Quantifying the impacts of air transportation on economic productivity: a quasi-experimental causal analysis

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ARTICLE INFO

JEL classification:
L93
R4
R1

Keywords:
Air transport
Aviation
Causal inference
Productivity

ABSTRACT

Air transport capacity expansions are often justified on the grounds that they will improve economic performance and induce growth. Such causal impacts are hard to identify empirically due to the fundamentally endogenous nature of the relationship between air transport and the economy. This paper contributes to the empirical literature on aviation-economy effects by conducting a case study of the impacts of air transport activity on productivity in Chinese provinces. For exogenous variation we exploit a policy scenario created by the 2003 deregulation of the Chinese aviation sector, which was applied in all provinces of China except Beijing and Tibet. We find that this policy intervention resulted in substantial growth in air transport passengers and cargo. We estimate the causal effect of air transport on productivity by comparing GDP per employee in Tibet relative to a synthetic control region affected by the deregulation policy. We find a significant positive productivity effect from aviation expansion following the 2003 deregulation. Use of a differences-in-differences specification confirms this result.

1. Introduction

The literature documents various mechanisms through which aviation can induce positive effects on the economy (for recent reviews see Zhang and Graham, 2018; Button and Yuan, 2013). There are supply-chain activities that include direct impacts from airport operations or aircraft manufacture and maintenance. There are indirect effects arising from links with fuel suppliers, and induced effects such as expenditure by aviation industry employees. There are also spillover effects due to the influence that aviation has on access to markets, resources, labour, knowledge and other benefits of enlargement in economic scale and scope.

While associations between aviation and economic performance are frequently reported in the literature, often with supporting empirical evidence, the causal nature of such relationships has been found hard to demonstrate, largely due to the fact that there is strong bi-directional causality. On the one hand, air transport affects the economy through the aforementioned mechanisms; on the other, economic growth stimulates more air transportation demand.

In this paper we exploit exogenous spatial variation introduced via a Chinese aviation deregulation policy to provide causal estimates of the effect of air transport on regional economic productivity. The policy intervention of interest, referred to as airport localization, was implemented by the Civil Aviation Administration of China (CAAC) in 2003, and involved the transfer of airport ownership and management to local governments. This in turn provided incentives for local governments and private investment to construct and improve airports, resulting in greater financial accountability and efficiency (Chi-Lok and Zhang, 2009). The policy was applied in all provinces of China, except in Beijing and Tibet, and it led to substantial growth in air passenger and cargo volumes.

Using Tibet as a case study, we estimate the causal effect of air transport activity on regional productivity by comparing GDP per employee in Tibet relative to a synthetic control region (SCR) that was subject to the deregulation policy, and consequently experienced a dramatic increase of air passengers and cargo. The synthetic control method (SCM) has been used in comparative case studies since the work of Abadie and Gardeazabal (2003). Our SCR is a weighted average of control regions which can best approximate the relevant economic characteristics of Tibet (our treated region). We consider all Chinese provinces as possible control regions.

As mentioned before, Beijing was also excluded from the policy along
with Tibet, but its case cannot be compared to the Tibet exclusion. Beijing is a municipality, which is the smallest level of administration in China, and is directly under the central government. Additionally, even though Beijing was excluded from the policy, it experienced an increase in passengers and cargo after 2003 in the same line as the rest of the country. This could be attributed to the 2008 Olympic Games and the fact that Beijing is the current and historical capital of China. On the other hand, air passengers and cargo growth was substantially lower in Tibet with respect the rest of the country from 2003 onwards.

A key assumption required to establish casual inference via the SCM approach is that the treatment is exogenous to the variable of interest. In our context, this requires us to believe that Tibet was excluded from the deregulation policy due to reasons not related to its economic performance. To the best of our knowledge, there has been no official economic explanation as to why the airport localization policy was not implemented in Tibet. Among other consequences, this policy allowed provinces to attract foreign investment in airports and new airlines up to 49% of total ownership and the degree and control of the provinces by CAAC was significantly reduced (Lei and O’Connell, 2011). Thus, the supervision of Tibet by the Chinese central government would have been materially affected had the policy been applied in that region. In addition, Tibet has a long story of unrest within the People’s Republic of China. These factors support our view that the decision to exclude Tibet from the airport localization policy was not primarily motivated by concerns over economic performance.

We find a substantial positive causal effect on air transport activity due to implementation of the deregulation policy. Air passengers and cargo were 50% lower in Tibet than in our benchmark SCR just four years after the policy was introduced. Our key finding is that, by 2007, labour productivity was 19% lower in Tibet than in the SCR due to policy exclusion. Our benchmark SCR is formed by four Chinese regions that were comparable to Tibet in 2003 in several relevant economic characteristics. The main difference between the four regions that form the SCR and Tibet is that those regions had access to the deregulation policy of 2003 and experienced a sudden an immense increase in air transport capacity thereafter, while Tibet did not. The level of labour productivity was exactly the same in the SCR and Tibet prior 2003, and by 2007 labour productivity was 19% higher in the SCR than in Tibet. Since the main difference between the SCR and Tibet was the increase of aviation capacity in the SCR due to the deregulation policy, our results are indicative of a strong labour positive productivity effect from expansion of aviation activity. There are several possible mechanisms through which the increase in air transport capacity could have affected productivity. Following Zhang and Graham (2018), air transport can boost productivity due to the expansion of markets. The better the transport links, the easier for local companies to expand its operations, and the stiffer the competition. Also, companies would have access to a wider pool of skilled labour. However, in our paper we are not able to unravel which of these mechanisms are at work. We leave this for further research.

Estimation of a conventional differences-in-differences (DID) specification confirms our SCM exercise, finding that labour productivity was between 11% and 13% lower in Tibet due to the policy exclusion. We also conduct robustness tests in the form of lower bound tests which supports the robustness of our results, finding that labour productivity was 9% lower in Tibet as a consequence of the policy exclusion. Thus, our SCM exercise could be considered an upper bound for the effects of air transport on the economy. In any case, all our results show a substantial positive productivity effect from aviation expansion following the 2003 deregulation.

We believe that there were no other factors that could have affected simultaneously the control and treatment regions during the period of interest. The main threat in this sense was the extension of China’s National Trunk Highway System, particularly from 2004 onwards. This extension implied a massive increase in the length of highways around the country, since it aimed to connect cities with urban population larger than 200,000 by 2007 (Faber 2014; Jing and Liao 2019). This infrastructure plan was applied to the whole country, and Tibet was not an exception. We show in the Appendix that Tibet was actually among the provinces that received more investments through the plan. Therefore, the difference in labour productivity between Tibet and the control regions could not be explained by this infrastructure expansion.

Our findings indicate that increasing air transport capacity (in terms of air passengers and air cargo) has a significant positive effect on the economy. This implies that there are incentives for policymakers around the world to invest in the aviation sector as the economic returns of these policies could have a significant magnitude. Our paper also illustrates how regulation can create a more favorable environment for companies and the economy. Future studies could explore this issue further by exploring the effect of different regulations on air transportation (such as decentralization of airport management, deregulation of entry exit of airlines, etc.), identifying the main mechanisms through which air transport causes productivity increases, and studying the possible negative consequences of air transport in terms of environmental impact.

The paper is organized as follows. Section 2 provides a brief review of the literature on aviation and economic performance. Section 3 explains the deregulation of Chinese aviation and its consequences. The data and method used for analysis are described in section 4. Results are presented and discussed in Section 5, along with robustness tests undertaken to check the validity of our SCM estimates. Conclusions are then drawn in the final section.

2. Economic impacts of aviation

There is an extensive theoretical and empirical literature on the economic impacts of transport (for reviews see Redding and Turner, 2015; Venables et al., 2014; Melo et al., 2013). The vast majority of work has focused on road and rail, where effects are thought to arise via the location of economic activity (Redding and Turner, 2015), the demand for skills (Michaels, 2008), trade patterns (Donaldson 2018; Duranton et al., 2014), urban growth and market access (Duranton and Turner 2012; Banerjee et al., 2012), and via positive benefits from agglomeration economies (Venables, 2007; Graham, 2007).

However, the evaluation of the effect of aviation on economic performance remains understudied. This is because modeling the causal relationship between aviation and the economy is a complex task. Air transport is highly endogenous to economic activity, and most existing studies in the field have found identification of causal effects challenging. Consequently, there is a lack of consensus in the existing literature on the magnitude of economic impacts from air transportation. Table 1 summarizes key results found in the literature, which vary by sector, study units and periods. Among the first studies analyzing the economic impact of air transport, Irwin and Kasarda (1991) investigated the effect of extending the airline network of metropolitan areas on economic outputs. They found that a 10% increase in urban aviation centrality/accessibility was associated with a 4.29% increase in employment. Button et al. (1999) and Button and Taylor (2000) used data collected after the 1978 deregulation of the US domestic air transport market to estimate the relationship between air transport and high technology employment. The former paper found a significant and positive effect on technological employment, while the latter found that 1.5 jobs are created for every 1000 air passengers in industries dependent on the quality of local transportation services. These results, however, are derived from associational inference and thus tell us little about the causal economic effect of air transportation.
Italian provinces. He found that a 10% increase in passengers corresponds to a 1% increase in employment in service related industries in US. Percoco (2010) used a similar approach to Brueckner (2003), studying the impact of airports on passenger flow can predict total employment at the metropolitan level, while air cargo activity cannot. However, the exogeneity of instruments is in this case is perhaps hard to demonstrate. Other authors have used historical IVs to deal with the endogeneity problem, a popular approach within the transport literature. Sheard (2014) used the 1944 National Airport Plan to instrument for current distribution of airports. He found that the effect of airport size is positive on the employment of tradeable services, but the effect on total local employment is practically zero. McGraw (2014) used three instruments (collection point locations on the Air Mail system of 1938, a network of emergency air fields in the early years of aviation, and a 1922 plan of airways for US defense) to estimate the effect of airports on population and employment. He found a positive effect ranging between 14.6% and 29% on population growth, and between 14.6% and 29% on employment growth. Bloningen and Cristea (2015) used changes in air traffic resulting from the 1978 Airline Deregulation as an instrument, and found that a 50% increase in an average city’s air traffic growth rate generates an increase of 7.4% in real GDP. All of these studies are focused on developed countries. Among the few studies focused on developing countries, Gibbons and Wu (2017) found that in China, air connections have a positive effect on GDP, especially on the manufacturing sector rather than services. They used military airports from the Second World War as instrument for current airports.

Our paper contributes to this ongoing literature by exploiting the 2003 Chinese air deregulation for causal inference. This policy provides a unique opportunity to test the effects of a significant and exogenous change in air transport on the economy.

3. Aviation and Chinese reforms

This section briefly outlines the regulative history of Chinese aviation, focusing in particular on the background to the 2003 policy deregulation (for comprehensive reviews see Zhang and Chen, 2003; Lei and O’Connell, 2011).

Before 1978, the Chinese central government fully controlled air transport through the Civil Aviation Administration of China (CAAC). The CAAC was made independent from the military in 1987 and six state-owned airlines were created. In addition, local governments were allowed to operate their own airlines, and competition was encouraged. In 1994, foreign capital was permitted for investment in airlines and airports (up to 35% of total ownership), but the CAAC retained control over which airports could use this regulation. In 1997 the CAAC introduced airfare deregulation by encouraging airlines to adopt price discrimination (age discounts or discounts for buying tickets in advance) to improve efficiency. In 2002, the CAAC merged all state owned airlines into “The big three” airlines: Air China, China Eastern and China Southern. Lei and O’Connell (2011) and Wang et al. (2016) argue that this consolidation actually acted as a protectionist measure for the big three against the new local airlines. They further argue that this consolidation negatively affected airline competition in China.

In 2003, the CAAC completed the final transfer of ownership and management of all airports to local governments. This process was called ‘airport localization’. It provided incentives for local governments and private investment from foreign sources to construct and improve airports. According to Winston and de Rus (2009) as a consequence of the airport localization program of 2003, the central government began to phase out its subsidization of airports. This motivated airports to improve significantly their efficiency since the end of subsidization would have made many airports difficult to sustain. Therefore, the policy made airports more financially accountable, and airports started attracting more funds from foreign and private sectors. Overseas investors were allowed to invest in the construction and improvement of airports with a maximum equity interest of 49% (before 2003 it was only 35%, and with the direct control of the CAAC). Chi-Lok and Zhang (2009) also found that the 2003 policy made the airports more efficient, with positive and significant outcomes for airport productivity in terms of passengers and cargo. They performed an OLS analysis on 25 major Chinese airports from 1995 to 2006, in which the dependent variable was an airport efficiency score (built between 0 and 1 through a non-parametric technique known as Data Envelopment Analysis). They included as controls a dummy variable to take into account the airport localization program, as well as other characteristics like population, hub status, local economy, tourism, merger of airlines, and the open skies agreement between USA and China in 2005. They found that the airport localization program was one of the major drivers of efficiency.
Shortly after the implementation of the airport localization program of 2003, other regulations in air transportation took place in China. In 2004, the ‘Regulation on Domestic Investment on Civil Aviation’ allowed for the emergence of private airlines from 2005 onwards (Zhang and Zhang, 2016). By the end of 2008, 14 new carriers had been approved (Lei and O’Connell, 2011). Eventually, Tibet would also get its own airline, in 2010, but this does not affect our analysis since we perform our analysis up to 2007. Another important aviation policy that took place after the airport localization program was the open skies between USA and China called ‘Sino-US Expansion of Aviation Services Agreement’ of 2005 (Wang et al., 2019).

We acknowledge that it is not possible to entirely disentangle the effects of these three regulations, but we consider the airport localization program of 2003 is the main driver of our results for the following reasons: First, Chi-Lok and Zhang (2009) found that the airport localization program of 2003 is one of the main drivers of airport efficiency, even after controlling for the open skies agreement and airline competition. Second, the sudden and substantial increase of air transport in terms of passengers and cargo from 2003 coincides with the implementation of the airport localization program, while the effects of the airline deregulation started to take effect on 2005. And finally, Tibet was deliberately left out of the airport localization program, and the divergence in air transportation between Tibet and the rest of China started in 2003, as we will see below.

The 2003 localization policy was applied in all provinces of China, except Beijing and Tibet, and it resulted in dramatic increases in passengers and cargo activity. This effect is illustrated in Fig. 1, which compares the post 2000 evolution of passengers and cargo volumes (measured in metric tons) in Tibet, relative to the average for all Chinese provinces, using data obtained from the CAAC.\footnote{We use data from the 100 busiest airports in China each year, from 2000 to 2011.} Before 2003, trends for both passenger and cargo were similar for Tibet and the rest of China, especially for passenger volumes. By 2002, passengers and cargo in Tibet were 1.34 and 1.17 times higher than in year 2000, while the averages of all the other provinces were 1.27 and 1.30 higher. But after the policy was implemented, passenger and cargo in Tibet grew at a much lower rate. By 2007, passengers and cargo in Tibet were 2.42 and 1.51 times higher than in year 2000, while the averages of all the other provinces were 3.45 and 2.72 higher.

The change in trend in Tibet relative to the average of Chinese provinces from 2003 onwards is remarkable, and is not driven by particular provinces. This can be seen in Fig. 2, which plots the evolution of air passengers and cargo for each of the 30 provinces in China. Tibet is represented in black, while the others provinces are represented in grey dotted lines. Tibet was among the top 10 provinces in 2002 in terms of passenger growth, and it was close to the median in cargo growth. However, by 2007, Tibet became one of the provinces with lowest growth in terms of both passenger and cargo. The change in the trend from 2003 for all the others provinces is clear.

4. Data and methods

4.1. Data

To implement the SCM we require data to construct a SCR that closely resembles relevant economic characteristics of the treated region, before the treatment was applied. Following Abadie and Gardeazabal (2003), we selected economic characteristics that are predictors of future economic growth: the education level of the
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population, investment, trade, and the sectoral decomposition of GDP. As a proxy for education we considered the percentage of population with primary studies, since before 2002 most of the educated population in China had at most primary studies. Including the percentage of illiterate population does not change our results, and the inclusion of higher level of education considerably worsens the SCR fit. As a proxy for investment, we have selected gross capital formation over GDP. For trade, we use the sum of total foreign exports and imports over GDP. Our results do not change significantly if we consider separately exports and imports. We decompose GDP into primary, secondary and tertiary sectors. Lastly, we add real growth of GDP and GDP per employee, where GDP is price adjusted and measured in 1995 Yuan. We have examined the consequence of including additional regional characteristics such as density or tourism per capita, and our main results do not change. All of the data has been collected from the National Bureau of Statistics of China. After creating the synthetic Tibet, we compare the evolution of our variable of interest in the synthetic region with respect to the treated region. In our benchmark exercise, the variable of interest is labour productivity, measured as GDP per employee. In the Appendix, we perform two additional exercises in which the variables of interest are air passengers and cargo.

Since the Tibet unrest of March 2008 could affect our results, we conduct our analysis up to the year 2007. In 2008, Chinese authorities temporarily closed Tibetan airports from March to July. The negative effect on air transport was huge, as Fig. 3 reveals. But we cannot use this event to analyse the effect of air transportation in the economy, since the Tibetan unrest could have affected the Tibet economy in ways other than restricting air transport.

It is important to note here how relevant aviation is for Tibet. Tibet has a high volume of air passengers per inhabitant. The average aviation passenger per capita in Tibet for the period 2000–2002 is 0.21, while for the rest of provinces in China is 0.11. Moreover, the total number of air passengers over all modes (rail, water, highways and air) is much higher in Tibet that for the rest of China, as shown in Table 2 below. In 2007, air transport captured 9.4% of mode share in Tibet while for the rest of China it represented only 0.8%. These data emphasize the potential important of aviation activity for Tibet’s economic performance.

4 Excluding the municipalities.

Fig. 3. (a) Passengers, reference year 2000, (b) Cargo, reference year 2000.

Table 2
Aviation in Tibet relative to the rest of China, 2007.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Tibet</th>
<th>China</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage of air passengers</td>
<td>0.094</td>
<td>0.008</td>
</tr>
<tr>
<td>Percentage of railway passengers</td>
<td>0.147</td>
<td>0.060</td>
</tr>
<tr>
<td>Percentage of highway passengers</td>
<td>0.759</td>
<td>0.912</td>
</tr>
<tr>
<td>Percentage of waterway passengers</td>
<td>0.000</td>
<td>0.010</td>
</tr>
</tbody>
</table>

Fig. 4. Regions in synthetic Control.

4.2. Synthetic control method

We adopt the synthetic control method introduced by Abadie and Gardeazabal (2003) and Abadie et al. (2015) to create a synthetic Tibet formed as a weighted average of available control regions (i.e. Chinese provinces where the 2003 policy was implemented). Let J be the number of available control regions and let K be the number of economic characteristics. We assign a weight to each control region. These weights are chosen so that the synthetic region better approximates the economic characteristics of the treated region. The optimal J × 1 vector of weights \( W = (w_1, ..., w_J) \) is obtained from the following minimization problem:

\[
\text{Minimise} \sum_{i} \left( X_{i1} - X_{i0}W \right)^{'} V \left( X_{i1} - X_{i0}W \right)
\]

such that
where \( X_1 \) is a \( K \times 1 \) matrix containing all the economic characteristics of the treated region and \( X_0 \) is the \( K \times J \) vector containing the economic characteristics of the control regions. The solution to this problem is a vector of optimal weights \( W^* \), which should add up to one.

The optimal vector depends on \( V \), a \( K \times K \) diagonal matrix that assigns weights to each economic characteristic. We choose the matrix \( V \) so that the variable of interest in Tibet is best replicated by its synthetic counterpart before 2003. Let \( T_p \) be the number of years observed previous to the treatment. The problem of choosing \( V \) can be specified as follows:

\[
\min_V \quad \frac{1}{V} (Z_1 - Z_0 W^*(V))' (Z_1 - Z_0 W^*(V))
\]

where \( Z_1 \) is a \( T_p \times 1 \) vector with a time series of the variable of interest in the treated region, and \( Z_0 \) is a \( T_p \times J \) vector with a time series of the variable of interest in the control regions.

Once we have built our SCR, we compare its evolution with respect to the treated region during the years following the treatment. Let \( T \) be the number of years observed after the treatment. We are interested in the gap between the treated region and its synthetic analogue:

\[
Y_1 - Y_0 W
\]

where \( Y_1 \) is a \( T \times 1 \) vector with a time series of the variable of interest in the treated region for the post treatment years, and \( Y_0 \) is a \( T \times J \) vector with a time series of the variable of interest in the control regions for the post treatment years.

### 4.3. Differences in differences

We complement our main SCM analysis with a differences in differences specification of the effect of the 2003 deregulation on GDP per employee, passengers and cargo.

![Fig. 5. (a) Passengers in synthetic Tibet and Tibet (b) Cargo in synthetic Tibet and Tibet.](image)

![Fig. 6. (a) Synthetic Tibet and Tibet, (b) Difference with synthetic Tibet.](image)
Y_{st} = \alpha_s + \lambda_t + \delta(T_{st}D_{st}) + X'_{st} + \epsilon_{st} \tag{3}

where \(Y_{st}\) is the variable of interest (productivity measured as GDP per employee, or passengers and cargo) in province \(s\) at time \(t\), \(\alpha_s\) and \(\lambda_t\) are state and time fixed effects, \(D_{st}\) is a dummy variable that takes a value of one if \(t > 2002\) during the intervention periods, \(T_{st}\) is a dummy that equals one if the province \(s\) is Tibet, \(\epsilon_{st}\) is a random error term, and \(X'_{st}\) is a vector the following covariates: percentage of population with primary studies, gross capital formation over GDP, trade over GDP, primary sector over GDP and secondary sector over GDP.

The key parameter of interest is \(\delta\), which measures the causal effect of the aviation deregulation policy on labour productivity and air transport. To obtain an unbiased estimate of this parameter, the treatment must be independent of the error term. As mentioned previously, we argue that Tibet’s economic determinants are uncorrelated with the fact that Tibet did not have access to the deregulation policy.

5. Results

5.1. Benchmark exercise: Synthetic Tibet

In Table 3 and Fig. 4 we show the regions that constitute the synthetic control region for Tibet in our benchmark exercise, when the variable of interest is GDP per employee. The synthetic Tibet is a weighted average of Guizhou (51%), Hunan (27.6%) Inner Mongolia (16.4%), and Qinghai (04.3%). Table 4 compares the economic characteristics of Tibet with the SCR and the average of all available controls in China. The values are the averages of economic characteristics between 1997 and 2002. Matching the economic characteristics of Tibet is a complex task. Tibet is the second largest region in China and the least populated. Compared with the rest of China, it has low GDP per employee (measured in Yuan at constant prices, 1995) and the primary...
sector represents a high percentage of GDP. Furthermore, it has an unusually low percentage of secondary sector GDP and high percentage of services. Finally, the population has low educational attainment (42% of the population has only primary school studies) and trade does not play an important role compared to the average of China provinces.

The synthetic Tibet performs much better than a simple average of Chinese provinces in terms of GDP per employee, growth of GDP, primary sector, investment, education and trade. But it cannot match the percentage shares of industry and services. The regions, weights, and main conclusions of the paper do not change significantly if we drop the secondary and service sector share variables. In fact, the omission of those variables improves the fit of the synthetic model and reduces the minimum squared error in equation (2).

5.2. Air transport in Tibet vs Synthetic Tibet

Fig. 5a and b compare the post 2000 evolution of passengers and cargo volumes (measured in metric tons) in Tibet (red dotted line), relative to our benchmark SCR (blue line). Before 2003, the evolution of air transport was similar in Tibet and its SCR, especially in terms of passengers. After 2003, there is a significant difference. By 2007, one year before the Tibet unrest, passengers in SCR were 2.66 higher and cargo was 1.94 times higher than in 2002, while in Tibet passengers and cargo were 1.80 and 1.29 higher than in 2002. We can then compute which would have been the level of passengers and cargo in Tibet if it had experienced the growth in passengers and cargo of its SCR from 2002 to 2007. The result is that passengers and cargo in Tibet would have been 48% and 50% higher respectively. In order to test this result, in the Appendix we build two new synthetic control regions in which the variable of interest are number of passengers and cargo respectively, instead of GDP per employee. This way we can compare air transport in Tibet with synthetic regions that match perfectly the air transport behaviour in the pre-treatment years. The result is that, by 2007, passengers and cargo in SCRs are 50% and 52% higher than in Tibet.

5.3. Synthetic analysis of the effects on GDP per employee

In Fig. 6a we show the evolution of GDP per employee in synthetic Tibet which the policy was implemented. Synthetic Tibet provides an excellent fit for productivity in Tibet prior to 2003. After 2003, productivity in Tibet is lower than in its synthetic counterpart. We find that, by 2007, GDP per employee is 19% lower in Tibet than in the SCR. This can be observed in Fig. 6b, which shows the percentage difference in GDP per employee between synthetic Tibet and Tibet. Thus, from or synthetic control analysis we get a strong indication that differences in air transport behaviour between Tibet and the SCR, are key in explaining differentials in GDP per employee post 2003. In the next section we perform a series of robustness tests, which also show a substantial positive effect, although of lower magnitude, of air transportation on GDP per employee. Therefore, we consider the results of this section as an upper bound of the positive effects of air transportation on the economy.

5.4. Robustness tests

The weights on regions and variables are chosen so that the synthetic region best replicates the variable of interest in the treated region pre-treatment. Consequently, we expected to find a bigger gap between the regions and its synthetic counterparts after the treatment year. How significant are the differences we found between Tibet and synthetic Tibet? To address this question we perform several robustness checks.

First, we apply the same SCR method to all available provinces in China. We expect to find a good fit before 2003, and some difference in GDP per employee between regions and their synthetic regions after 2003.\(^5\) We plot the difference in GDP per employee between all regions and their synthetic counterparts in Fig. 7. The orange line represents the difference between Tibet and synthetic Tibet, and is the same result as observed in Fig. 6b. The grey lines represent each one of the other 30 provinces in China. Most of the synthetic regions provide a good fit for productivity prior to 2003. The fit for Tibet is one of the best. After 2003, the percentage difference between regions and synthetic regions increase for all provinces. By 2007, the negative effect in Tibet is clearly the lowest of all.

As a further placebo test, we focus our analysis on some particular regions. We apply the synthetic control method to the neighbouring regions of Tibet. These are Qinghai (which is included among the synthetic Tibet), Sichuan, Xinjiang and Yunnan (see Fig. 8). These are among the least populated and largest provinces in China (Qinghai, Xinjiang and Tibet are the 3 biggest provinces, and the 3 with lowest density). The SCR results are shown in Figs. 9 and 10. The behaviour of GDP per employee in the regions and their synthetic regions is almost identical before and after 2003.

Finally, in our robustness tests we consider the influence of the particular weighted used to construct the SCR. In our main analysis, synthetic Tibet is formed using four regions: Guizhou (51%), Hunan (27.6%), Inner Mongolia (16.4%), and Qinghai (94.3%). This combination of provinces is the one that delivers the better fit for GDP per employee before 2003, i.e. the lower error for equation (2). However, it is useful to consider the extent to which our main results could be driven by a particular weighted province. Since our SCR is made by four regions, if one of the four regions has an unusual behaviour (such as uncommon growth or decline) then the results could be driven by that particular region. To do so, we conduct robustness tests which drop each of the regions of the synthetic group. This is done at the expense of a higher error in the fit of the variable of interest. After performing those exercises, we found that the only province whose absence can significantly alter our results is Inner Mongolia. Inner Mongolia is a region that performs particularly well in terms of GDP per employee after 2003. For this reason, if we remove Inner Mongolia from the analysis, the difference between Tibet and synthetic Tibet is necessarily lower than in our benchmark exercise. Fig. 11a shows the evolution in GDP per employee in Tibet (black line), in the benchmark SCR (dotted black line), and a SCR that does not include Inner Mongolia (grey line).

The SCR without Inner Mongolia also provides a very good fit before treatment, although the error is 12% larger than in our main analysis, because it does the match for GDP per employee is poor for the year 2002. The fit of the economic characteristics is also worse in the SCR without Inner Mongolia. After 2003, GDP per employee is higher in the SCR without Inner Mongolia than in Tibet, although this difference is smaller than in our benchmark exercise. This can be seen in Fig. 11b, which plots the difference between Tibet and its synthetic counterpart including Inner Mongolia (orange line) and not including it (dotted grey line). By 2007, the difference with Inner Mongolia is 19%, while if we do not include Inner Mongolia it is 7.2%. We should take into account that the gap between Tibet and Synthetic Tibet in the model without Inner Mongolia was positive in 2002 and 2003, around 2%, so the negative effect of the deregulation policy on GDP per employee in that model is 9%. In any case, we interpret this exercise as a lower bound on the gap in GDP per employee between Tibet and synthetic Tibet. Removing any other region (Guizhou, Hunan or Qinghai) instead of Inner Mongolia, slightly amplifies the results that we found in section 5, but also yield a lower pre-treatment fit than the benchmark model. The fact that, regardless of which region we remove from the SCR, the SCRs labour productivity is always between 9% and 19% higher than Tibet shows that the positive economic effect of deregulation is robust.

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\(^5\) The average of trade over GDP in China is heavily influenced by Beijing, Shanghai and Tianjin.

\(^6\) In the Appendix we perform the same analysis for passengers and cargo.
In order to complement our results from the synthetic control analyses, we have estimated the DID specification shown in equation (3). We have estimated three such models with the logarithm of GDP per employee, passengers, and cargo as dependent variables. Regressions have been conducted for the period 1995 to 2007. The regressors include gross capital formation over GDP, exports and imports over GDP, percentage of the population with primary studies, and percentage of primary sector over GDP. We define Tibet as the treated province, and all Chinese provinces as control units, excluding the municipalities. The results from this analysis confirm our main results obtained with the SCM, and are summarized in Table 5.

We find a negative average treatment effect on GDP per employee, passengers and cargo, significant at 1%. The magnitude of the effect is very similar to the results obtained with the SCM. On average, we find that not having access to the deregulation policy had a negative effect of 49% on passengers and of 68% on cargo. These estimates are in line with the results obtained with the SCM, where we found that, by 2007, passengers and cargo where 48% and 52% lower in Tibet with respect its SCR.

In this paper we contribute to the literature by conducting a novel causal analysis of the effects of air transportation on the economy. We do so by exploiting a policy intervention in the form of 2003 deregulation of the Chinese aviation sector, which was applied in all provinces of China except Beijing and Tibet. We use the exogenous variation generated by this policy to undertake a case study of the economic impacts of air transportation on regional productivity.

Our results show that the deregulation policy caused a dramatic growth in air passengers and cargo volumes from 2003 onwards. We find that, from 2003 to 2007, GDP per employee was significantly lower in Tibet than it otherwise would have been, ceteris paribus, due to exclusion from aviation deregulation. We perform our main analysis with synthetic control methods (SCM), and we complement it with a differences-in-differences specification and a set of robustness tests involving placebo tests, which supports the robustness of our main results.
Causality between air transport and the economy has proven hard to demonstrate because such relationship tend to be highly endogenous. Our contribution to the literature is that we tackle the problem of causality by exploiting a unique scenario created by the 2003 deregulation in China, in which Tibet was excluded for reasons other than economic reasons. Unfortunately, we cannot identify the exact mechanism through which air transport influenced labour productivity (air transport can boost productivity due to the expansion of markets, promotion of competition, or greater access to access to a wider pool of skilled labour, among other mechanisms). Another limitation is that we cannot perfectly separate the effects of the 2003 deregulation from the possible effects of other air regulations that came immediately after in 2004 and 2005 in China.

However, in our paper we have shown reasons that make us believe that the 2003 deregulation is the main driver of our results.

Our findings indicate that increasing air transport capacity, in terms of air passengers and air cargo, has a significant effect on the economy. This implies that there are incentives for policymakers around the world to invest in the aviation sector as the economic returns of these policies would be of larger magnitude. Throughout this article we have summarized some of the policies that can develop the aviation sector and increase the volume of passengers and cargo: Encourage airports to be more financially accountable and efficient, allow regional governments to invest in infrastructure (e.g., airport extensions), regulate properly of entry and exit of airlines, and the creation of open skies agreements. Future studies could explore the effect of different types of regulations on air transport, identifying the main mechanisms through which air transport causes productivity increases, and study the possible negative consequences in terms of environmental impact. Our work also illustrates how regulation can create a more favorable environment for companies and the economy. Up to 2003, Chinese airports were heavily subsidized and controlled by central authorities, as was the entry and exit of airlines. The immense and sudden increase in aviation from 2003 highlights the importance of proper regulation.

**Authorship contributions**

Jose M. Carbo: Conception and design of study, Acquisition of data, Analysis and/or interpretation of data, Drafting the manuscript, Revising the manuscript, Approval of the version of the manuscript to be published.

Daniel J. Graham: Conception and design of study, Analysis and/or interpretation of data, Drafting the manuscript, Revising the manuscript, Approval of the version of the manuscript to be published.

**Appendix**

**Synthetic analysis of aviation activity**

To establish whether the deregulation policy really did have an impact on aviation activity, we build two new SCRs for Tibet, one for passengers and one for cargo, using the set of covariates described in section 4.1. Table 7 and Fig. 12 show the regions that constitute the SCRs for Tibet when the variables of interest are passenger and cargo volumes. Table 8 compares the economic characteristics of Tibet with the SCRs. The economic characteristics are averaged for the period 2000 to 2002. Again, the new SCRs for Tibet perform much better than a simple average of Chinese provinces in terms of passengers, cargo, GDP per employee, education and trade, although they do not manage to match the sectoral decomposition. As in our benchmark exercise, the regions, weights, and main results of this exercise do not change if we drop the secondary and service sector share variables.

**Table 7**

<table>
<thead>
<tr>
<th>Provinces</th>
<th>Passengers</th>
<th>Cargo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Guangxi</td>
<td>0.000</td>
<td>0.050</td>
</tr>
<tr>
<td>Guizhou</td>
<td>0.057</td>
<td>0.027</td>
</tr>
<tr>
<td>Inner Mongolia</td>
<td>0.000</td>
<td>0.153</td>
</tr>
<tr>
<td>Jiangxi</td>
<td>0.082</td>
<td>0.759</td>
</tr>
<tr>
<td>Qinghai</td>
<td>0.824</td>
<td>0.000</td>
</tr>
<tr>
<td>Sichuan</td>
<td>0.036</td>
<td>0.011</td>
</tr>
<tr>
<td>Zhejiang</td>
<td>0.001</td>
<td>0.000</td>
</tr>
</tbody>
</table>

**Table 8**

<table>
<thead>
<tr>
<th>Variables</th>
<th>Tibet</th>
<th>SCR for air passengers</th>
<th>SCR for cargo</th>
<th>China</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passengers</td>
<td>583128</td>
<td>587004</td>
<td>4668009</td>
<td></td>
</tr>
<tr>
<td>Cargo</td>
<td>7893</td>
<td>7918</td>
<td>109719</td>
<td></td>
</tr>
<tr>
<td>GDP per employee</td>
<td>9342</td>
<td>11005</td>
<td>10916</td>
<td>18871</td>
</tr>
<tr>
<td>Growth GDP</td>
<td>0.111</td>
<td>0.102</td>
<td>0.860</td>
<td>0.092</td>
</tr>
<tr>
<td>Primary Sector</td>
<td>0.275</td>
<td>0.159</td>
<td>0.185</td>
<td>0.187</td>
</tr>
<tr>
<td>Secondary Sector</td>
<td>0.223</td>
<td>0.425</td>
<td>0.415</td>
<td>0.436</td>
</tr>
<tr>
<td>Service Sector</td>
<td>0.502</td>
<td>0.416</td>
<td>0.400</td>
<td>0.377</td>
</tr>
<tr>
<td>Investment</td>
<td>0.380</td>
<td>0.600</td>
<td>0.381</td>
<td>0.435</td>
</tr>
<tr>
<td>Primary School</td>
<td>0.405</td>
<td>0.384</td>
<td>0.419</td>
<td>0.357</td>
</tr>
<tr>
<td>Trade</td>
<td>0.068</td>
<td>0.057</td>
<td>0.067</td>
<td>0.259</td>
</tr>
</tbody>
</table>

Fig. 13 shows the evolution of passengers and cargo for Tibet and its synthetic region. Before 2003, the SCRs manage to replicate almost perfectly the behaviour of Tibet. However, after 2003, the difference is very significant. Passengers and cargo grew at a much more rapid rate in the SCRs. By 2007, the difference is approximately 50% in both passengers and cargo volumes. The difference for cargo was almost of 100% for 2004 and 2005. These results provide a strong indication that deregulation had large scale positive impacts on volumes of aviation activity.
Robustness cargo and passengers

In this subsection we conduct a similar robustness test to the one performed in section 5 for GDP per employee. We apply the SCM to all the provinces, using passenger and cargo volumes as the variable of interest. We plot the difference in the variables of interest between all regions and their synthetic counterparts in Fig. 14. The orange line represents the difference between Tibet and synthetic Tibet. The grey lines represent each one of the other 30 provinces in China. Most of the synthetic regions provide a good fit for passengers and cargo prior to 2003. Fits for Tibet are again among the best. After 2003, the percentage difference between regions and synthetic regions increase for all provinces. By 2007, the negative effect in Tibet is clearly the lowest of all in passengers, and one the lowest for cargo.

China’s National Trunk Highway System expansion

One of the main threats to the identification of our casual estimate is the huge expansion in highways infrastructure that took place in China, from 2004 onwards. This expansion happened almost simultaneously with the deregulation of aviation of 2003. Between 2004 and 2007, the length of expressways and highways in the country increased by a factor of 1.77, according to data collected from National Bureau of Statistics of China. The length of highways almost doubled in just three years. In Fig. 15 we show the post 2001 evolution of the length of highways in all Chinese regions, relative to their value in 2001⁹. Tibet is represented in black, while the others provinces are represented in grey dotted lines. It can be seen that the length of the highways increased considerably for most provinces, and Tibet was among the provinces that received more investments through the plan. Consequently, the highway expansion cannot explain the difference in labour productivity between Tibet and the control regions that we found in section 5.

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⁹ We take into consideration the length of all expressways and Class I to IV highways. Highways below class IV are local roads, and since 2005 its data includes village roads. We disregard highways below class IV because there is a break in the data between 2004 and 2005.
References


Fig. 14. (a) Percentage difference in passengers (b) Percentage difference in cargo.

Fig. 15. Length of highways.

Wang, Jiaoe, Yang, Haoran, Wang, Han, 2019. The evolution of China’s international aviation markets from a policy perspective on air passenger flows. Sustainability 11 (13), 3566.
