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History and Industry Location: Evidence from German Airports

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Abstract
A central prediction of a large class of theoretical models is that industry location is not necessarily uniquely determined by fundamentals. In these models, historical accident or expectations determine which of several steady-state locations is selected. Despite the theoretical prominence of these ideas, there is surprisingly little systematic evidence on their empirical relevance. This paper exploits the combination of the division of Germany after the Second World War and the reunification of East and West Germany as an exogenous shock to industry location. We focus on a particular economic activity and establish that division caused a shift of Germany's air hub from Berlin to Frankfurt and there is no evidence of a return of the air hub to Berlin after reunification. We develop a body of evidence that the relocation of the air hub is not driven by a change in economic fundamentals but is instead a shift between multiple steady-states.

Keywords: Industry Location, Economic Geography, German Division, German Reunification
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1. Introduction

A central prediction of a large class of theoretical models is that industry location is not necessarily uniquely determined by fundamentals. While these ideas date back to at least Marshall (1920), they have recently returned to prominence in the theoretical literature on new economic geography that has emerged following Krugman (1991a).[1] These models predict that there are ranges of parameter values where there are several steady-state spatial distributions of economic activity. Which of these steady-states is selected depends on either initial conditions and the history of shocks or agents' expectations.[2] This contrasts with the view that fundamentals, such as institutions and endowments, are the primary determinants of location choices. In such a world, there is a unique steady-state distribution of economic activity, which the economy gravitates back to after temporary shocks.

The existence of multiple steady-state distributions of economic activity is not only of theoretical interest but also has important policy implications. In this class of models, small and temporary policy interventions can have large and permanent effects by shifting the economy from one steady-state to another. These ideas have reinvigorated debates about regional and industrial policy. They appear to offer the prospect that temporary subsidies or regulations can permanently alter the long-run spatial distribution of economic activity, with important consequences for the welfare of immobile factors.

While there is some anecdotal evidence that industrial location is not uniquely determined by fundamentals, as discussed for example in Krugman (1991c), there is a surprising lack of systematic empirical evidence in favor of multiple steady-state distributions of economic activity. On the contrary, in a seminal paper, Davis and Weinstein (2002) examine the Allied bombing of Japanese cities as a large and temporary shock that varies substantially across locations. Surprisingly, they find that city populations recovered very quickly from the war-time shock and cities return to their pre-war growth path within less than 20 years. If even the vast

[1] See Fujita *et al.* (1999) and Baldwin *et al.* (2003) for syntheses of the theoretical literature and Overman *et al.* (2003) and Head and Mayer (2004a) for surveys of the empirical literature. Recent contributions to the empirical literature include Amiti and Cameron (2007), Davis and Weinstein (2003), Ellison and Glaeser (1997), Hanson (2004, 2005), Head and Mayer (2004b), Redding and Venables (2004), and Redding and Sturm (2005).

[2] The role of initial conditions and historical accident in selecting between steady-states is also referred to as "path dependence" or "hysteresis" (see for example Arthur 1994, Baldwin and Krugman 1989 and David 1985), while the role of expectations in selecting between steady-states is sometimes described in terms of "co-ordination failures" (see for example Cooper and John 1988, Murphy, Shleifer and Vishny 1989 and Shleifer 1986). See also Krugman (1991b) and Matsuyama (1991).

wartime devastation of cities observed in Japan cannot move the economy between multiple spatial configurations of economic activity, this appears to suggest an overwhelming role for fundamentals in determining the location of economic activity.

In this paper, we provide new evidence on this question by using the combination of the division of Germany after the Second World War and the reunification of East and West Germany in 1990 as a source of exogenous variation. This natural experiment has a number of attractive features. German division, which was driven by military and strategic considerations during the Second World War and its immediate aftermath, provides a large exogenous shock to the relative attractiveness of locations. Division lasted for over 40 years, and was widely expected to be permanent, which makes it likely that it had a profound influence on location choices. The reunification of East and West Germany in 1990 and the broader opening of the Iron Curtain provides a second shock to the relative attractiveness of locations, which partially reverses the impact of division. We use this combination of shocks to examine whether division resulted in a permanent shift in the location of economic activity from one steady-state to another.

We focus on a particular industrial activity, namely an airport hub, which has a number of advantages. First, there are substantial sunk costs in creating an airport hub. These make the location of the air hub particularly likely to be prone to multiple steady-states, in the sense that once the sunk costs of creating the hub have been incurred there is no incentive to relocate. Second, the existence of multiple steady-state locations may be reinforced by network externalities which imply that the profitability of operating a connection to an airport is likely to be increasing in the number of other connections to that airport. Third, a wealth of historical and contemporary data are available on airports and passenger flows.

To guide our empirical work, we develop a simple general equilibrium model of air transportation. In the model the decision whether to create an air hub depends on the trade-off between the fixed costs of operating direct connections and the longer distances of indirect connections. In addition, there are sunk costs of creating an air hub. The economic fundamentals that determine the attractiveness of a location for the hub are its population and bilateral distances to other locations. If the variation in the economic fundamentals is not too large relative to the sunk costs, the model exhibits multiple steady-states.

Our basic empirical finding is that division led to a shift in the German air hub from Berlin to Frankfurt and there is no evidence of a return of the air hub from Frankfurt to

Berlin after reunification. The shares of Berlin and Frankfurt in overall passenger traffic are almost exactly reversed between the pre-war and division periods. In 1937 Berlin and Frankfurt accounted for 30.8 and 9.5 per cent of the passenger traffic in pre-war Germany, while in 1988 they accounted for 8.4 and 36.5 per cent of the passenger traffic of West Germany. Since re-unification, Berlin's share of overall passenger traffic exhibits a slight negative trend, while Frankfurt's share has marginally increased. We use simple difference-in-differences estimates to show that the treatment effect of division on the location of the hub is highly statistically significant, but there is no statistically significant treatment effect of reunification.

While this evidence is suggestive of multiple steady-state locations, the observed relocation of Germany's air hub from Berlin to Frankfurt could be instead driven by a change in economic fundamentals. In particular, reunification may not have sufficiently reversed the impact of division to make Berlin again a viable potential equilibrium location for the air hub. To rule out this alternative explanation, we present a number of additional pieces of evidence. First, we compare the experience of Germany to that of other European countries. Data on the location of the largest airport prior to the Second World War and today show – with the exception of Germany – a remarkable stability over time. Furthermore, in all European countries but Germany, the air hub is located in the country's largest city at both points in time. This suggests that the location of Germany's hub is very unusual and that its relocation is not part of wider secular changes in airport location.

Second, we use a gravity equation based on the theoretical model to show that Frankfurt's current dominance of Germany's air traffic cannot be accounted for by a superior location relative to destinations worldwide. Third, we decompose the stream of departing passengers into local passengers and several types of transit passengers. We show that, while local passenger departures are related to local population and GDP as suggested by the theoretical model, Frankfurt's dominance is entirely accounted for by its role as a transit hub. Finally, we use our empirical estimates to evaluate the implied change in profitability from relocating the air hub to alternative German cities and show that the implied differences in profitability are small relative to plausible estimates of the sunk costs of establishing a hub.

Despite the theoretical prominence of the idea that industry location is not uniquely determined by fundamentals, there is a relatively small empirical literature on this question. Following Davis and Weinstein (2002), a number of papers have examined the impact on bombing on the spatial distribution of economic activity. Davis and Weinstein (2004) show that not only the total population of Japanese cities but also the location of specific industries quickly return to their pre-war pattern. Brakman *et al.* (2004) find that the populations of West German cities recover rapidly from the devastation caused by the Second World War. Similarly, Miguel and Roland (2005) find that even the extensive bombing campaign in Vietnam does not seem to have had a permanent impact on the distribution of population and basic measures of economic development across the regions of Vietnam. Two exceptions are Bosker *et al.* (2006) and Bosker *et al.* (2007), who find some evidence of a permanent change in the distribution of population across West German cities after the Second World War.

While war-related destruction is an ingenious source for a large and temporary shock, a potential concern is that this shock may not be sufficient to change location decisions, which are forward-looking and involve substantial sunk costs. In addition the continued existence of road networks and partially-surviving commercial and residential structures may serve as focal points around which reconstruction occurs. Institutional constraints such as property rights and land-use regulations may also provide additional reasons why existing concentrations of population and industrial activity re-emerge. Finally, even if one observes changes in the location of population, as in Bosker *et al.* (2006) and Bosker *et al.* (2007), it remains unclear whether these are due to secular changes in fundamentals or a move between multiple steady-states.

The remainder of the paper is organized as follows. Section 2 discusses the historical background to German division and reunification. Section 3 outlines a simple model of air transportation which is developed in further detail in the appendix. Section 4 discusses our data and empirical approach. Section 5 presents our basic finding that division permanently relocated the German air hub from Berlin to Frankfurt. Section 6 develops a body of evidence that the relocation of the air hub is indeed a movement between multiple steady-states and is not due to a change in economic fundamentals. Section 7 concludes.

2. Historical Background

In the wake of the Second World War and with the onset of the cold war, Europe was divided by an Iron Curtain between Western and Eastern spheres of influence. This dividing line ran through the centre of pre-war Germany, cutting the country into two areas of roughly equal size.[3] The origins of Germany's division can be traced back to a wartime protocol that organized the country into zones of military occupation. West Germany was founded in 1949 on the area of the American, British and French zones, while East Germany was founded in the same year on the Soviet zone (see for example Loth 1988).

Berlin was situated approximately 200 kilometers to the East of the border between East and West Germany. Due to its status as the capital of pre-war Germany, Berlin was jointly occupied by American, British, French and Soviet armies and for this purpose was divided into four sectors of occupation. With the building of the Berlin Wall in August 1961, the city was firmly divided into West Berlin, which comprised the American, British and French sectors, and East Berlin, which consisted of the Soviet sector (see Sharp 1975). While West Berlin functioned as a de facto part of West Germany, it formally remained under Allied occupation until 1990.

The location of West Berlin as an island surrounded by East German territory raised the problem of access from West Germany to West Berlin. An initial agreement between the Allied and Soviet commanders about access routes broke down in June 1948, when the Soviets blocked rail and road connections to West Berlin. During the ensuing blockade West Berlin was supplied for over a year through the Berlin airlift. A formal agreement on access routes from West Germany was only reached in 1971, with the signing of the Four Power Agreement of September 1971 and the subsequent Transit Agreement ("Transitabkommen") of December 1971. The Transit Agreement designated a small number of road, rail and air corridors and substantially eased East German border controls on road and rail traffic between West Berlin and West Germany.

While division was widely believed to be permanent, the Soviet policies of "Glasnost" and "Perestroika" introduced by Mikhail Gorbachev in 1985 started a process of opening up of Eastern Europe.[4] As part of this wider transformation, large-scale demonstrations in East Germany in 1989 led to the fall of the Berlin Wall on 9 November 1989. In the aftermath of these events, the East German system rapidly began to disintegrate. Only eleven months later

[3] The areas that became West Germany accounted for about 53 per cent of the area and about 58 per cent of the 1939 population of pre-war Germany.

[4] After the signing of the Basic Treaty ("Grundlagenvertrag") in December 1972, which recognized "two German states in one German Nation", East and West Germany were accepted as full members of the United Nations. West German opinion polls in the 1980s show that less than 10 percent of the respondents expected a re-unification to occur during their lifetime (Herdegen and Schultz 1993).

East and West Germany were formally reunified on 3 October 1990. In June 1991 the German parliament voted to relocate the seat of the parliament and the majority of the federal ministries back to Berlin. The broader process of integration between Eastern and Western Europe has continued with the signing of the Europe Agreements in the early 1990s, which culminated in the recent accession of a group of Eastern European countries to the European Union.

3. Theoretical Framework

To guide our empirical research, we outline a simple model of air travel and hub creation, which is discussed in further detail in the appendix.[5] The model formalizes the conditions under which air hubs form and the circumstances under which there are multiple steady-state locations of the hub. We use the model to examine the impact of Germany's division and the reunification of East and West Germany on the location of the air hub.

3.1. Air Travel and Hub Creation

We consider a model with three locations or cities, which is the simplest geographical structure in which a hub and spoke network can form.[6] If a hub forms, it will have direct connections to the other two cities, while travel between these other two cities will occur through an indirect connection via the hub. A monopoly airline chooses whether to operate direct connections between all three cities or to create a hub.[7] The airline faces a downward-sloping demand curve for air travel between each pair of cities derived from the demand for consuming non-traded services from other cities. There is a fixed cost of $F > 0$ units of labor of operating each direct connection and then a constant marginal cost in terms of labor for each return passenger journey which depends on the distance flown. In addition, we assume that there is a sunk cost of $H > 0$ units of labor of creating a hub. The hub itself can be located in any one of the three cities. To make the airline's choice an interesting one, we assume that direct connections are profitable on all three routes.

[5] Our model builds on the literature on the airline industry and on hub formation in networks more broadly. See, for example, Brueckner (2002, 2004), Campbell (1996), Drezner and Drezner (2001), Hendricks *et al.* (1999) and Hojman and Szeidl (2005).

[6] This structure excludes the possibility of multiple air hubs. While the model could be extended to allow for multiple air hubs, we abstract from the additional complications that this would introduce. The empirical evidence presented below suggests that the assumption of a single air hub is a reasonable approximation to the current and historical structure of air travel in Germany.

[7] Introducing multiple air carriers into the model would increase the likelihood of multiple steady-state locations of the air hub due to the network externalities that this introduces.

The airline is assumed to be able to segment the markets for travel between each pair of cities, and therefore chooses the price on a route to maximize profits subject to the downward sloping demand curve for that route. Equilibrium prices are a mark-up over marginal cost and variable profits are proportional to the revenue derived from a route. Since markets are segmented, evaluating the profitability of operating a hub relative to pair-wise direct connections is straightforward. Whether or not there is a hub, two of the three bilateral routes are always served by direct connections. Therefore, the decision whether to create a hub depends on the relative profitability of a direct and indirect connection on the third bilateral route compared to the sunk costs of creating the hub. The per-period difference in profits from locating the hub in city i and serving all three routes with direct connections, denoted ω_i, equals:

$$\omega_i = F - \left(\pi^D_{kj} - \pi^I_{kj}\right) \tag{1}$$

where π^D_{kj} and π^I_{kj} denote variable profits from a direct and indirect connection between cities k and j, and we denote the present discounted value of the difference in profits by Ω_i.

Condition (1) captures a simple trade-off. On the one hand, creating a hub in city i and operating an indirect connection between cities k and j saves fixed costs F. On the other hand, variable profits between cities k and j are lower if the route is served by an indirect connection rather than a direct connection: $\pi^D_{kj} - \pi^I_{kj} \geq 0$. The reason is the higher marginal costs on indirect connections, together with the reduction in the demand for air travel due to any disutility of changing planes on indirect connections, which reduce variable profits on indirect connections compared to direct connections. The larger the fixed cost and the smaller the difference in variable profits between direct and indirect connections, the more attractive will be a hub relative to pair-wise direct connections.

The three cities will generally differ in terms of their attractiveness as a location for the hub. The airline will prefer to maintain direct connections on routes where there is high demand for air travel, namely those between populous cities, cities with a central location and cities whose non-traded services receive a high weight in consumers' utility. The reason is that the reduction in variable profits from operating an indirect rather than a direct connection is larger when the demand for air travel between a pair of cities is greater.

Without loss of generality, we choose to index cities so that lower values of i correspond to more profitable locations for the hub: $\Omega_1 \geq \Omega_2 \geq \Omega_3$. There are multiple steady-state locations of the hub if there are several cities i where it is profitable to create a hub and, once the city is chosen as the hub, there is no incentive to relocate to another city j:

$$\Omega_i > H \qquad \text{and} \qquad \Omega_j - \Omega_i < H \qquad \text{for all } j \neq i \tag{2}$$

In contrast, city i would be the unique steady-state location of the hub if creating the hub in city i is profitable and, if the hub was located in any other city j, there is an incentive to relocate to city i:

$$\Omega_i > H \qquad \text{and} \qquad \Omega_i - \Omega_j > H \qquad \text{for all } j \neq i \tag{3}$$

Therefore, the existence of multiple steady-states depends on the variability in cities' profitability as the location for a hub being sufficiently small relative to the value of sunk costs. When the sunk cost of creating the hub is equal to zero, there is a unique steady-state location of the hub except in the knife-edge case when cities are symmetric. However, if the sunk cost of creating the hub is larger than the difference in profitability between alternative possible locations for the hub, there are multiple steady-states. When multiple steady-states exist, initial conditions determine which is selected. Thus, if cities A and B both satisfy equation (2), city A will be the equilibrium location if the hub is initially located in city A, and city B will be the equilibrium location if the hub is initially located in city B.

3.2. German Division and Reunification

The model can be used to examine the implications of German division and the reunification of East and West Germany. Suppose that the airline has initially located the hub in the city with the most attractive location ($i = 1$). In the empirical analysis below, city one will correspond to Berlin. We model German division as an exogenous shock that temporarily reduces the relative attractiveness of city one as a location for the hub.

The model suggests two main reasons why division reduced the relative profitability of locating the hub in Berlin. First, division substantially reduced the size of the local population, which decreases local demand for air travel. West Berlin not only accounted for just 60 percent of the city's 1939 population, but division also isolated West Berlin from its immediate economic hinterland which was now part of East Germany. Second, the division of Germany and the wider division of Europe as a whole substantially increased the remoteness of Berlin due to its location about 200 kilometers East of West Germany in the middle of East Germany, which left it surrounded by territory East of the Iron Curtain. In addition, access to West Berlin for air traffic from West Germany was restricted to a limited number of air corridors.[8]

The temporary shock of division will shift the location of the hub between multiple steady-states if two conditions are satisfied. First, the impact of division on the profitability of city one, denoted S, is sufficiently large that the increase in profits from relocating the hub from city one to city two is greater than the sunk cost. Second, reunification reverses this shock to a level S' which is sufficiently small that both city one and city two are again possible equilibrium locations after reunification. These conditions are:

$$\Omega_2 - (\Omega_1 - S) > H \qquad \text{and} \qquad |\Omega_2 - (\Omega_1 - S')| < H. \tag{4}$$

Note that we do not require the profitability of city one to completely return to its level prior to division. All we need is that division sufficiently reduces city one's profitability that it is no longer a potential equilibrium, and reunification sufficiently increases city one's profitability that both city one and city two are again potential equilibrium locations.

The two conditions in equation (4) illustrate the difficulties in finding a suitable experiment to provide empirical evidence for multiple steady-state distributions of economic activity. On the one hand, large sunk costs increase the range of parameter values for which multiple steady-states occur. On the other hand, large sunk costs increase the size of the shock required to shift the economy between multiple steady-states.

4. Data and Empirical Strategy

4.1. Data Description

One of the attractive features of airports is that, in contrast to other economic activities which are likely to be prone to multiple steady-state locations, detailed current and historical data are available. Our basic dataset is a panel on departing passengers from the ten main German airports during the pre-war, division and reunification periods. For the pre-war period, data are available from 1927 onwards until 1938. For the period after the Second World War, we have data from 1950, which is the earliest year for which information is available, until 2002.[9]

[8] Although not directly captured by the model, the status of West Berlin as an occupied city until 1990 and the consequent fear that investments in West Berlin could be expropriated is likely to have further reduced the attractiveness of the city as a location for the hub.

[9] The ten main German airports are: Berlin, Bremen, Cologne, Dusseldorf, Frankfurt, Hamburg, Hanover, Munich, Nurenberg, and Stuttgart. Berlin was served by a single airport (Tempelhof) during the pre-war period,

We combine our basic dataset with information from a variety of other sources. To compare the experience of Germany with that of other European countries which were not subject to division, we have collected data on departing passengers from the largest airports in other European countries in 1937 and 2002. To examine the determinants of the relative size of airports, we exploit data for 2002 on bilateral departing passengers between German airports and the universe of worldwide destinations flown to from these airports. These data are available for an additional five German airports.[10] The location of all 15 airports within the boundaries of present-day Germany is shown in Map 1. We combine the bilateral departures data with information on the latitude and longitude co-ordinates of each airport and worldwide destination, which are used to construct bilateral great circle distances.

To explore the importance of local economic activity for the relative attractiveness of different cities as locations for Germany's air hub, we have assembled for 2002 several measures of total population and Gross Domestic Product (GDP) proximate to each airport. Finally, to examine the importance of hub status for the size of airports we have obtained a breakdown of total passenger departures at the main German airports into local and various types of transit traffic. Detailed references to the data sources are in the data appendix.

4.2. Baseline Econometric Specification

Our baseline econometric equation allows for changes in trends and intercepts of airport passenger shares for each airport during the pre-war, division and reunification periods:

$$share_{at} = \sum_{a=1}^{A} \eta_{ap} + \sum_{a=1}^{A} \beta_{ap}\text{time}_t + u_{at} \tag{5}$$

where a indexes airports, t denotes years, and p indicates periods (pre-war, division and reunification). The dependent variable, $share_{at}$, is the share of an airport in passenger traffic in year t. The parameters η_{ap} are a full set of airport-period fixed effects that allow for changes in mean passenger shares for each airport between the pre-war, division and reunification periods. The coefficients β_{ap} allow trends in passenger shares for each airport to also vary between the pre-war, division and reunification periods; u_{at} is a stochastic error.

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and there were two airports in West Berlin (Tempelhof and Tegel) and one airport in East Berlin (Schoenefeld) during division. We aggregate Tempelhof and Tegel during division, and aggregate all three Berlin airports during reunification.

[10] The five additional airports for which bilateral departures data were available in 2002 are Dresden, Erfurt, Leipzig, Munster and Saarbrucken.

In equation (5) we allow both mean levels and trend rates of growth of passenger shares to vary across airports and periods because it may take time for a new hub to emerge in response to an exogenous shock. A change in the location of the hub, therefore, will be first visible in a change in an airport's trend rate of passenger growth before a significant difference in mean passenger levels emerges. This is particularly important for the reunification period where we have a relatively short period of time over which to observe the impact of the exogenous shock. For this reason, we will concentrate below on statistical tests based on changes in airports' trend rates of passenger growth.[11]

5. Basic Empirical Results

5.1. Evolution of Airport Passenger Shares

Before we estimate our basic specification, Figure 1 displays the share of the ten largest German airports in total departures at these airports over the period 1927 to 2002. This graph reveals a number of striking patterns. Before the Second World War Berlin has the largest airport in Germany by a substantial margin and was in fact the largest airport in Europe in 1937. Already in 1927, when our data series starts, Berlin has more than twice as large a market share as the next largest German airport. From 1931 onwards, which is a period of rapid growth in air traffic at all German airports, Berlin's market share steadily increases and reaches a peak of over 40 percent in 1938. The four airports ranked after Berlin are Frankfurt, Munich, Hamburg and Cologne. These airports have very similar market shares, which remain remarkably stable at around 10 percent throughout the pre-war period.[12]

The dominance of Berlin in German air traffic changes dramatically after the division of Germany. While Berlin is still the largest airport in Germany in terms of total departures in 1950, when data become available again, Frankfurt is now already the second largest airport substantially ahead of Hamburg and Munich. Over the next decade Berlin steadily declines in importance and by 1960 Frankfurt overtakes Berlin as the largest German airport.[13] A further

[11] Re-estimating equation (5) only allowing changes in intercepts between the pre-war, division and reunification periods yields a similar pattern of results.

[12] In the pre-war period, the states ("Laender") of Germany held substantial shareholdings in the dominant German air carrier (Luft Hansa AG) and actively sought to promote the development of regional airports such as Cologne, Frankfurt, Hamburg and Munich.

[13] The spike in departures in 1953 in Berlin is mainly due to a wave of refugees leaving East Germany via West Berlin after the violent uprisings in East Germany in June 1953. The Statistical Yearbook of West Germany reports that 257,308 East German refugees left West Berlin by plane in 1953, which accounts for as much as 47

acceleration in the decline of Berlin's share occurs immediately after 1971, when the transit agreement between East and West Germany substantially improved road and rail connections between West Berlin and West Germany. By the 1980s Frankfurt and Berlin have almost exactly changed roles. Frankfurt now has a stable market share between 35 and 40 percent, while Berlin's market share has declined to just below 10 percent.[14]

In contrast to the striking change in the pattern of air traffic following division, there is hardly any visible impact of reunification. There is a small step-increase in Berlin's share of passenger traffic. This is due to the re-integration of East and West Berlin, so that total departures from Berlin are now the sum of departures from Tempelhof and Tegel airports in West Berlin and Schoenefeld airport in East Berlin. If departures from Schoenefeld airport in the East are excluded from total departures for Berlin, there is no visible change in Berlin's passenger share in response to reunification. Apart from this small step-increase, the trend in Berlin's share of passenger traffic is slightly negative after reunification. At the same time Frankfurt clearly remains Germany's leading airport and its share of passenger traffic is virtually flat after reunification, if anything increasing marginally.

Compared to the dramatic change in the relative fortunes of the airports in Berlin and Frankfurt other changes in the pattern of German air traffic appear relatively minor. The change in Berlin and Frankfurt's average shares of passenger traffic between the ten years leading up to 1938 and the ten years leading up to 2002 were -25.6 and 23.9 percent. These compare with a change in the average passenger share for Munich, which has risen to become the second largest German airport, of 3.6 per cent over the same period. The airport with the largest change in average passenger shares after Berlin and Frankfurt is Dusseldorf, which experienced a rise of 10.5 percent. However this increase coincides with a decline of 6.9 percent at the airport in Cologne over the same period, which is only 54 kilometers away from the

percent of total departures in Berlin in this year. This stream of East German refugees departing from West Berlin by plane continues at a rate of approximately 95,000 people per year, which accounts for on average 16 percent of departures in Berlin during 1954-60, and ceases with the building of the Berlin Wall in 1961.

[14]The similarity in the market shares of Frankfurt, Cologne, Hamburg and Munich prior to the Second World War raises the question why Frankfurt, rather than one of these alternative locations, attracted Germany's hub after the war. The most likely reason is the decision of the U.S. military in 1948 to chose Frankfurt as the European terminal for the U.S. Military Air Transport Service (MATS), which made the airport the primary airlift and passenger hub for U.S. forces in Europe. As a result Frankfurt airport became the main airport for the Berlin airlift in 1948-9. During the Berlin airlift, a second runway was constructed at Frankfurt and the airport's facilities were further upgraded. Frankfurt airport therefore seems to have gained an early advantage relative to its main competitors, which led to its subsequent emergence as the new German air hub.

airport in Dusseldorf.[15]

While there is no evidence so far of a return towards pre-war patterns of passenger traffic, is there any expectation of a future relocation of Germany's air hub to Berlin? Berlin plans to open a new airport in 2011 which will replace the current system of three airports which have a capacity of about 7.5 million departing passengers. The new airport is designed to have a starting capacity of approximately 10 million departing passengers. In 2015 Frankfurt airport plans to open a third passenger terminal, which will increase the airport's capacity from its current 28 million departing passengers a year by approximately another 12.5 million passengers.[16] Therefore, over the coming years Frankfurt plans to increase its capacity by an even larger amount than Berlin's overall capacity, which illustrates that there is little expectation of a return of Germany's air hub to Berlin.

5.2. Difference-in-Differences Estimates

To examine the statistical significance of the changes shown in Figure 1, Table 1 reports results for our baseline specification (5). The coefficients on the time trends in each airport in each period capture mean annual rates of growth of passenger shares. The final column of Panel A of Table 2 compares the time trends between the pre-war and division periods for Berlin and Frankfurt (a difference within airports across periods) and shows that Berlin's mean rate of growth of passenger shares declines by 2.7 percentage points per annum, while Frankfurt's rises by 0.4 percentage points per annum. Both these changes are highly statistically significant.[17]

We next consider the statistical significance of the difference in time trends between Berlin and Frankfurt within the pre-war and division periods (a difference within periods across airports). The final row of Panel A of Table 2 shows that within each period the difference in the mean annual rate of growth of passenger shares is in excess of 1 percentage point per annum and is highly statistically significant. Finally, we consider the difference-in-differences, by

[15] We see a similar pattern in freight departures. Following division Frankfurt replaces Berlin as Germany's leading airport for freight and there is again no visible impact of reunification. Berlin's average share in total freight departures falls from 36.5 to 0.7 percent between the ten years leading up to 1938 and the ten years leading up to 2002. Over the same period the average share of Frankfurt increases from 11.2 to 70.6 percent.

[16] These numbers are taken from http://www.berlin-airport.de and http://www.ausbau.flughafen-frankfurt.de. While we report capacity as the number of departing passengers, airports often report their capacity as the sum of arriving and departing passengers, which is simply twice the capacity for departing passengers.

[17] As is evident from Figure 1, the within-airport change in time trends for Frankfurt understates its rise between the pre-war and division periods, since some of the rise in Frankfurt's post-war share of passenger traffic has already occurred prior to 1950 when data become available (and is therefore captured in Frankfurt's intercept for the division period).

comparing the change in Berlin's time trend between the pre-war and division periods to the change in Frankfurt's time trend between the same two periods. The bottom right-hand cell of Panel A of Table 2 shows that this difference-in-differences in mean annual growth rates is over 3 percentage points per annum and is again highly statistically significant (p-value < 0.001).

We now turn to examine the treatment effect of reunification. Figure 1 suggests that the evolution of airport passenger shares during much of the 1950-89 period is influenced by the treatment effect of division, but by the 1980-89 period passengers shares have completely adjusted to the impact of division. Therefore, we estimate an augmented version of our basic specification (5) where we break out the division period into decades, including fixed effects and time trends for each airport in each decade during the division period. To examine the treatment effect of reunification, we compare the 1992-2002 period to the 1980-89 period immediately preceding reunification.

The final column of Panel B of Table 2 shows that the change in both Berlin and Frankfurt's mean annual rate of growth of passenger shares in the periods immediately before and after reunification is close to zero and far from statistical significance. The final row of Panel B of Table 2 shows that there is a small but nevertheless statistically significant difference in the mean rate of growth of passenger shares between Berlin and Frankfurt that is of the same magnitude within the two periods. The lack of a significant change in the within-airport time trends in the final column of Panel B of Table 2 already suggests that reunification had little impact on passenger shares. The difference-in-differences estimate that compares the change in time trends between the two periods for both airports confirms this impression. As reported in the bottom right-hand cell of Panel B of Table 2, the difference-in-differences estimate is close to zero and entirely statistically insignificant (p-value $= 0.854$).

Therefore, the results of estimating our baseline specification confirm the patterns visible in Figure 1. There is a highly statistically significant treatment effect of division on the location of Germany's leading airport. In contrast, there is no evidence of a statistically significant treatment effect of reunification.

6. Are There Really Multiple Steady-States?

While the results in the previous section are suggestive that Germany's air hub has shifted between multiple steady-states, an alternative possible explanation for our findings is that the relocation of Germany's largest airport is driven by changes in economic fundamentals. In particular reunification may not have reversed the impact of division sufficiently for Berlin to again be a potential equilibrium location. In this section, we provide several additional pieces of evidence to strengthen the case that there has indeed been a shift between multiple steady-states. To demonstrate how unusual the changes in Germany's pattern of air-traffic are, we first compare the experience of Germany to that of other European countries. To establish that differences in economic fundamentals are small relative to the sunk costs of creating the hub, we next examine the role played by the various factors emphasized in the theoretical model in explaining Frankfurt's current dominance of German air traffic.

6.1. International Evidence

Table 3 presents information on the structure of airport traffic in other European countries in 1937 and 2002.[18] Column (1) reports the country's largest airport in 1937; Column (2) lists the market share of the largest airport in 1937; Column (3) shows the market share of the largest airport in 2002; and Column (4) reports the rank of the largest 1937 airport in 2002.

The first striking feature of the table is that Germany is the only country where the leading airport in 1937 is not the leading airport in 2002 (Berlin is ranked fourth in 2002). In all other countries, there is a perfect correlation between the past and present locations of the leading airport. The 1937 airport market shares are not only qualitatively but also quantitatively good predictors of the 2002 airport shares. There is a positive and highly statistically significant correlation between the past and present market shares, and we are unable to reject the null hypothesis that the 2002 market shares equal their 1937 values.[19] The remarkable persistence in the location of the leading airport suggests that there is little secular change in the location of such airports. Within the context of our theoretical model, this is consistent with sunk costs being large relative to the variation over time in economic fundamentals.

A second striking implication of comparing Germany with other European countries is that Germany is the only country where the largest airport is not currently located in the largest city. In all other European countries, there is a perfect correspondence between the present-day

[18] The countries are the EU 15, Norway and Switzerland, but excluding Luxemburg, which did not have an airport prior to the Second World War and, due to its size, only has one airport today.

[19] If the 2002 market shares are regressed on the 1937 market shares excluding the constant, we are unable to reject the null hypothesis that the coefficient on the 1937 market shares is equal to one (p-value=0.162).

location of the largest airport and the location of the largest city. Taken together these two findings support the idea that, in the absence of division, the German air hub would be today located in Berlin and that it is at least not obvious that Berlin, which is Germany's largest city by a substantial margin, would not be a possible location for the country's air hub.

6.2. The Role of Market Access

One of the key determinants of the volume of bilateral passengers departures in the theoretical model is an airport's proximity to other destinations. In this section we use a gravity equation to estimate the role played by proximity to destinations in explaining variation in bilateral passenger departures. Under the assumptions specified in the theoretical appendix, the following standard gravity relationship can be derived from the model:

$$\ln(A_{ij}) = m_i + s_j + \varphi \ln(dist_{ij}) + u_{ij} \tag{6}$$

which explains bilateral departures A_{ij} as a function of destination fixed effects (m_i), source airport fixed effects (s_i), bilateral travel costs which we model using distance $(dist_{ij})$ and a stochastic error term u_{ij}.

Using the fitted values from this regression relationship, taking exponents, and summing across destinations, equation (6) can be used to decompose variation in total departures from an airport into the contributions of proximity to destinations (market access, MA_j) and source airport characteristics (source airport fixed effects):

$$\widehat{A}_j = \sum_i \widehat{A}_{ij} = \left[\sum_i dist_{ij}^{\hat{\varphi}} \widehat{M}_i\right] \widehat{S}_j = \widehat{MA}_j \widehat{S}_j \tag{7}$$

where hats denote estimates, $M_i = \exp(m_i)$ and $S_j = \exp(s_i)$. Market access is the distance-weighted sum of the destination fixed effects and summarizes an airport's proximity to destinations worldwide (see Redding and Venables 2004 for further discussion in the context of international trade). Finally, choosing one airport as the base, percentage differences in total departures can be expressed as the sum of percentage differences in market access and percentage differences in source airport characteristics:

$$\ln\left(\frac{\widehat{A}_j}{\widehat{A}_b}\right) = \ln\left(\frac{\widehat{MA}_j}{\widehat{MA}_b}\right) + \ln\left(\frac{\widehat{S}_j}{\widehat{S}_b}\right) \tag{8}$$

where b indicates the base airport which we choose to be Berlin.[20]

To estimate the gravity equation in (6), we use data on bilateral passenger departures from the 15 German airports for which data were available in 2002 to destinations worldwide.[21] We begin with a standard baseline specification from the gravity equation literature, in which we add one to the bilateral departures data before taking logarithms, and estimate the gravity equation (6) using a linear fixed effects estimator. To abstract from substitution from other modes of transport, we focus in the baseline specification on departures to destinations more than 300 kilometers away from any German airport. We discuss the robustness of the results to alternative estimation strategies below.

Table 4 reports the results of the gravity equation estimation. Our baseline specification explains a substantial proportion of the overall variation in bilateral departures, with an R^2 of 0.68, and the source and destination fixed effects are both highly statistically significant (p-values < 0.001). As the destination fixed effects capture any destination characteristic that is common across all German airports, such as average distance from German airports, the distance coefficient is identified solely from the variation in distance induced by airports' differential location within Germany. Nonetheless, we find a negative and highly statistically significant coefficient on distance: a one percent increase in distance travelled is associated with an 1.6% decline in passenger departures, so that doubling distance more than halves bilateral passenger departures.

Figure 2 displays the results of the decomposition on the right-hand side of equation (8). The two bars correspond to log differences in market access and the source airport fixed effects from their respective values for Berlin. The sum of the two bars is by construction equal to the log difference of fitted total departures from the value for Berlin. A striking impression from the figure is that, although market access varies across German airports, its contribution to differences in total departures is dwarfed by that of the airport fixed effects. This suggests that in a comparatively small country such as Germany, which is approximately the size of Montana, airports are sufficiently close together that there is relatively little variation in distance

[20] The fixed effects in the gravity equation are estimated relative to an excluded category and, therefore, their absolute levels depend on the choice of the excluded category. The normalization relative to a base airport in equation (8) ensures that the results of the decomposition do not depend on the choice of excluded category in the gravity equation estimation. As is clear from equation (8), the choice of base airport does not affect relative comparisons between any pair of airports j and i: since $\ln(A_j/A_b) - \ln(A_i/A_b) = \ln(A_j/A_i)$.

[21] We exploit the data on the additional five airports where it is available, but all our results are robust to continuing to focus on the ten main German airports.

to destinations, and so variation in market access is unable to explain Frankfurt's current dominance of German air-traffic.[22]

This basic finding is robust across a wide variety of alternative specifications. First, we re-estimated the baseline specification for departures to all destinations, including those less than 300 kilometers away from any German airport. Second, we re-estimated the baseline specification excluding bilateral connections from Frankfurt, since the coefficient on distance could be different for a hub airport. In both cases, we find that market access makes a minor contribution towards explaining variation in total passenger departures. Third, we also constructed a simpler measure of market potential, based on Harris (1954), where we use aggregate passenger departures from Germany as a whole to each destination as a proxy for the importance of a destination. For each of our 15 German airports we calculate the distance-weighted sum of aggregate German passenger departures to each destination more than 300 kilometers away from any German airport. The variation in this simpler measure of market potential across German airports is again small relative to the variation in total passenger departures.[23] Finally, while the linear fixed effects estimator is widely used in the gravity equation literature, we have also re-estimated equation (6) using a Poisson fixed effects specification (see Silva and Tenreyro 2006). Also in this specification we find that market access contributes little to explaining Frankfurt's dominance of German air travel.

6.3. The Roles of Local Economic Activity and Transit Traffic

Apart from market access the theoretical model suggests two alternative explanations for Frankfurt's dominance in German air traffic. First local economic activity, in particular population and income, influences local demand for air travel. Second the airports' role as a hub mechanically increases counts of departing passengers, as passenger changing planes are also counted as departing passengers. In this section we provide evidence that – while local economic activity influences departures in the way suggested by the model – Frankfurt's dominance is accounted for by its hub status rather than superior local economic activity.

[22] To illustrate this point, consider the distances from Frankfurt and Berlin to the following examples of destinations that are currently only serviced by regular connections from the hub in Frankfurt and the much smaller secondary hub in Munich: New York 6184 and 6364 kilometers, San Francisco 9142 and 9105 kilometers, and Tokyo 9363 and 8936 kilometers, respectively. The average distances from Frankfurt and Berlin to all destinations in the gravity regression are 3818 and 3838 kilometers respectively.

[23] The correlation coefficient between this simpler measure of market potential and our baseline measure of market access from the gravity equation estimation is 0.92 and statistically significant at the 1% level.

To provide empirical evidence on the relative importance of these two sets of considerations, we exploit data on the origin of passengers departing from each German airport. We decompose total passenger departures into the following four components: (i) international air transit passengers, who are changing planes at a German airport on route from a foreign source to a foreign destination; (ii) domestic air transit passengers, who are changing planes at a German airport and have either a source or final destination within Germany; (iii) ground transit passengers, who arrived at the airport using ground transportation, and who travelled more than 50 kilometers to reach the airport; (iv) local passengers, who arrived at the airport using ground transportation, and who travelled less than 50 kilometers to reach the airport.

To undertake this decomposition we combine data on air transit passengers collected by the German Federal Statistical Office with information from a harmonized survey of departing passengers at all major German airports in 2003 coordinated by the German Airports Association. While the disaggregated results of the survey are proprietary data, Wilken *et al.* (2007) construct and report a number of summary results including the share of all passengers commencing their journey at an airport (i.e. the share of non-air transit passengers) who travelled less than 50 kilometers to the airport. This share varies substantially from 85 percent in Berlin to 37 percent in Frankfurt, with an average share of 59 percent across the fifteen airports.

Figure 3 breaks out total departures at the German airports in 2002 into the contributions of these four categories of passengers. Panels A to D display respectively total departures, total departures minus international air transit passengers, total departures minus all air transit passengers, and total departures minus all air and ground transit passengers (i.e. local departures). Total departures in Panel A vary substantially across airports: from 0.2 million in Saarbrucken to nearly 24.0 million in Frankfurt. Simply subtracting international air transit passengers from total departures in Panel B substantially reduces the extent of variation: from 0.2 million in Saarbrucken to 16.4 million in Frankfurt.

Since international air transit passengers are on route from a foreign source to a foreign destination, and are merely changing planes within Germany, this category of passengers seems most closely connected with an airport's hub status. International air transit passengers alone account for around 32 percent of Frankfurt's total departures and Frankfurt accounts for around 82 percent of international air transit passengers in Germany. The only other airport with a non-negligible share of international air transit passengers is Munich, which has developed over the last two decades into a much smaller secondary hub. This category of passengers account for 14 percent of Munich's total departures and its share of international air transit passengers in Germany is 17 percent.

The data on international air transit passengers suggest that Frankfurt's hub status plays a major role in understanding its dominance of German passenger traffic. This conclusion is further strengthened by also subtracting both international and domestic air transit passengers from total departures, as shown in Panel C. International and domestic air transit passengers together account for 49 percent of Frankfurt's total passenger departures and Frankfurt accounts for 75 percent of all air transit passengers in Germany. The corresponding numbers for Munich are 28 percent of the airport's total departures and 20 percent of all air transit passengers in Germany.

Moving to local departures in Panel D (i.e. subtracting both air and ground transit passengers from total departures) entirely eliminates Frankfurt's dominance of German air travel. Local departures originating within 50 kilometers of Frankfurt airport are 4.55 million, compared to 4.23 million for Munich, 4.28 for Dusseldorf and 5.07 million for Berlin. The results of this decomposition therefore suggest that Frankfurt's role as Germany's leading airport cannot be explained by a denser volume of passenger traffic originating from within the 50 kilometer area surrounding the airport, even though this is a densely populated and industrialized part of Germany.

While variation in local departures cannot explain Frankfurt's dominance of German air travel, Figure 4 shows that this category of passengers is closely related to local economic activity, as suggested by the theoretical model. The figure plots the logarithm of the number of passengers originating within 50 kilometers of each airport against the logarithm of GDP within 50 kilometers of each airport, as well as the linear regression relationship between the two variables.[24] The figure shows a tight relationship between local passenger volumes and local GDP. Over 80 percent of the variation in local departures is explained by the regression and the coefficient on local GDP is highly statistically significant.[25] Berlin is the most positive

[24]GDP within 50 kilometers of an airport is calculated from the population of all municipalities within 50 kilometers of the airport and the GDP per capita of the counties ("Kreise") in which the municipalities are located. See the data appendix for further discussion.

[25]The estimated coefficient (standard error) on local GDP are 1.602 (0.239). As a robustness check, we have also regressed local passenger departures on population within 50 kilometers of an airport, and found a very similar pattern of results.

outlier from the regression relationship, and Frankfurt has a lower local GDP than Cologne and Dusseldorf, which are located close to the concentration of economic activity in the Ruhr area.

6.4. The Relative Attractiveness of Alternative Locations for the Hub

The analysis so far suggests that Frankfurt's dominance of German air travel can neither be explained by superior market access nor the concentration of economic activity within 50 kilometers of the airport, but is instead largely due to its role as a transit hub. The theoretical model shows that there will be multiple steady-state locations of the hub if the difference in profitability between alternative locations is small relative to the sunk costs of establishing a hub. In this section, we use our estimates to undertake a simple evaluation of the relative profitability of alternative locations for Germany's air hub. We first construct an estimate of the impact of the relocation of the hub on the total number of departing passengers across the 15 German airports as a whole. To provide a rough estimate of how the relocation of the hub would affect the net present value of profits, we then combine the change in total passengers departures with an estimate of net profits per passenger and an assumption about the net discount rate. Finally, we compare the change in the net present value of profits with plausible values of the sunk costs of creating the hub.[26]

The relocation of the hub from Frankfurt to another German airport would have general equilibrium effects on the volume of passengers on each bilateral connection as a result, for example, of changes in the price indices for non-traded services which affect the demand for air travel on each route. However, the first-order impact of a change in the location of the hub is likely to be that the transit passengers currently travelling via Frankfurt would have to travel via the new location of the hub. To evaluate the magnitude of this impact, we consider each category of transit passengers separately.[27] For domestic and international air transit passengers, we calculate the difference in distance travelled if the hub is in another German city

[26]This exercise evaluates the profitability of relocating the hub for the system of airports as a whole. In reality, airports are incorporated separately from one another (and also from airlines). In such a decentralized system it is likely to be substantially more costly for a single airport to induce a relocation of the hub. The reason is that the sunk costs of creating a hub are large relative to the fixed and variable costs of operating the hub. Therefore it is likely to be difficult for a new entrant to induce the exit of an existing hub.

[27]Data are available on the overall number of transit passengers at each airport and total passenger departures on each bilateral connection. To estimate the number of transit passengers travelling on each bilateral connection, we assume the total number of transit passengers at an airport is uniformly distributed across all bilateral connections from that airport: i.e., we assume that the share of each type of transit passenger in total passenger departures on a bilateral connection is the same as the share of this type of transit passenger in total departures at an airport.

instead of Frankfurt.[28] We then use the coefficient on distance from the estimation of the gravity equation (6) to infer how the volume of passengers would change in response to the change in distance travelled. Column (1) of Table 5 reports the estimated change in the number of air transit passengers in response to a relocation of the hub to Berlin, Dusseldorf, Hamburg and Munich respectively. Consistent with our earlier findings that market access plays a relatively minor role, the estimated changes in the number of air transit passengers as a result of the relocation of the hub are small compared to total passenger departures.

We next estimate the impact of relocating the ground transit passengers from Frankfurt to another airport. The two key determinants of the volume of ground transit passengers that an airport attracts are likely to be its proximity to population and economic activity and also its status as a hub due to the large number of direct connections that a hub airport offers. To estimate the relationship between ground transit departures and the surrounding concentration of economic activity, we regress the log number of ground transit passengers departing from an airport on the log of distance-weighted GDP for the airport, where the latter is calculated as the distance-weighted sum of GDP in all German counties ("Kreise"). To isolate the contribution of the surrounding concentration of economic activity and to abstract from the role of hub status, we exclude Frankfurt and also Munich from the regression.

The estimated coefficient on distance-weighted GDP is positive and statistically significant at the 1 percent level, with this variable alone explaining 60 percent of the cross-section variation in ground transit passengers (the estimated coefficient (standard error) are 2.986 (0.624)). We use this estimated coefficient to calculate the predicted change in the number of ground transit passengers at the hub as a result of the difference between distance-weighted GDP at the alternative location of the hub and that at Frankfurt. Column (2) of Table 5 reports the predicted changes in the volume of ground transit traffic at the hub as a result of the change in the hub's proximity to surrounding economic activity. The estimated changes in ground transit passengers are somewhat larger than those in air transit passengers, but are small relative to

[28]Given the current structure of air travel, there is a flow of transit passengers from each of the alternative potential locations of the hub to Frankfurt. If the hub were relocated to one of these locations, the flow of transit passengers from the new location of the hub to Frankfurt would cease, and instead there would be a flow of transit passengers from Frankfurt to the new location of the hub. To capture this change in the structure of air travel, we assume that the current flow of transit passengers from the new location of the hub to Frankfurt is a good proxy for the flow that would travel from Frankfurt to the new location of the hub. This assumption is likely to be a reasonable approximation as long as the differences in economic fundamentals between the new location of the hub and Frankfurt are relatively small.

total departures at Frankfurt and across the 15 German airports.

Column (3) of Table 5 reports the implied change in total passenger departures across the 15 German airports as a result of the hypothetical relocation of the hub. Column (4) reports this change as a percentage of total passenger departures across the 15 German airports. For each of the alternative locations of the hub, the change in total passenger departures is relatively small. As a point of comparison, the average annual growth in the number of departing passengers at these 15 airports over the period 1992 to 2002 was 4.5 percent. To convert the implied change in total passenger departures into a change in profits, we assume a value for airport profits of 10 Euro per passenger.[29] Assuming a discount rate of 3 percent per annum, the net present value of a change in total passengers by 2.5 million would, for example, be equal to 0.86 billion Euro. In comparison, the construction costs of the new terminal facilities in Berlin, which are at best a third of the size necessary to replace Frankfurt, are projected to be around 2 billion Euro.[30]

Our analysis of the impact of relocating the hub from Frankfurt to another German airport clearly makes a number of simplifying assumptions and assumes that apart from the relocation of transit traffic from Frankfurt to an alternative airport the structure of German air traffic remains unchanged. Despite these caveats the stark difference between the implied change in the net present value of profits and plausible estimates for the sunk costs of creating the hub suggests that it is unlikely the difference in profitability across alternative locations for the air hub in Germany outweighs the large sunk costs of creating the hub. This reinforces the conclusion that several other locations apart from Frankfurt – including Berlin – are potential equilibrium locations for Germany's air hub.

7. Conclusion

While a central prediction of a large class of theoretical models is that industry location is not uniquely determined by fundamentals, there is a surprising scarcity of empirical evidence on this question. In this paper we exploit the combination of the division of Germany in the wake of the Second World War and the reunification of East and West Germany in 1990 as a natural

[29] The figure of 10 Euro per passenger is likely to be an overestimate. According to the German Association of Airports ("Arbeitsgemeinschaft Deutscher Verkehrsflughäfen"), average after-tax profits per passenger for the largest German airports in 2005 were 2.53 Euro per passenger. While according to the 2006 Annual Report of Lufhansa, average operating profits on passenger business during 2005 and 2006 were 5.14 Euro per passenger.

[30] This estimate is taken from http://www.berlin-airport.de/DE/BBI/.

experiment to provide empirical evidence for multiple steady-states in industry location. We find that division results in a relocation of Germany's leading airport from Berlin to Frankfurt, but there is no evidence of a return of the leading airport to Berlin in response to reunification.

To provide evidence that this change in location is indeed a shift between multiple steady-states rather than a change in fundamentals, we compare Germany with other European countries, examine the determinants of bilateral departures from German airports to destinations worldwide, and exploit information on the origin of passengers departing from each German airport. We find that Frankfurt's current dominance of patterns of German air traffic cannot be explained by its location relative to destinations worldwide or by the density of local departures originating within 50 kilometers of the airport, but is instead driven by transit activity. We use our estimates to evaluate the implied change in passenger departures from relocating the German air hub from Frankfurt to other cities within Germany and show that the implied change in passenger departures and profitability is small relative to plausible values for the sunk costs of creating the hub.

The key advantage of our natural experiment and industrial activity is that they allow us to provide compelling evidence for the existence of multiple steady-states in industry location. An important open question for future research is to establish what other types of economic activities have this feature. For other economic activities it is likely to be substantially more difficult to empirically disentangle a shift between multiple steady-states from changes in fundamentals. Nevertheless, it seems likely that other economic activities besides air hubs have sufficiently large sunk costs and agglomeration forces for their locations not to be uniquely determined by fundamentals.

One of the key appeals of models of multiple steady-states in industry location is the possibility that temporary policy interventions can result in permanent changes in the economy. German division was not a policy intervention designed to influence location choices and involved substantial changes in the relative attractiveness of locations. Nonetheless, the length and apparent irreversibility of division suggest the importance of commitment and credibility for policies which are designed to influence location patterns. In the presence of multiple steady-states, the ability to commit to much less dramatic temporary interventions than the division of Germany could permanently affect the location of economic activity.

A Data Appendix

Total Departing Passengers at the ten main airports: The data for 1927-1938 are from the Statistical Yearbook of Germany ("Statistisches Jahrbuch für das Deutsche Reich") of the German Statistical Office ("Statistisches Reichsamt"). The data for 1950-89 are from the Statistical Yearbook of the Federal Republic of Germany published by the Federal Statistical Office of Germany ("Statistisches Bundesamt"), as are the data on departing passengers by airport from 1990-2002.

Bilateral Departures: Data on bilateral departures between the 15 main German airports in 2002 and destinations worldwide is taken from Federal Statistical Office (2003).

Transit Passengers and Local Departures: Information on the number of air transit passengers, who are passengers changing planes at an airport on route to another destination, is reported for 2002 in Federal Statistical Office (2003). Wilken *et al.* (2007) report summary results from a harmonized passenger survey in 2003 including the percentage of all passengers commencing their air journey at each German airport who have traveled to that airport from a location less than 50 kilometers away in 2003. We use these percentages to divide non-air transit passenger departures in 2002 into two groups: ground transit passengers, who have travelled more than 50 kilometers to the airport using ground transportation, and local departures, who have travelled less than 50 kilometers to the airport using ground transportation.

Departing Passengers in other European Countries: Data on the concentration of departing passengers in other European countries in 2002 is reported in "Worldwide Airport Traffic Report 2002" of the Airports Council International (ACI). The comparable data for 1937 were taken from the 1938 issue of the "Revue Aeronautique Internationale".

Population and GDP data: Data on population and GDP in each German county ("Kreis") in 2002 are taken from Arbeitskreis Volkswirtschaftliche Gesamtrechnungen der Länder (2005). Data on population in all municipalities within 50 kilometers of each German airport - typically over 100 municipalities per airport - was supplied in electronic form by the Federal Office for Building and Regional Planning ("Bundesamt für Bauwesen und Raumordnung"). We combine these two data sources to estimate GDP within 50 kilometers of each airport. We identify the county in which each municipality is located, multiply its population with the GDP per capita of the county in which it is located, and then sum over all municipalities within 50 kilometers of each airport.

Distances between Locations: Data on the longitude and latitude of each airport were extracted from http://worldaerodata.com, which is based on the data from the DAFIF database originally compiled by the US National Geospatial-Intelligence Agency. Data on the longitude and latitude of the administrative capital of each German county was supplied by the Federal Statistical Office in electronic form. The latitude and longitude data was used to compute great circle distances between locations.

B Theoretical Appendix

This appendix develops in further detail the general equilibrium structure which underlies the simple model of air travel and hub creation outlined in the main text.

B1. Endowments and Preferences

We assume that each location (or city) supplies a differentiated non-traded service that can only be consumed at the point of production. To focus on the demand for air travel, we assume that air travel is the only means of consuming non-traded services in other cities. For a resident of a city to consume one unit of the non-traded service produced by another city requires one return flight. Consumers also derive utility from a homogeneous numeraire good which is assumed to be freely traded between cities.[31]

The representative consumer's preferences are Cobb-Douglas in a consumption index of non-traded services and in the homogeneous numeraire good. The modelling of the demand for non-traded services follows Anderson and van Wincoop (2003). The non-traded services consumption index is assumed to take the standard Constant Elasticity of Substitution (CES) form so that:

$$U_j = \left(\sum_{i=1}^{N} \beta_{ij}^{\frac{1-\sigma}{\sigma}} c_{ij}^{\frac{\sigma-1}{\sigma}} \right)^{\left(\frac{\sigma}{\sigma-1}\right)\alpha} (q_j)^{1-\alpha}, \qquad 0 < \alpha < 1, \ \sigma > 1 \tag{9}$$

where $N = 3$ denotes the number of cities; α is the share of expenditure on non-traded services; σ is the elasticity of substitution between the varieties of non-traded services; β_{ij} is an inverse

[31] This formulation sweeps all economic activity that is traded through routes other than air travel into the homogeneous numeraire good, and allows us to focus on the demand for and supply of air travel.

measure of the weight allocated by consumers in city j to the non-traded services produced in city i; c_{ij} denotes the consumption of non-traded services produced in city i by residents of city j; q_j indicates the consumption of the homogeneous numeraire good.[32]

Cities are populated with a mass of L_i consumers who have identical preferences, have a fixed city of residence from which they may travel to consume non-traded services, and are endowed with one unit of labor that is supplied inelastically with zero disutility.

B2. Technology and Market Structure

The numeraire good is produced under conditions of perfect competition and according to a constant returns to scale technology: $y_i = l_i^y$, where y_i and l_i^y denote output and labor used in production of the numeraire. We choose units in which to measure the numeraire good so that the unit labor requirement is equal to one. Since the numeraire good is freely traded, its price is equal to one in all cities: $p_i^y = p^y = 1$. In addition, we focus on parameter values for which all cities produce the numeraire good, which pins down the equilibrium wage as equal to one: $w_i = w = 1$.[33]

Non-traded services are produced under conditions of perfect competition and according to a constant returns to scale technology:[34]

$$x_i \equiv \sum_{j=1}^{N} x_{ij} = l_i^x \tag{10}$$

where x_i corresponds to total production of non-traded services in city i, x_{ij} is the quantity of non-traded services produced in city i and sold to residents of city j, and l_i^x denotes total employment of labor in non-traded services in city i. We also choose units in which to measure non-traded services so that the unit labor requirement for this sector is equal to one.

The differentiation of non-traded services by city of origin ensures that all cities produce non-traded services. With the equilibrium wage equal to one, perfect competition and the production technology (10) imply that the equilibrium price of non-traded services is equal

[32] Throughout the analysis, the first subscript corresponds to the point of production and the second subscript to the point of consumption. We use i to indicate the city of production and j to indicate the city of residence of consumers.

[33] Incomplete specialization can be ensured by an appropriate choice of values for the preference parameters β_{ij} and labor endowments for each city.

[34] Note that, from equation (9), non-traded services are differentiated by city of production (as in Armington 1969) but are homogeneous within cities. Allowing for differentiated varieties of non-traded services within cities is straightforward, but merely complicates the analysis without adding any additional insight.

to one: $p_i^x = p^x = 1$. Since consuming one unit of a non-traded service from another city requires one return flight, the number of passenger journeys (a_{ij}) equals demand for non-traded services (c_{ij}), that is $a_{ij} = c_{ij}$ for $i \neq j$. As the source and destination cities are not necessarily symmetric, the total number of return flights between cities j and i is equal to $a_{ij} + a_{ji}$.

As discussed in the main text, we consider a monopoly airline that has the choice whether to operate direct connections between cities or to operate indirect connections via a hub. We assume that there is a fixed cost of $F > 0$ units of labor of operating each direct connection and then a marginal cost in terms of labor for each return passenger. In addition, we assume that there is a sunk cost of $H > 0$ units of labor of creating a hub. Since we focus on equilibria where specialization is incomplete, and so the wage in all cities is equal to one, the airline is indifferent as to where to source labor. The marginal cost is a function of the distance flown d_{ij}, $\psi(d_{ij})$, where distance flown depends on whether a direct or indirect connection is operated between cities j and i. With a direct connection, the airline flies the shortest feasible distance between cities i and j, δ_{ij}, and so $d_{ij} = \delta_{ij}$. With an indirect connection, the airline flies the shortest feasible distance from city i to the hub in city k plus the shortest feasible distance from city k to city j, and so $d_{ij} = \delta_{ik} + \delta_{kj} \geq \delta_{ij}$. The total labor required for a_{ij} passenger journeys from city i to city j is therefore:

$$l_{ij}^a = \begin{cases} a_{ij}\psi(\delta_{ij}) + F & \text{if the connection is direct} \\ \\ a_{ij}\psi(\delta_{ik} + \delta_{kj}) & \text{if the connection is indirect} \end{cases} \tag{11}$$

B3. Airline Equilibrium Prices and Profits

Consumers are price-takers and take into account the full cost of consuming non-traded services, which equals their price at the point of production plus the cost of air-travel. Expenditure minimization yields the standard CES demand for non-traded services. Therefore city j residents' demand for the non-traded services produced in city i, and hence city j residents' demand for air travel to city i, is:

$$c_{ij} = a_{ij} = \beta_{ij}^{1-\sigma} T_{ij}^{-\sigma} P_j^{\sigma-1} E_j^T \tag{12}$$

where β_{ij} is the inverse measure of the weight allocated by consumers in city j to the non-traded services produced in city i; $T_{ij} = p_i^x + p_{ij}^a$ is the composite cost of purchasing one unit of non-traded services at price p_i^x and one return air journey at price p_{ij}^a; $E_j^T = \alpha E_j = \alpha w L_j$ is expenditure on the composite good of non-traded services and air travel which equals a constant share of total expenditure which equals income; P_j is the CES price index summarizing the full cost of consuming non-traded services for residents in city j:

$$P_j = \left[\sum_{i=1}^{N} \left(\beta_{ij} T_{ij}\right)^{1-\sigma}\right]^{\frac{1}{1-\sigma}} \tag{13}$$

As we assume that the airline is able to segment markets for travel between each pair of cities. Combined with our assumption of constant marginal cost, this implies that pricing is independent on travel between each pair of cities. Profit maximization yields the standard result that the equilibrium price of a return trip between two cities is proportional to marginal cost:

$$p_{ij}^a = \begin{cases} \left(\frac{\varepsilon(a_{ij})}{\varepsilon(a_{ij})-1}\right) \psi\left(\delta_{ij}\right) & \text{if the connection is direct} \\ \\ \left(\frac{\varepsilon(a_{ij})}{\varepsilon(a_{ij})-1}\right) \psi\left(\delta_{ik} + \delta_{kj}\right) & \text{if the connection is indirect} \end{cases} \tag{14}$$

where $\varepsilon\left(a_{ij}\right)$ denotes the elasticity of demand.

From the equilibrium pricing rule, variable profits from passenger journeys from city j to city i equal revenue divided by the elasticity of demand: $\rho_{ij} = \left(p_{ij}^a a_{ij}\right) / \varepsilon\left(a_{ij}\right)$. Variable profits for the route as a whole equal the sum of variable profits on passenger journeys in each direction: $\pi_{ij} = \rho_{ij} + \rho_{ji}$. Variable profits will be lower if a route is served by an indirect rather than a direct connection for two reasons. First, marginal cost is higher if a route is served by an indirect connection, which increases prices. Since demand is elastic, the higher prices decrease revenues and so diminish variable profits. Second, one can allow for a disutility of changing planes on indirect connections (e.g. by assuming that β_{ij} is higher if a route is served by an indirect rather than a direct connection), which further reduces the demand for air travel on indirect connections, and so decreases revenue and variable profits.[35]

B4. Bilateral Passenger Departures

The number of return passenger journeys from city j to city i is determined by equation (12). Since passenger journeys are round-trips, the total number of departing passengers from city j to city i is the sum of passengers travelling in each direction:

$$A_{ij} = a_{ij} + a_{ji} = \beta_{ij}^{1-\sigma} T_{ij}^{-\sigma} P_j^{\sigma-1} E_j^T + \beta_{ji}^{1-\sigma} T_{ji}^{-\sigma} P_i^{\sigma-1} E_i^T \tag{15}$$

[35] A richer model would be able to explain the co-existence of direct and indirect connections on routes and the empirically observed lower prices for the indirect connections. While this would complicate the analysis, the decision to create a hub would still depend on the trade-off between profits on direct and indirect connections and the fixed costs of operating a direct connection.

Equation (15) implies that bilateral passenger departures depend on characteristics of the source city j, characteristics of the destination city i, and bilateral travel costs. Log-linearizing this relationship, collecting terms in source city characteristics in a fixed effect s_i, collecting terms in destination city characteristics in another fixed effect m_i, and modelling bilateral travel costs using distance and a stochastic error u_{ij}, we obtain the gravity equation (6) in the main text.

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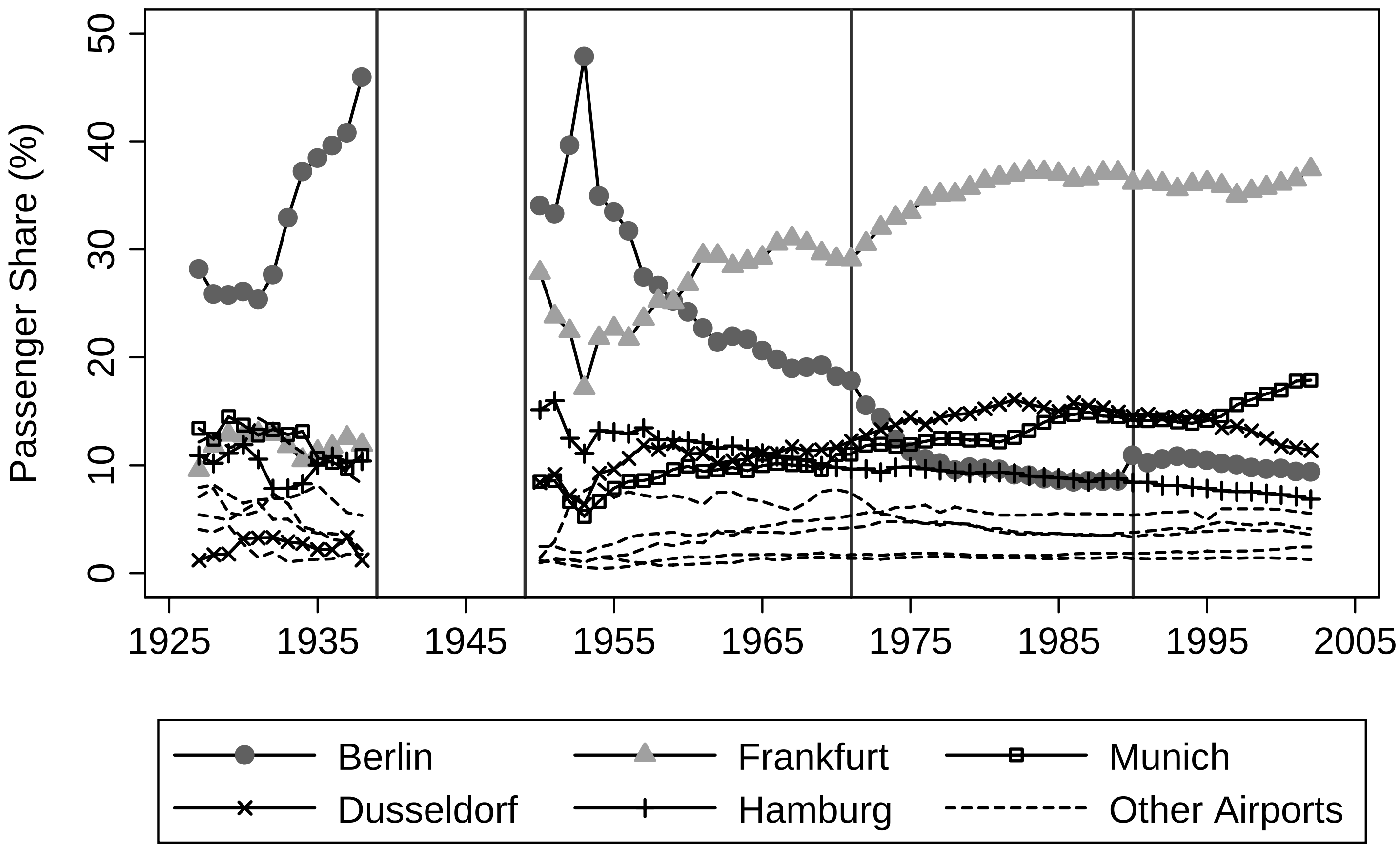
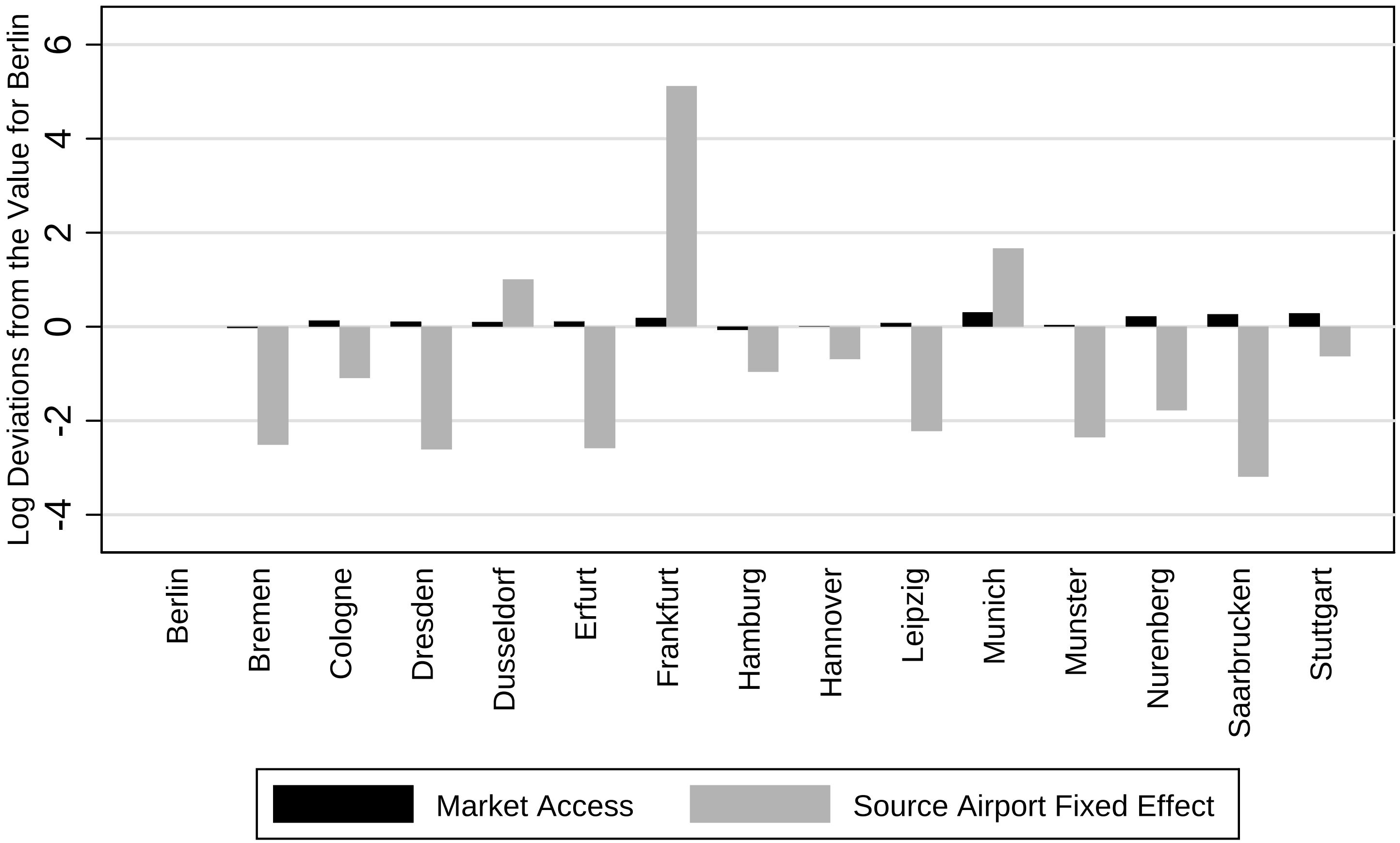
Map 1: The Location of the Airports in Our Sample

Figure 1: Airport Passenger Shares



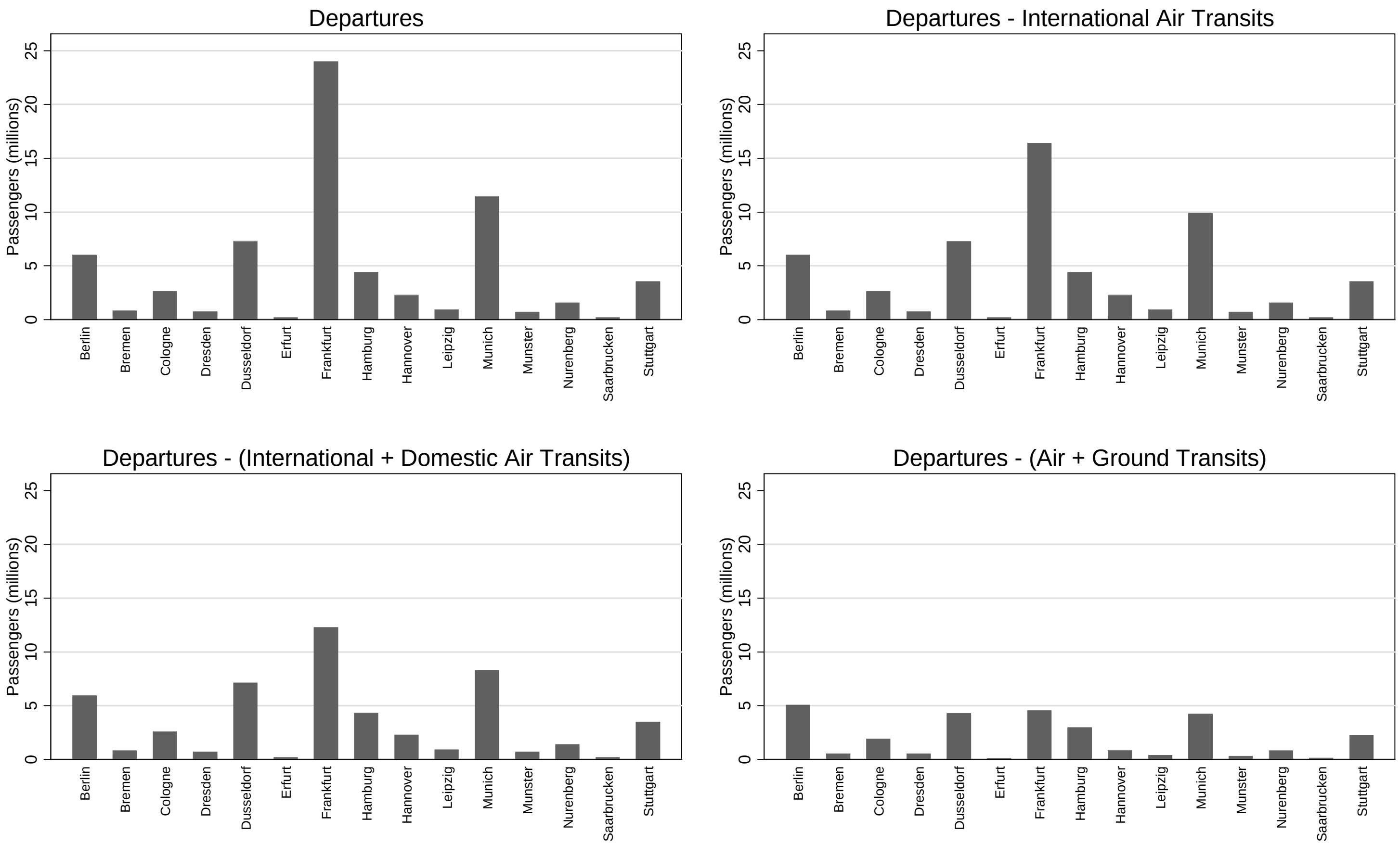
Note: share of airports in departing passengers at the ten main German airports

Figure 2: The Role of Market Access



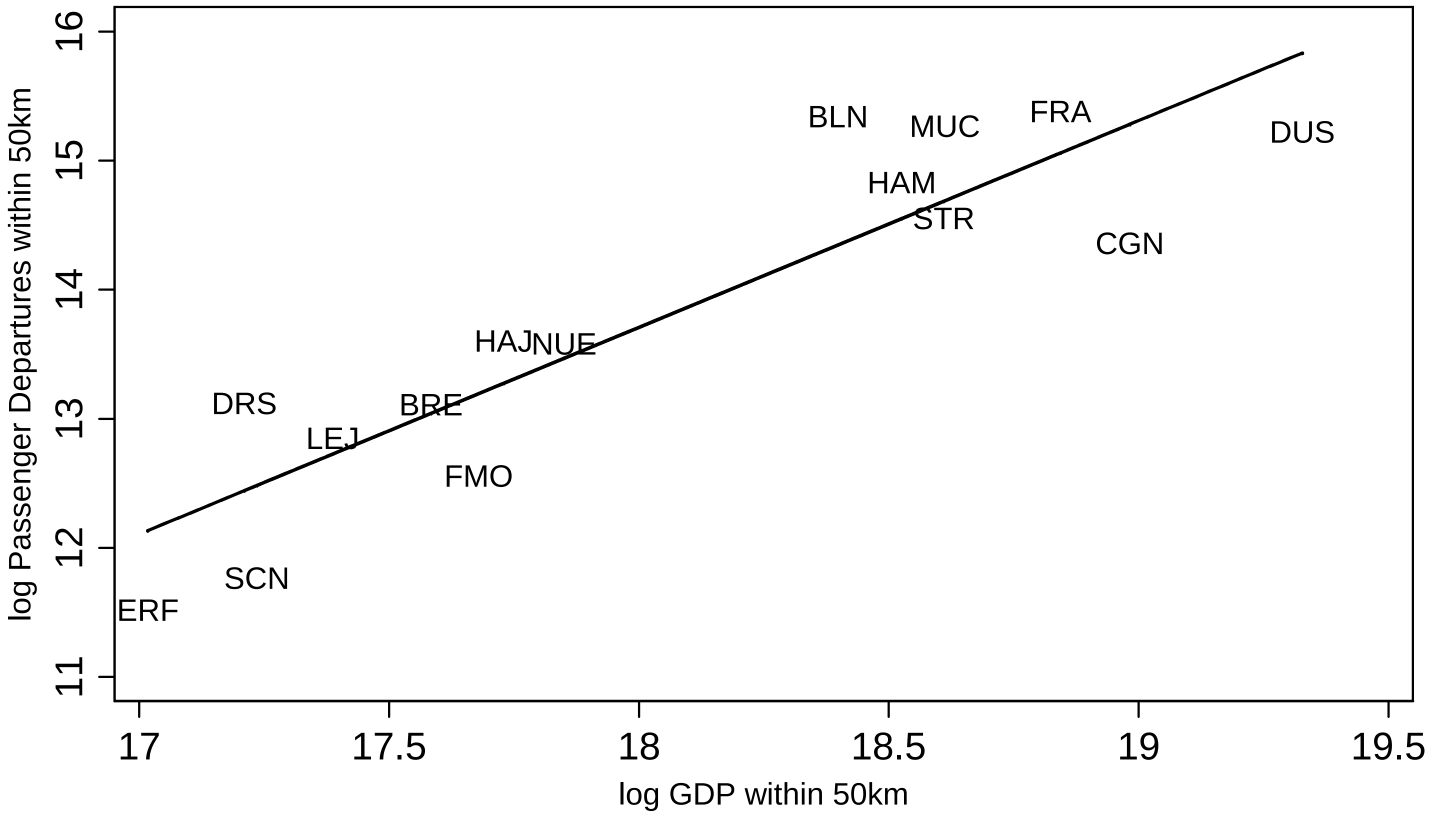
Note: the estimates of market access and the source airport fixed effects are derived from the gravity equation (6) for bilateral passenger departures in the main text. The log deviations from Berlin for market access and the source airport fixed effects sum to the log deviation from Berlin for fitted total departures.

Figure 3: Transit and Local Passenger Departures



Note: international air transit passengers are those changing planes at an airport on route from a foreign source to a foreign destination. Domestic air transit passengers are those changing planes at an airport with either a source or destination within Germany. Ground transit passengers are those who travelled more than 50 kilometers to an airport using ground transporation. See the data appendix for further discussion of the data sources.

Figure 4: Local Departures and Local GDP



Note: local departures are those who travelled less than 50 kilometers to an airport using ground transportation. GDP within 50 kilometers is calculated from the population of all settlements within 50 kilometers of an airport and the GDP per capita of the counties ('Kreise') in which the settlements are located. The three letter codes are: BLN: Berlin; BRE: Bremen; CGN: Cologne; DUS: Dusseldorf; DRS: Dresden; ERF: Erfurt; FRA: Frankfurt; HAM: Hamburg; HAJ: Hannover; LEJ: Leipzig; FMO: Munster; MUC: Munich; NUE: Nurenburg; SCN: Saarbrucken; STR: Stuttgart.

TABLE 1

Estimated Time Trends for Pre-war, Division and Reunification Periods

Period	(1) 1927-1938	(2) 1950-1989	(3) 1990-2002	(4) 1980-1989
Berlin	1.851***	-0.814***	-0.123***	-0.139***
	(0.267)	(0.067)	(0.018)	(0.024)
Bremen	-0.259***	0.022***	-0.001	0.004
	(0.062)	(0.003)	(0.004)	(0.005)
Cologne	-0.360***	0.064***	0.044**	-0.043**
	(0.086)	(0.013)	(0.021)	(0.020)
Dusseldorf	0.036	0.203***	-0.300***	-0.050
	(0.080)	(0.015)	(0.032)	(0.038)
Frankfurt	0.029	0.436***	0.037	0.034
	(0.098)	(0.036)	(0.048)	(0.031)
Hamburg	-0.078	-0.145***	-0.125***	-0.084***
	(0.068)	(0.014)	(0.006)	(0.017)
Hannover	-0.453***	-0.082***	0.031*	-0.071***
	(0.056)	(0.028)	(0.017)	(0.015)
Munich	-0.337***	0.195***	0.360***	0.320***
	(0.081)	(0.013)	(0.043)	(0.053)
Nurenberg	-0.274***	0.017***	0.048***	0.028***
	(0.058)	(0.002)	(0.005)	(0.005)
Stuttgart	-0.156***	0.096***	0.030**	0.001
	(0.056)	(0.009)	(0.014)	(0.010)
Airport-period intercepts	Yes	Yes	Yes	Yes
R-squared	0.98	0.98	0.98	0.99

Notes: columns (1)-(3) report results from a single regression of airport departing passenger shares on separate intercepts and time trends for each airport and time period (1927-38, 1950-89 and 1992-2002). Columns (1)-(3) report the coefficients on the time trends. Column (4) is based on an augmented specification where the 1950-89 period is broken out into decades and separate intercepts and time trends are included for each airport in each decade. Column (4) reports the estimated coefficients on the time trends for 1980-89. The estimated coefficients on the time trends for 1927-38 and 1990-2002 in the augmented specification are the same as in Columns (1) and (3), but the standard errors are larger as a result of the increase in the number of parameters estimated. The sample includes 649 observations on 10 airports during 1927-38, 1950-89 and 1990-2002; the departing passenger data are missing for Cologne in 1950. The standard errors in parentheses are heteroscedasticity robust. Statistical significance: *** 1% level; ** 5% level; * 10% level.

TABLE 2

Estimated Differences in Time Trends

	(1)	(2)	(3)
Panel A: Division			
	Period 1926-1938	Period 1950-1989	Between-Period Difference
Berlin	1.851***	-0.814***	2.665***
	(0.267)	(0.067)	(0.275)
Frankfurt	0.029	0.436***	-0.407***
	(0.098)	(0.036)	(0.104)
Within-Period Difference	1.823***	-1.250***	**3.072*** **
	(0.284)	(0.075)	**(0.294)**
Panel B: Reunification			
	Period 1980 - 1989	Period 1990-2002	Between-Period Difference
Berlin	-0.139***	-0.123***	-0.016
	(0.024)	(0.018)	(0.031)
Frankfurt	0.034	0.037	-0.003
	(0.031)	(0.050)	(0.059)
Within-Period Difference	-0.172***	-0.160***	**-0.012**
	(0.039)	(0.053)	**(0.066)**

Notes: the coefficients and standard errors for the estimated time trends for Berlin and Frankfurt are from the regressions reported in Table 1. The bottom right cell of each panel contains the difference-in-differences of the estimated time trends. Heteroscedasticity robust standard errors in parentheses. Statistical significance: *** 1% level; ** 5% level; * 10% level.

TABLE 3

The Largest Airports of European Countries in 1937 and 2002

	(1) Largest Airport in 1937	(2) Market share of largest airport in 1937	(3) Market share of largest airport in 2002	(4) Rank of largest airport 1937 in 2002
Austria	Vienna	94.1	76.5	1
Belgium	Brussels	65.6	89.9	1
Denmark	Kopenhagen	96.2	91.7	1
Finland	Helsinki	80.3	73.7	1
France	Paris	70.2	61.4	1
Germany	Berlin	30.8	35.0	4
Greece	Athens	43.9	34.7	1
Ireland	Dublin	100.0	78.1	1
Italy	Rome	35.7	34.5	1
Netherlands	Amsterdam	62.3	96.4	1
Norway	Oslo	75.6	45.8	1
Portugal	Lisbon	100.0	46.3	1
Spain	Madrid	43.5	26.8	1
Sweden	Stockholm	56.9	61.9	1
Switzerland	Zurich	55.7	62.0	1
United Kingdom	London	52.7	65.6	1

Notes: The countries are the EU 15 countries without Luxembourg (which had no airport prior to the Second World War and has only one airport in 2002) and Norway and Switzerland. The pre-war data for Austria refer to the year 1938. The pre-war data for Spain are the average over 1931 to 1933. See the data appendix for detailed references to the sources.

TABLE 4

Determinants of Bilateral Passenger Departures

	(1) Logarithm of Bilateral Passenger Departures
Logarithm of Distance	-1.652***
	(0.343)
Source Airport Fixed Effects	Yes
Destination Airport Fixed Effects	Yes
Observations	5130
R-squared	0.680

Notes: the dependent variable is the logarithm of one plus bilateral passenger departures. The sample includes all worldwide destinations with direct connections from a German airport that are more than 300 kilometres away from any German airport. The German airports are: Bremen, Berlin, Cologne, Erfurt, Dresden, Dusseldorf, Frankfurt, Hamburg, Hannover, Leipzig, Munich, Munster, Nurenburg, Saarbrucken and Stuttgart. Standard errors in parentheses are heteroscedasticity robust. *** denotes statistical significance at the 1 percent level.

TABLE 5

Estimated Impact of Relocating the Air Hub from Frankfurt on Total Passenger Departures

Alternative Location of the Air Hub	(1) Estimated Change in Air Transit Passengers	(2) Estimated Change in Ground Transit Passengers	(3) Estimated Change in Total Passenger Departures	(4) Estimated Percentage Change in Total Passenger Departures
Berlin	-293,666	-1,862,056	-2,075,622	-3.14%
Dusseldorf	287,004	-18,331	283,511	0.43%
Hamburg	-149,112	-1,644,620	-1,582,114	-2.39%
Munich	889,700	-865,146	-112,053	-0.17%

Notes: the table reports the estimated change in passenger departures as a result of the hypothetical relocation of the air hub from Frankfurt to each of the alternative locations. All air transit passengers who currently change planes at Frankfurt are assumed to instead fly via the alternative airport and the coefficient on distance from Table 4 is used to infer the change in the number of air transit passengers as a result of the change in distance travelled caused by the relocation of the hub. The logarithm of ground transit departures is regressed on the logarithm of the distance-weighted sum of GDP in all German Kreise and the estimated coefficient is used to infer how the number of ground departures currently observed in Frankfurt would change if it instead had the distance-weighted GDP of the alternative location of the hub. See the main text for further discussion. Total departures across the 15 German airports in 2002 were 66,134,048. Total departures from Frankfurt airport in 2002 were 23,782,604.

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