /transformed
<i>RS GD</i>	Stock of bond sales in real terms		£bn 1980 /transformed
<i>RSW</i>	World interest rate, eurocurrency 3-months-deposit	C.E.F.	%
<i>SBLPRIVS</i>	Stock of sterling bank lending to private sector	BOE	£bn /transformed
<i>SGDETPRI</i>	stock of debt sales to non-bank private sector	BOE	£bn /transformed
<i>SNA</i>	Oil supply in NA	BP	bn bbl
<i>SONOUK</i>	Oil supply in ONOUK	BP	bn bbl
<i>SOPEC</i>	Oil supply in OPEC	BP	bn bbl

<i>STOCKS</i>	Level of stocks	CSO	£bn 1980
<i>SUKB</i>	Oil supply in UK	BP	bn bbl
<i>SUKBAD</i>	Adjustment factor for UK oil GDP identity		bn bbl
<i>TFE</i>	Total final expenditure		£bn 1980 /transformed
<i>TR70</i>	Dummy: 0 for 1955-69, 1 for 1970-85		
<i>TREBILL</i>	Rate of treasury bill	CSO	%
<i>TREND</i>	Time trend		
<i>WEALPC</i>	Stock of private wealth in real terms		£bn 1980 /transformed
<i>WEALTH</i>	<i>FACO</i> + <i>FAPER</i> , stock of financial assets in private sector	NIER	£bn /transformed
<i>WHR</i>	hourly wage rate	NIER	1980=1.0 /transformed
<i>WOCAGDP</i>	Total GDP in WOCA	S/H	internat. PPP dollars
<i>X</i>	Exports of goods and services	CSO	£bn 1980
<i>XCPE</i>	Oil exports from communist areas	BP	bn bbl
<i>XOIL</i>	Exports of North Sea oil	CSO	£bn 1980 /transformed
<i>XOX</i>	Non-oil exports	CSO	£bn 1980 /transformed
<i>XWM</i>	World exports of manufactures	NIER	1980=1.0 /transformed

Explanation:

BP	British Petroleum
CSO	Central Statistical Office
NA	North America
NIER	National Institute of Economic Research
ONOUK	Other-non-OPEC-non-UK areas
OPEC	Organisation of Petroleum Exporting Countries
C.E.F.	Centre for Economic Forecasting databank, LBS
WOCA	World outside communist areas
S/H	Summers and Heston (1984)

£bn	Variable measured in £1,000,000,000 (current prices)
£bn 1980	Variable measured in £1,000,000,000 (1980 prices, i.e. adjusted for inflation)
1980=1.0	Variable measured by an index with 1980 as the base year equal to 1.0
%	Variable measured in per cent per annum
bn bbl	1,000,000,000 barrel

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