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Author
McGraw, Marquise Jason

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by

Marquise Jason McGraw

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Professor David E. Card
Professor Victor Couture

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Abstract

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This study examines the effects of infrastructure improvements on various outcome measures of economic performance. I focus on three different examples: (1) the opening of the aviation system in the United States, (2) the effects of improving or labeling certain airports as "hub" airports, and (3) improvements in decades-old public school buildings for energy efficiency and sustainability. Together, each case provides substantial evidence that infrastructure is an important input in the functioning and/or performance of economic activity.

The first chapter considers the effects of small and mid-size commercial airports on their local economies over the post World War II period, specifically 1950-2010. To estimate these effects, I use a detailed, novel dataset of Census Based Statistical Area (CBSA) level employment outcomes, geographic, transportation, and city characteristics, along with previously unexploited historical aviation data. Using an instrumental variables approach, one-to-one Mahalanobis distance matching with caliper and pooled synthetic controls, I show that airports have had substantial effects on CBSA population and employment over time. The larger effect on tradable industry employment implies that the overall employment and population effects may result from direct effects on tradable sector industry productivity, perhaps by facilitating information flows. Effects vary by initial city size and region, and are generally robust to the choice of instruments and/or estimator.

The second chapter considers the marginal effect of having a hub designation by an airline on its cities economic fortunes relative to cities that have airports, but not hub airports. Using panel regression methods and event study techniques, I find that while hub airports do not significantly affect city employment levels, hubs do contribute 1-2 percent of personal income to their respective cities, as well as establishment growth of 1-2 percent. I find the effects of hubs on employment to be most salient in the air transportation and hotel industries; however, the same is not necessarily true for other sectors where tourism might affect employment. This implies that the effects of hub airports, in most cases, operate through their ability to facilitate business travel, as hubs increase non-stop market access by at least 15 percent.

The third chapter considers an infrastructure improvement of a different type: improvements to public school buildings to increase sustainability and reduce energy costs. Said improvements, such as improving ventilation systems, temperature control, and adding more sunlight, are thought to enhance student learning outcomes. To test this, two panel data sets are created: a nationwide panel with school districts as the unit of observation, and a California panel with schools themselves as the unit of analysis. Panel data methods including fixed-effects regression and event study techniques exploit differences in conversion timing to examine the schools' effect on dropout rates, test scores, and school quality indices. Nationwide, I find evidence that energy cost reductions may not be the primary factor driving adoption of green schools. Additionally, considering the evidence from California, it appears that in general energy efficient school buildings have a negligible effect on academic performance, even after looking at a variety of measures, suggesting that sustainable buildings are no panacea for improving school performance.

Taken together, this study demonstrates that infrastructure can affect economic performance. Larger interventions will have a larger effect, while more marginal interventions may have smaller, or even negligible, effects.

To my students, past, present, and future.

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Preface

As policymakers at various levels consider the question of how to improve job growth and economic development in cities large and small, it is important to have a careful understanding of the role played by infrastructure. Infrastructure, broadly defined, refers to basic physical and organizational structures and facilities necessary for the proper functioning of an enterprise. While roads and bridges often first come to mind, our airports and air transportation network, ports, pipelines, even buildings fall within this broader umbrella.

In popular circles, there is a popular belief that infrastructure is a sure-fire way to promote growth. However, the reality appears to be much more nuanced. In order to improve our understanding of this, I focus on three examples of infrastructure improvements. First, I consider infrastructure improvements from a long-term historical perspective. I take the development of the aviation system in the United States, and the role airports have played in cities since, as the first case. A second case has to do with airlines' investments in and labeling of airports. What are the effects of improving or labeling certain airports as "hub" airports? The third case considers more incremental building improvements, in the form of sustainability upgrades and labeling of decades-old public school buildings, with the express goals of enhancing energy efficiency and improving school performance. Together, each case provides substantial evidence that infrastructure is an important input in the functioning and/or performance of economic activity. But this comes with a caution – some improvements may yield more modest benefits than expected, while others can be transformative.

The first chapter considers the effects of small and mid-size commercial airports on their local economies over the post World War II period, specifically 1950-2010. To estimate these effects, I use a detailed, novel dataset of Census Based Statistical Area (CBSA) level employment outcomes, geographic, transportation, and city characteristics, along with previously unexploited historical aviation data. Using an instrumental variables approach with three instruments – the locations of collection points on the Air Mail system of 1938, a network of Federally constructed emergency air fields in the early years of aviation, and a 1922 plan of airways for national defense – as well as two alternative estimators – one-to-one Mahalanobis distance matching with caliper and pooled synthetic controls – I show that airports have had substantial effects on CBSA population and employment over time. Specifically, I find that relative to non-airport cities, the presence of an airport in a CBSA has caused population growth ranging between 14.6 percent and 29 percent, total employment growth of between 17.4 percent and 36.6 percent, tradable industry employment growth of between 26.6 percent and 42.6 percent, and non-tradable industry employment growth of between a non-statistically significant 2.7 percent and 16.1 percent. These effects vary by region, city size, and traffic levels. Most of these growth effects occurred over two periods: first, at the beginning of the post-war period, 1950-1960, and then, during the formative years of the jet age, 1970-1980, after which the effects of aviation remained constant. The larger effect on tradable industry employment

implies that the overall employment and population effects may result from direct effects on tradable sector industry productivity, perhaps by facilitating information flows. Effects vary by initial city size and region, and are generally robust to the choice of instruments and/or estimator.

The second chapter considers the marginal effect of having a hub designation by an airline on its cities economic fortunes relative to cities that have airports, but not hub airports. Using panel regression methods and event study techniques, I find that while hub airports do not significantly affect city employment levels, hubs do contribute between 1 and 2 percent of personal income to their respective cities, as well as establishment growth of 1 percent. I find the effects of hubs on employment to be most salient in the air transportation and hotel industries; however, the same is not necessarily true for recreation-based sectors. This implies that the effects of hub airports, in most cases, operate through their ability to facilitate business travel. As hubs increase non-stop market access by at least 15 percent. This appears to be confirmed by evidence of increased service sector establishment growth.

The third chapter considers the effect of improvements to school buildings on student performance. Over the past decade, labeling programs such as LEED and Energy Star have become increasingly commonplace, with the goal of enhancing environmental sustainability in buildings. While much of the research to date has focused on the benefits of sustainability in commercial real estate prior, this paper focuses on a different class of building: "green" public schools. I examine the factors influencing the adoption of sustainability in green schools and their potential effects on student achievement. Two panel data sets are created: a nationwide panel with school districts as the unit of observation, and a California panel with schools themselves as the unit of analysis. Panel data methods including fixed-effects regression and event study techniques exploit differences in conversion timing to examine the schools' effect on dropout rates, test scores, and school quality indices. In terms of achievement outcomes, the evidence is decidedly mixed. While the district-level evidence indicates that the "greening" of schools results in positive benefits for inhabitants as evidenced by up to a 5 percent reduction in high school dropout rates. However, considering the evidence from California, it appears that in general energy efficient school buildings have a negligible effect on academic performance, even after looking at a variety of measures, suggesting that sustainable buildings are no panacea when it comes to student performance.

Taken together, this study demonstrates that infrastructure can affect economic performance. Larger interventions will have a larger effect, while more marginal interventions may have smaller or negligible effects. The policy lesson is that to some degree, better infrastructure can cause growth. But not all forms of infrastructure are created equally, nor is any particular improvement guaranteed to have an effect.

Acknowledgments

This project could not have been completed without a great deal of assistance and support. First, I would like to thank my committee members, Chair Enrico Moretti, David Card, and Victor Couture for their expert guidance and advice on this project. I also thank Bob Helsley, Pat Kline, Dan Chatman, Mark Hansen, Severin Borenstein, Charles Becker, and Janet Kohlhase, as well as seminar participants at the University of Mannheim MAYBE Workshop, the Federal Reserve Bank of Chicago, the 2014 meeting of the Western Regional Science Association, the AEA Mentoring Program Conferences held in 2012-2014, and the 2013 All-California Labor Economic Conference Poster Session for helpful comments and suggestions. I am grateful to Severin Borenstein for providing historical market level aviation sector data for use in the airline hubs study. I thank Nils Kok and Bill Gentry for helpful discussions and suggestions on the green schools study. This project was conducted while I was a NSF Graduate Research Fellow at UC Berkeley, and I gratefully acknowledge their financial support. I also thank the UC Berkeley Graduate Division and the NSF/AEA Mentoring Program for additional financial support.

I am grateful to the late John Quigley, who first introduced me to research in urban economics, and specifically, to research in the area of sustainable buildings. I dedicate Chapter 3, which examines the role of sustainable public school buildings on academic achievement, to his memory.

I could not have completed this project without the assistance of a remarkable team of undergraduate research assistants. All of them worked extremely hard to ensure that this work was the best it could possibly be. For contributions to Chapter 1, I am indebted to Alice Wang, Kathleen Hui, and Xiaoxi (Cathy) Liu. I am grateful to Alice Wang, Chau Nguyen and Zitian Deng for excellent research assistance on Chapter 2. Finally, I am grateful to Margaret Shyu, Dominique Meroux, and Xiaoxi (Cathy) Liu for their outstanding efforts on Chapter 3.

Finally, to my close friends who have seen me through this journey - Nathaniel Dumas, Elaine Yau, Candace Hamilton Hester, Patrick Lapid, Armando Franco, and even to the team at Crossroads Dining who have fed me over the years - and to so many others, thank you! I could not have done it without you. And to all my students who have encouraged and inspired me along this journey as well, thank you!

Chapter 1

Airports and Employment in Local Economies: An Historical Approach

1.1 Introduction

To the casual observer, airports and aviation in general appear to be beneficial for cities. In fact, many cities consider their airports a vital part of their local economies. Consistent with this belief, the Federal government subsidizes air travel through the provision of funds to necessary infrastructure such as the air traffic control system, and also to very small airports through programs such as the Essential Air Service. These expenditures are not trivial; as of October 2012, 120 communities in the contiguous United States received a total of nearly $225 million dollars yearly in such subsidies Wittman and Swelbar (2013). Local municipalities themselves also subsidize aviation by offering incentives to air carriers for service to their cities with the goal of increasing economic activity within their borders. For example, in 2010, Huntsville International Airport, a 12-gate airport in Madison County, Alabama, spent $1.5 million in local taxpayer money to attract service from AirTran Airways. In 2013, it set aside $5 million in hopes of luring more service.[1] Local leaders fear that the loss of service would hurt Huntsville's ability to attract new jobs and to compete for new conventions and tourists.

Would Huntsville, and similar places, be different had it not been for their airports? If so, how might those differences come about? How is it that airports might play such an important role, and through what mechanism? Answers to these questions are unclear from the current literature. In an era where many airlines are pulling out of smaller airports, this is a critical question. In fact, Wittman and Swelbar (2013) note that between 2007 and 2012, 24 airports lost all their commercial service at some point. Understanding how aviation might affect cities, particularly smaller cities, is critical to understanding whether there is a proper policy response. This is also important for understanding how transportation infrastructure, more generally, might affect cities, and how those effects may have developed over time. The primary goal of this paper is to examine the question of how airports have affected their local economies over the post World War II period, 1950-2010, in the hope of providing new evidence of the role of airports in these cities, particularly in medium-sized and smaller communities.

In identifying the causal effect of airports on population and employment, econometrically, the major concern is endogeneity. Airports, similar to other pieces of infrastructure such as roads, are not randomly assigned to cities, which could lead to biased estimates. In the case of airports, this is even more of a concern, given the law in the United States specifically stipulates that the construction and operation of airports is a local responsibility. This gives rise to questions which may complicate estimation of these effects. Were airports strategically constructed in cities that expected to thrive anyway, so that effects casually attributed to the airport could potentially result from other unexplained factors? Or, alternatively, were airports built in places with relatively dim prospects in the hope of stimulating growth in those local economies, with the true effect of aviation actually larger than initially thought?

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[1] Carey, Susan. "Why Small Airports are in Big Trouble". Wall Street Journal. http://online.wsj.com/news/articles/SB10001424052702304688104579465711898215996

A key innovation of this paper is a research design that examines the entire recent history of aviation in the United States during the period 1900-2010, while employing previously unexploited historical aviation data to address endogeneity concerns. I use three alternative estimation strategies to identify the causal effects of airports on local economic outcomes over the post World War II period, with a focus on population and employment (total, tradable industries, non-tradable industries, and the transportation sector) as outcomes of interest.[2] The first is an instrumental variables (IV) strategy with three instruments – the locations of mail collection points on the Air Mail system of 1938, the locations of a network of Federally constructed emergency air fields from the early years of aviation, and primary cities on a 1922 plan of airways for national defense – to estimate these effects. I argue that these factors are directly related to the eventual placement of airports in the pre World War II period, but conditional on pre-period controls, are exogenous to the outcomes of interest in later periods, enabling causal identification of the effect of interest. The second, "Caliper Matching", is a variant of one-to-one matching, which combines a caliper (to remove outliers and inliers) with a Mahalanobis distance estimator to estimate causal treatment effects under the assumption of conditional independence. Finally, the third, "Pooled Synthetic Controls", combines and averages individual case estimates generated by the synthetic control estimator Abadie and Gardeazabal (2003) to measure the average treatment effect. It accomplishes this by generating a counterfactual outcome for each Census Based Statistical Area (CBSA), which is then differenced from the actual observed outcomes to estimate effects for an individual case.

I find that relative to non-airport cities, the presence of an airport in a CBSA has caused population growth ranging between 14.6 percent and 29 percent, total employment growth of between 17.4 percent and 36.6 percent, tradable industry employment growth of between 26.6 percent and 42.6 percent, and non-tradable industry employment growth of between a non-statistically significant 2.7 percent and 16.1 percent. These effects vary by region, city size, and traffic levels. I show that airports boosted local economies over two periods: at the beginning of the post-war period, 1950-1960, and during the formative years of the jet age, 1970-1980, after which the effects of aviation remained constant. Given that the airports appear to have a somewhat larger effect on tradable industry employment, it appears that the overall employment and population effects result from direct effects on tradable sector industry productivity, perhaps by facilitating information flows, which through multiplier effects leads to higher employment in non-tradable sectors as well. To put these effects in context, the observed growth effects in the 1970s translates into \$83.8 million in added payroll and 3,300 jobs for a local economy, of which roughly 950 are in tradable industries. Effects vary by initial city size and region, and are generally robust to the choice of instruments and/or estimator.

This paper proceeds as follows. In Section 1.2, I present a brief review of the relevant

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[2] Tradable goods are produced in the agriculture, mining, manufacturing, and wholesale trade sectors. Non-tradable goods are produced in the construction, retail trade, finance, insurance and real estate, public administration, and services sector. (The transportation, communications, and utilities sector is considered separately.)

literature. Section 1.3 presents a simple framework for thinking about how airports may affect employment in local economies. Section 1.4.1 discusses sample selection and data sources and characteristics. Section 1.5 presents two case studies illustrating how airports may impact local economies. Finally, I present results in Section 1.6, and Section 1.7 concludes.

1.2 Literature Review

The literature on the specific topic of airports and regional economic development, while growing, is still relatively small. However, this paper is also related to the broader literature on the effects of public infrastucture, as well as the literature on roads and economic development. For instance, Aschauer (1989) was one of the first to provide evidence that public capital, specifically "core" infrastructure, plays a significant role in economic growth.[3] Munnell (1990) showed that states that have invested more in infrastructure tend to have greater output, more private investment, and more economic growth. She notes, but cannot conclusively prove, that causation seems to run from investment to increased productivity.

Closely related to the topic of airports and urban development is the literature on roads. Baum-Snow (2007a) estimated the effect of highways on suburbanization using the 1947 national highway plan as an instrument for the highway system that was eventually constructed. He found if the interstate highway system had not been built, aggregate central city population in each metropolitan statistical area (MSA) would have increased by 8 percent between 1950 and 1990; however, it actually decreased by 17 percent over the period. Michaels (2008) found that the opening of the interstate highway system increased trade-related activities in rural counties. In so doing, the highways raised the demand for skilled workers in skill-abundant counties and reduced it elsewhere. Duranton et al. (2013), using the 1947 national highway plan as an instrument, showed that highways play an important role in determining the specialization of urban sectors in terms of production and trade in heavy goods. Duranton and Turner (2012) examine causality between road transportation and city growth, finding significant effects of road miles on employment and population growth. For the period between 1983 and 2003, they find that a 10 percent increase in a city's initial stock of highways leads to a 1.5 percent increase in employment over the 20-year period.

In aviation, Brueckner (1982) was among the first study to explicitly consider the question of whether and how the quality of airline service received by a city impacts its business climate. Focusing on smaller cities, he was unable to obtain conclusive evidence of a relationship. He did note, however, that traffic was higher when a military base was nearby and was also increasing in the share of professional ("white-collar") jobs. Brueckner (2003) found that a 10 percent increase in passenger enplanements in a metro area leads

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[3] Aschauer includes streets, highways, airports, electrical and gas facilities, mass transit, water systems and sewers in this group.

approximately to a one percent increase in employment in service-related industries, with no effect on manufacturing or other types of employment, based on 1979 data. Green (2007) uses time-series data and finds that a 10 percent increase in boardings per capita leads to a 3.9 percent increase in population growth and a 2.8 percent higher employment growth for the ten-year period of 1990 to 2000. Taken together, these papers indicate a likely relationship between air service and local economic outcomes. However, these findings could be dominated by the effects of airports on larger metropolitan areas, such as New York and San Francisco.

Blonigen and Cristea (2012a) exploit the market changes induced by the 1978 Airline Deregulation Act to examine the relationship between air traffic and local economic growth. Using time-series variation in local growth rates over a 20-year period centered around deregulation (1969-1991), they find that air service has a positive and significant effect on regional growth, with the size of these effects differing by the size of the MSA and its industrial mix. Sheard (2014) uses the Civil Aeronautics Administration's 1944 National Airport Plan as an instrument for the current distribution of airports (by size, as measured by air traffic) in the U.S. His dependent variable of interest is employment shares. He estimates that airport size has a positive effect on local employment in tradable services, with an elasticity of approximately 0.1, and a negative effect on manufacturing. He finds no measurable effect on non-tradable services. Note that his instrument is relevant to his question (of employment shares), but endogenous if one is interested in understanding aggregate population or employment outcomes, since, by 1944, planners were basing their assessments on outcomes observed well after the aviation system had become established, and were thus assigning airports to places that planners believed would need them in the future.

This paper contributes to the literature in two ways. First, unlike other papers that consider the effects of aviation only over limited periods, I consider the entire period of aviation in the United States (1900-2010), allowing for a better understanding of how the role of airports may have shifted over time. Second, by explicitly focusing on mid-sized and smaller airports, and using new data from the formative period of aviation to better identify counterfactual cities, I am able to examine these effects in a context that more closely resembles a natural experiment, improving the likelihood of identifying the effects of interest.[4] Third, by focusing on airports in CBSAs as the unit of observation, rather than air traffic, I reduce the likelihood that the observed effects of aviation are unfairly weighted toward the largest cities, which allows for a better understanding of how airports impact smaller metropolitan areas. Finally, the use of three alternative estimation strategies, each operating under different sets of identifying assumptions, allows for a fuller characterization of the role of airports on employment in local economies.

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[4] While understanding the effects of airports on the New York City or San Francisco-Oakland Metropolitan Area is a daunting challenge, it is relatively straightforward, by comparison, to assess how an airport has affected a smaller, more isolated economy, such as the one in Elmira, NY.

1.3 Local Labor Markets and Airports

Public infrastructure, such as airports, may affect the economic activity of a metropolitan area by: (1) acting as an unpaid factor of production in a firm's production function, (2) working to making other inputs more productive, (3) helping to attract other inputs from elsewhere, and/or (4) stimulating demand for more infrastructure (e.g. roads) and related services Eberts and McMillen (1999). In this paper, I focus on the first channel, but note the other three channels could potentially be of importance as well.

The effect of the airport shock on a representative local labor market is shown in the highly stylized model given in Figure 1.1. In this city, labor demand is assumed to be downward sloping, while labor supply slopes upward. In the short run (panel a), the opening of the airport acts as a shock to labor demand, which, being a productive amenity increases as the airport makes (some) existing firms more productive and also attracts new firms to the city. Hence, demand shifts from D_1 to D_2. Wages increase as well, from w_1 to w_2. In the long run (panel b), workers in non-airport cities see the higher wages in the airport city and move there, increasing the supply of labor and shifting labor supply from S_1 to S_2. This shift depresses the short-run wage gains. However, long run employment rests at L_3, which represents a larger gain $(L_3 - L_1)$ relative to the original employment boost $(L_2 - L_1)$. As a result, the airport is expected to increase employment, but not necessarily wages, in long-run equilibrium.[5]

The magnitude of the employment effect $(L_3 - L_1)$ could potentially vary by industry. This would be true if an airport affected certain industries more than others. Assume that firms in all cities produce goods of two types - tradable and non-tradable. Tradable goods - goods that are destined for consumption outside the city where they were produced - are found in the agriculture, mining, manufacturing, and wholesale trade sectors. Non-tradable goods consist of output in the construction, retail trade, finance, insurance and real estate, public administration, and services sector.[6] Let X represent the set of goods produced in the economy. This is then composed of two subsets, tradable x_t and non-tradable x_m firms. There are J tradable industries producing goods x_{t1} through x_{tj}, and K non-tradable industries producing goods x_{m1} through z_{mk}.

Suppose the airport serves as a shock primarily to the tradable industry x_1 in city c. The direct effect of this is an increase in employment for industry x_1. The indirect effect is composed of changes in employment in both sectors. With the positive shock to x_1, aggregate income increases because there are more jobs and, if the labor supply curve slopes upward, local wages are higher, at least in the short-run. This, in turn, stimulates local demand for non-tradable goods. The size of this effect will depend on consumer preferences, the types of jobs in the tradable sector (skilled versus unskilled), and the elasticities of land and labor. The shock to x_1 may also stimulate additional demand for

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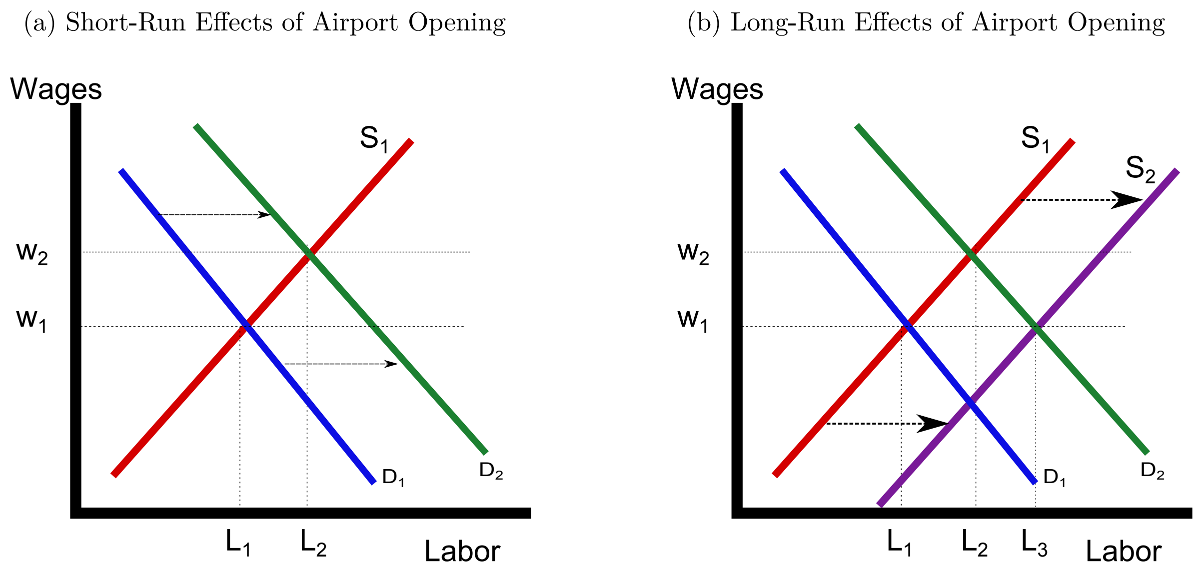
[5] An alternative examination of the city's response to the airport, based on the local labor markets model derived in Moretti (2011), can be found in the Appendix.

[6] The transportation, communications, and utilities sector is considered separately, but is included in all estimates of total employment.

Figure 1.1: Stylized Model of Airports and Local Labor Markets


(a) Short-Run Effects of Airport Opening

(b) Long-Run Effects of Airport Opening

In this highly stylized model, labor demand is assumed to be downward sloping, while labor supply slopes upward. In the short run (panel a), the opening of the airport acts as a shock to labor demand, which increases as the airport makes (some) existing firms more productive and also attracts new firms to the city. Hence, demand shifts from D_1 toD_2 . Wages increase as well, from w_1 to w_2 . In the long run (panel b), workers in non-airport cities see the higher wages in the airport city and move there, increasing the supply of labor and shifting labor supply from S_1 to S_2 . This shift depresses the short-run wage gains. However, long run employment rests at L_3 , which represents a larger gain ($L_3 - L_1$) relative to the original employment boost ($L_3 - L_2$). As a result, the airport is expected to increase employment, but not necessarily wages, in long-run equilibrium.

tradable goods in other tradable industries. However, this need not be a positive effect: the citywide increase in production costs reduces the competitiveness of the other tradable firms. As the price of tradables is fixed on the national market, if the local metropolitan area's cost of production becomes too high, it may become beneficial for some of these firms to shift production to other, less costly areas.

If airports are shown to affect employment in the tradable sector, then potentially gains in the non-tradable sector could be observed as well. However, the reverse would not be true if any employment growth is entirely due to increasing levels of non-tradable employment. I posit that if air travel has an effect on employment, it is likely due to the fact that it allows facilitation of information flows (Bel and Fageda (2008); Giroud (2013); Hovhannisyan and Keller (2011)), enhancing local level productivity. This could occur in either tradable industries, non-tradable industries, or both. It could also be the case that, just as the role of cities has changed over time from hubs of agricultural trade to information-based knowledge economies (see, for example, Boustan et al. (2013)), the role of airports may have shifted over time as well.

1.4 Research Design and Estimation Strategies

1.4.1 Research Design

In the absence of any endogeneity concerns, and under the strong assumption of identical cities with identical populations and sectoral employment structures, if airports were randomly assigned to cities, estimating the treatment effect of airports would be trivially given by the difference in outcomes between airport and non-airport cities. However, even after controlling for differences in city size and employment, there are numerous reasons to believe that airports were not randomly assigned to cities. The Air Commerce Act of 1926 stipulates that the construction of airports is a local responsibility. The demand for airports at a local level can be expected to be heterogeneous - for example, places with larger populations or that expect to grow faster could be more likely to establish airports. The opposite might be true as well - places that foresaw a loss in population or in key industries may have turned to airports as a way to rescue their troubled cities. Furthermore, places where policymakers believed in the "winged gospel" of aviation may have been more likely to put substantial local resources behind airport construction and maintenance Bednarek (2001). Finally, as I discuss below in more detail, efforts of the U.S. Army Air Service and the U.S. Post Office Department in the 1920s and 1930s played a key role in the determination of the post-1950 location of airports.

The timing of airport openings is also a concern. Although comprehensive data on opening dates is unavailable, information is available on service activation dates.[7] In order

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[7] Activation dates indicate when the Federal government added the airport to the National Airport System. Given that these records were not maintained until 1926, airports opening earlier than 1926 are shown as being activated in 1926.

for commercial aviation to affect the economy, not only did airports have to be built, but other pieces of infrastructure such as airways, beacons, and crucially, aircraft, had to be in place and capable of carrying significant numbers of passengers. Such technology did not exist until the post World War II period. Smaller, expensive-to-operate DC-3 propeller aircraft were used by most major airlines in the late 1940s and 1950s. With the advent and proliferation of jet aircraft through the 1960s, air travel quickly became the *de facto* mode of choice for long distance travel. Consistent with these factors, I follow Bednarek (2001) and consider the beginning of the post-war period as the key structural break. Since my data is decadal in nature, I consider 1950 as the base year for estimating treatment effects.[8] Hence, the treatment effect of interest in this study is the effect of a CBSA having an airport activated anytime before 1950, under the assumption that 1950 is the year during which the effects of aviation may first be measured. I also examine effects by decade.

In this study, cities of interest are those containing one (and only one) airport that is fully capable of handling commercial flight activity. To identify this set of airports and corresponding cities, airports are included in the study based upon certain criteria. First, the airport's FAA activation date must be 1950 or prior[9]. Secondly, an airport, by 1950, must be publicly owned and fully available for public use. As a proxy for capability of handling commercial operations, the airport must have an air traffic control tower. Moreover, because the process of receiving an airport in larger cities is determined by factors not common to other cities, an airport must not have been classified by the Federal Aviation Administration (FAA) as a "large hub" airport in 1964.[10] Data from FAA Form 5010 (Airport Master Record), as well as the *FAA Statistical Handbook*, was used to derive the initial sample.[11] Since I am interested in metropolitan area level outcomes, I use Core

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[8] One might argue that I could normalize each airport to its opening date, and look at its evolution after that. However, this would only complicate the analysis, and could even confound it. This is due to a variety of reasons: a) actual "opening dates" are really difficult to track down and are unavailable in many cases (though I have access to an "activation date", but this need not be the opening date; b) since air service essentially started in earnest in the 1945-1950 period in many places, without the technology and conditions for the rest of the aviation network in place, such an analysis would fail to pick up the desired effect of the post-WW II effects of aviation on the economy; and c) the effects of government efforts in fighting the second World War would be picked up in such a normalization (airport closures to civilian traffic, repurposing of some airfields as temporary military bases, etc).

[9] 17 commercial airports were opened after 1950; these were excluded from the sample

[10] Given all the economic processes at work in these larger cities, including such airports could lead to bias in the estimated effects. For example, one might be concerned about confounding arising from multiple issues in this initial sample. Cities such as, say, New York and San Francisco, were destined to get airports with high-frequency service, and to continue to grow independent of any single piece of infrastructure. Moreover, in these extremely large locales, air traffic is often constrained by capacity. Given these complications, and the lack of credible counterfactual CBSAs for such places, identifying the effect of one single piece of infrastructure on population or employment growth could be a task fraught with peril, particularly within the constraints of this project's research design. Therefore, I drop any airport that was classified as a "large hub city" airport in 1964. 1964 was the first year in which a Federal agency classified airports by their size and relevance to the national aviation system.

[11] FAA Form 5010 Data: http://www.faa.gov/airports/airport_safety/airportdata_5010/

Based Statistical Areas (CBSAs) as the unit of observation. Next, in order to reduce confounding, any CBSAs with multiple airports are dropped from the sample, along with CBSAs whose airports are less than 40 miles away from the nearest airport are dropped.[12] Airports that moved were also removed from the sample, giving the main sample of 131 airports. Figure 1.2 shows their locations. I also identify 14 "general aviation" (GA) airports that meet all the conditions above except for (3) to be used as a placebo sample.

To identify a suitable set of control CBSAs, I restrict the sample to the set of control CBSAs that (1) had, at a minimum, limited experience with aviation in the 1920s or (2) were slated to receive a first commercial-level airport under the Civil Aeronautics Administration's National Airport Plan of 1944.[13] For the former, I used the 1926 locations of emergency air fields, hand-entered from the Army Air Service's *Landing Fields in the United States*, as a proxy for a set of places that could support an airport, based on land availability, engineering considerations, and local-level knowledge required to construct an airport. In many (though certainly not all cases), it would have been rather easy to upgrade these facilities during the pre-period to full airport status if desired. After accounting for CBSAs dropped due to inconsistent geography, 379 CBSAs serve as controls. Of these, 110 CBSAs share a boundary with treated CBSAs.

1.4.2 Estimation Strategies

In order to consistently estimate airport treatment effects, I implement three alternative estimators, each considered below in turn: (1) Instrumental Variables (IV), (2) One-to-One Caliper Distance Matching (Matching), and (3) Pooled Synthetic Controls (Synth). Additionally, I present baseline OLS estimates.[14]

1.4.2.1 Instrumental Variables

To address the endogeneity concerns noted above, I propose three instruments for airport location. These are: (1) the locations of collection points on the Air Mail system of 1938, (2) primary cities located on a 1922 plan of airways for national defense, and (3) the locations of a network of Federally constructed emergency air fields from the early years of aviation.

Air Mail Network. As early as 1918, the U.S. Post Office Department was interested in developing a network of air routes to speed mail delivery and increase its revenues for its growing Air Mail service.[15] The Postmaster General originally drew routes with specific objectives (e.g. San Francisco to New York), with the placement of intermediate

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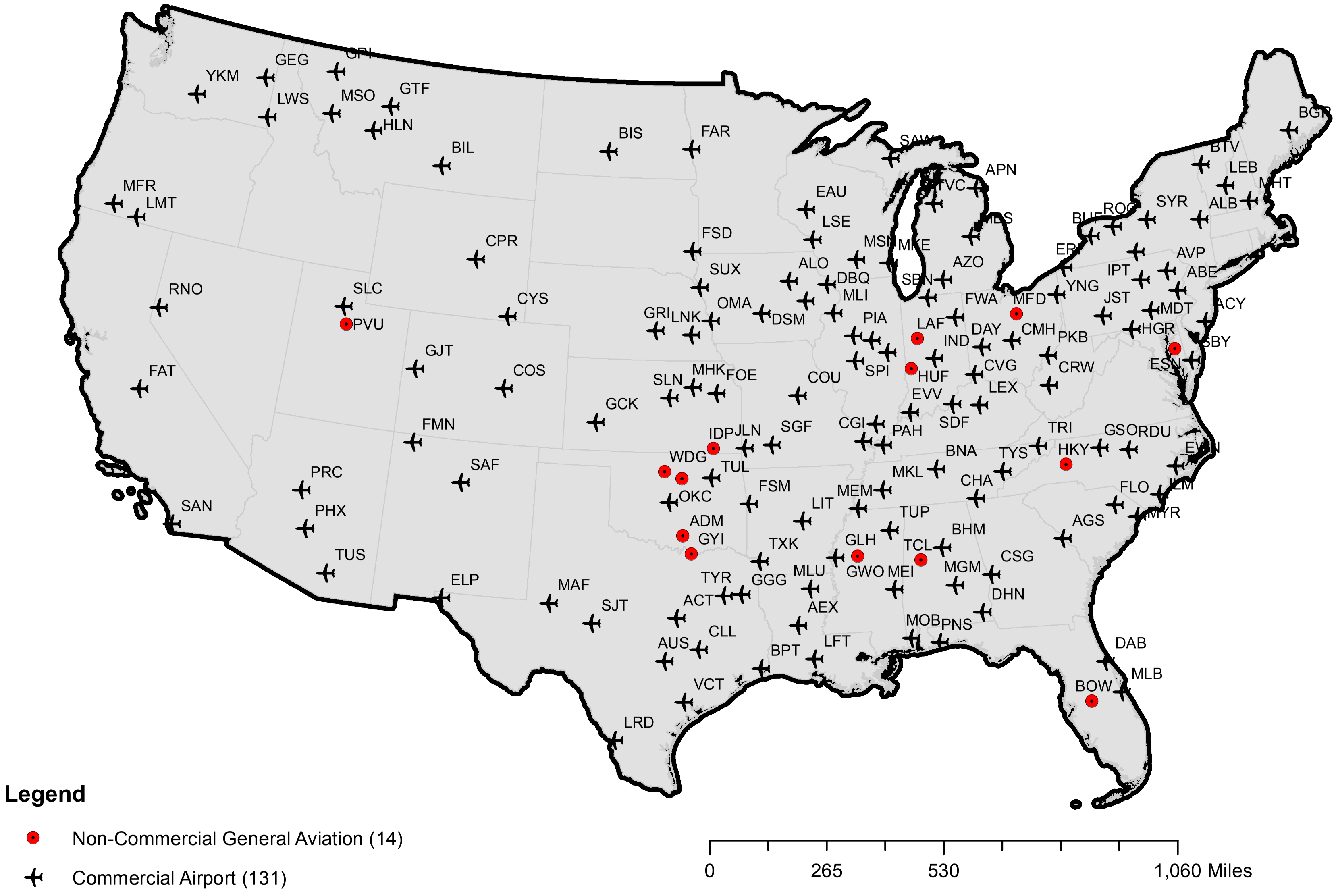
[12] ArcGIS software was used for these calculations.

[13] More precisely, locations proposed to receive airports of Class 3 or greater in the National Airport Plan.

[14] In the appendix, I also provide estimates from a difference-in-difference estimation strategy, but due to the lack of balanced pre-trends between treated and control units, do not use that method as a primary estimation strategy.

[15] See VanDerLinden (2002) for a comprehensive survey of the history of this program.

Figure 1.2: Map of Sample Airports



stops along these trunk lines in large part due to the constraints of early aircraft. Local municipalities, through lobbying efforts, were encouraged to build airports with the promise of profits that would later flow. The Post Office contracted out the actual work of carrying the mail to enterprising airlines, which would later add passenger service as well. In fact, by the mid-1930s, four of the major airlines that would go on to dominate domestic commercial travel for most of the twentieth century began operations as contractors for the Post Office: United, American, Eastern, and Transcontinental and Western Air (TWA). The result is that by 1938, a substantial number of airports had been established and their locations would generally remain fixed. Hence, Air Mail is a relevant instrument because of the pivotal role it played in the establishment of the national aviation network. Additionally, Air Mail should have little to do (directly) with productivity or population growth of today. One may argue, of course, that the places that received Air Mail were more populous and experiencing faster growth than others. Although this is true, this is not a major concern because I control for past growth. Validity of the IV approach requires only orthogonality between post-period outcomes and the instruments conditional on the controls, not unconditional orthogonality Duranton and Turner (2012). Moreover, the fact that the development of the Air Mail system occurred well before 1950 also enhances the case for the validity of Air Mail as an instrument. Data on Air Mail was hand-entered from the First Edition of the *American Air Mail Catalogue*, published in 1940. The *Catalogue* provides an index of all Air Mail routes and cities, including their start dates.

Army Air Service Plan. In 1923, the Army Air Service published the first comprehensive plan of airways and air routes deemed necessary for military navigation in *Airways and Landing Facilities,* a circular providing a template for cities to build their own airports. According to the original document, those airways would “promote commercial aviation, be an important transportation factor in the progress of civilization, and be available for national defense”. The Plan stipulated that airways would have main stations 200 miles apart, substations 100 miles apart with landing fields and some level of basic services, and intermediate airfields 25 miles apart for emergency use. Hence, the location of places chosen as main stations on this plan was stipulated by the requirements above. These airfields were envisioned as places where Army pilots, the National Guard and Reserve units could train. The network was also envisioned to connect parts of the Air Service located in disparate places. For example, one of the first lines was a route between New York City, Washington DC, and Rantoul, Illinois via Dayton, Ohio, where the Air Service’s engineering division was located. This plan is relevant as places located along this network likely were lobbied to construct airfields, as the Army Air Service did not have the budget to carry this out on their own. In some cases, there may have been overlap with the efforts of the Post Office as well. The validity of this plan as an instrument hinges on what was meant by “promote commercial aviation”. While the document says little about this, it appears that the Army Air Service envisioned a network of airways that would primarily serve their own purposes, but yet be open to other users such as the Post Office Department and private citizens. It appears reasonable to assume that these locations were chosen mainly according to the rules set out above, without much concern for the effects of the plan on any particular set of municipalities; hence, any effects that this plan might have on employment could reasonably be expected to happen only through any effect the plan had on airport location. Main cities on the Army Air Service Plan were hand-entered directly from the map.

CAA Intermediate Airfields. These airfields were created by the Civil Aeronautics Administration as a network of emergency landing fields throughout the 1930s and 40s solely for safety reasons. Many paralleled the Air Mail system, and the locations were determined by the Federal government. Given their creation as the result of a policy directive, as well as their proximity to airports that did eventually get constructed, I use their locations as an instrument in the analysis. Their locations are related to where airports might later be permanently located, given that they are essentially mini-airports, but are assumed to be unrelated to any effect on employment or population given their small size.

Estimation. The model is estimated in two stages. The first stage fits a reduced-form equation using the instruments to predict airport location in the post-war period.[16] The second stage takes these predictions and estimates their effect on the outcomes of interest.

I estimate the following system of equations for level effects:

$$A_m = \alpha_1 + \gamma S_m + \pi Z_m + \epsilon_{1,m} \tag{1.1}$$

$$Y^i_{m,t} = \alpha^i_{2,t} + \beta^i_1 A_m + \beta_2 Z_m + \epsilon^i_{2,m,t} \tag{1.2}$$

and the following for long-differences:

$$A_m = \alpha_1 + \gamma S_m + \pi Z_m + \epsilon_{1,m} \tag{1.3}$$

$$\Delta Y^i_m = \alpha^i_2 + \beta^i_1 A_m + \beta_2 Z_m + \epsilon^i_{2,m} \tag{1.4}$$

where Y represents an outcome of interest, S is the vector of instruments , $i \epsilon I$ is a set of sectors in the economy, A is a dummy variable for having an airport in CBSA m, $\boldsymbol{Z}$ is a vector of exogenous controls for pre-period outcomes in the sector of interest (with both level and growth effects included), geography, climate, and access to other transportation networks; α_1 and α^i_2 are intercepts, and β^i_1 is the parameter of interest.β^i_1 is the contribution of having an airport to a CBSA's local economic outcome at time$t > 0$, after controlling for pre-period characteristics, relative to time $t = 0$, where 1950 is normalized to $t = 0$. $\epsilon_{1,m}$ and $\epsilon^i_{2,m}$ represent error terms. In general, $\Delta Y^i_m = ln(Y^i_{m,2010}) - ln(Y^i_{m,1950})$, but the base and end years change to encompass only one decade in some specifications. Where the outcome is presented as an employment share, $ln(Y^i_m) = ln(\frac{Ei}{E_t} \times 100)$, where E_i is employment in the sector of interest, and E_t is total employment.

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[16] As a robustness check, I introduce two alternative instruments - stops on Charles Lindbergh's Guggenheim Tour in 1927, and the locations of commercial/municipal airports in 1926.

It is important to keep in mind that non-randomized studies, such as this, require methods that fully adjust for the imbalance in baseline covariates between treatment and control groups. Regression can be problematic in this case - it can be sensitive to parametric assumptions (e.g. normality), especially when the baseline covariates are highly imbalanced. In this case, the estimates will depend heavily on correct model specification. Moreover, while there is overlap between airport and non-airport counties in the sample, it is a relatively limited amount; regression will tend to extrapolate outside of the region of common support, potentially biasing the results. To check whether this is a concern, I repeat the analysis using two other matching-based methods as described below.

1.4.2.2 Caliper Distance Matching

In addition to the instrumental variables method, the research design lends itself to non-regression-based methods of analysis, such as matching. As a thought experiment, consider a set of cities, some which received airports, some which did not but with otherwise similar population or employment growth characteristics up to and including 1950. Under the assumption of conditional independence, the matching estimator would give the treatment effect of airports. Given the fact that this analysis considers airports of different sizes, with varied geographic endowments and patterns of service, it is necessary to adjust for inliers and outliers, which is done by imposing a caliper.

Let Y, the outcome variable, represent an outcome of interest as in Section 1.4.2.1. The group of treated counties ($A = 1$) are the participants. The interest here is in comparing the mean value of Y in the group of airport counties with the mean value of the non-airport counties ($A = 0$), which are free of any mean differences in outcomes that result from differences in the observed covariates X across the groups. One crucial distinction here from the IV model of Section 1.4.2.1: the X matrix includes all of the variables placed in the Z matrix of the IV, and also includes the instruments themselves. Additionally, I include decade-by-decade interactions for pre-period population and/or employment growth. I make the key identifying assumption that after including this matrix of covariates, the conditional independence assumption is satisfied.

To estimate the effect of interest, the average treatment effect on the treated (ATET), I follow Rosenbaum and Rubin (1985), who suggest a matching strategy that improves on naïve propensity score matching, which is to use a distance metric that not only includes the propensity score, but in addition those covariates that are particularly good predictors of the outcome (in addition to the treatment). Since this distance metric has many components, usually a Mahalanobis distance (MD) is used to compute the distance between the treated and the controls (see Rosenbaum and Rubin (1985)). This is even more important than usual in this case because of the limited overlap on propensity scores between the treated and control groups, and misspecification of the propensity score $\rho(X)$

may lead to biased estimates. The MD between the X covariates for two units i and j is

$$MD(X_i, X_j) = \sqrt{(X_i - X_j)^T \hat{C}^{-1}(X_i - X_j)}$$

where $\hat{C}$ is the sample covariance matrix of X and $X^T$is its transpose. In this project, I include the vector of covariates X, as well as the propensity score, in the match function.

Given the need for enforcing an optimal pre-treatment balance of treated and control units, a caliper is applied as well. A caliper is the distance which is acceptable for any match. Observations which are outside of the caliper are dropped. A caliper value should be provided for each covariate in X. The caliper is interpreted to be in standardized units. The caliper is set to a standard of 0.3 standard deviations for population/employment levels in the pre-treatment period. However, for values in 1940 and 1950, the caliper is enforced at 0.2 standard deviations. Note that caliper= .3 means that all matches not equal to or within 0.3 standard deviations of each covariate in X are dropped. While it is true that dropping observations generally changes the quantity being estimated, this is entirely consistent with the research design as given in Section 1.4.1. In the absence of the caliper, it is impossible to achieve useful pre-treatment covariate balance, given the fact that some airport cities are outliers relative to other CBSAs.

The caliper matching routine was implemented using Jaskeet Sekhon's `Matching` package for `R` Sekhon (2011).

1.4.2.3 Pooled Synthetic Control Analysis

Additionally, I consider a reweighting/matching strategy based on synthetic controls. The use of synthetic controls was first proposed by Abadie and Gardeazabal (2003) and Abadie et al. (2010). It allows for the extension of the traditional differences-in-differences framework by allowing treatment effects to vary over time. In my case, the synthetic control is constructed as the weighted average of CBSAs in the "donor pool" - that is, the set of control counties described in Section 1.4.1.

Suppose there is a sample of $C+1$ CBSAs, indexed by c, among which unit $c = 1$ is the treated CBSA and $c = 2$ to $c = C + 1$ are potential controls. We also assume a balanced panel with a positive number of pre-intervention periods, T_0, as well as a positive number of post-intervention periods, T_1, with $T_0 + T_1 = T$. Let Y_{ct} represent the outcome of unit c at time t. For a given t (with $t \geq T_0$), the synthetic control estimator of airport's effect is given by the difference between the treatment and synthetic control at that period:

$$Y_{1t} - \sum_{c=2}^{C+1} w_c^* Y_{ct}$$

where: $\mathbf{W} = (w_2, ..., w_{C+1})^T$ is a $(C \times 1)$ vector of positive weights that sum to 1; $\mathbf{X}_1$ is a $(k \times 1)$ vector containing a set of pre-intervention characteristic values; and $\mathbf{X}$ is a $(k \times C)$ matrix collecting the values of the same variables for the CBSAs in the set of airport potential CBSAs.

The synthetic control algorithm chooses optimal weights $\mathbf{W}^*$ that minimizes the mean square prediction error (MSPE) given by

$$\text{MSPE} = \|X_1 - X_0 W\|_V = \sqrt{(X_1 - X_0 W)^T V (X_1 - X_0 W)},$$

where an optimal choice of variable weights $\mathbf{V}$ assigns weights to linear combinations of the variables in X_0 and X_1.

In practice, I implement this estimation strategy using Abadie et al. (2011)'s `R` package `Synth`.

Next, I pool treatment and control units to create a set of matched cases. Importantly, to ensure optimal pre-period covariate balance, I discard units with poor fits before fitting the event-time specification to them. In this case, I discard units with MSPE < 0.05. I follow Severnini (2012) and pool treatment and control units to create a set of matched cases. For each outcome of interest Y, for each t in the analysis, estimate the following specifications:

Growth effects:

$$\Delta Y^i_m = \beta^y(\mathbf{1}(treat)) + \alpha_m + \epsilon \tag{1.5}$$

Level effects: For each $t \, \epsilon$ [1950, 1960, 1970, 1980, 1990, 2000, 2010],

$$Y^i_{m,t} = \beta^y_t(\mathbf{1}(treat)) + \alpha_m + \epsilon = \tag{1.6}$$

where α_m is a CBSA fixed effect. Standard errors are clustered at the case (CBSA) level.[17]

1.4.3 Data

A novel data set consisting of a balanced panel of CBSA-level outcomes for 1900-2010, inclusive, was constructed to estimate the effects of interest. It includes data on population, land areas, employment levels by sector, geography and climate characteristics, and previously unexploited historical information related to the development and creation of the aviation system. Most of the data was obtained at the county level and then aggregated into 2010 CBSAs.[18]

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[17] As an alternative, standard errors may be bootstrapped at the CBSA level. Standard errors given by this method are close to, but generally slightly smaller than, bootstrapped standard errors. The standard errors considered here consider the uncertainty in the estimated effects, but not the corresponding uncertainty in the selection of CBSAs in the donor pool.

[18] CBSAs consist of the county or counties or equivalent entities associated with at least one core (urbanized area or urban cluster) of at least 10,000 population, plus adjacent counties having a high degree of social and economic integration with the core as measured through commuting ties with the counties associated with the core. "CBSAs" refers collectively to metropolitan statistical areas and micropolitan statistical areas. CBSAs were selected as the unit of observation for the analysis since the service areas of airports are generally diffuse. The Data Appendix gives more information on how the data were aggregated and adjusted, where necessary, to ensure consistent geography throughout.

Employment data were obtained for the following sectors, in addition to total employment: Agriculture and Mining, Construction, Manufacturing; Transportation, Communications and Utilities; Wholesale Trade; Retail Trade; and Services. In general, data from 1900-1940 were obtained from the IPUMS database Ruggles et al. (2010) by aggregating the micro data to the county level; 1950-1970 data were obtained from aggregate county-level data found in the City and County Data Book; and the remainder was downloaded from National Historical Geographic Information System (NHGIS) at the county level. Population data was obtained from the NHGIS U.S. Census database as well. I use payroll values from the County Business Patterns (CBP). For 1950, data were hand-entered from the 1951 CBP where available, and imputed for the rest based on 1964 values and state level effects, with additional values from NHGIS. Earnings data was also obtained from the Bureau of Economic Analysis. For rents, I use median contract rents from the City and County Data Book for 1930 and 1940, as well as rents from the NHGIS Census database for 1980-2010 (the rest are missing). More details on the construction of the population and employment data can be found in Appendix A.

Additionally, data were collected on a variety of geographic, transportation, and climate characteristics as controls. Region controls include dummy variables for each of the nine Census divisions and CBSA land area. Other controls for 1887 straight-line rail mileage, planned 1947 highway mileage, having a port, having a political capital city, mean January temperature, having a coastal location, and for close proximity to a river. Please see Appendix A for more details on the source and construction of each of these variables.

Appendix Table A.1 gives characteristics of CBSAs with and without airports. Airport CBSAs are more likely to contain political capital cities and to have a land grant college. They are also more likely to have larger amounts of other transportation infrastructure such as roads, ports, or river access, and to be larger in overall land area as well. However, climate does not vary substantially between CBSAs with airports and those without. Additionally, the distribution of airports and non-airport CBSAs across regions are similar. Other findings are also consistent with the discussion given in Section 1.4. Airport CBSAs were more likely to have been located on the 1938 Air Mail network, and to have been home to a city listed in the 1922 Army Air Service Proposed System of Air Routes. Moreover, airport CBSAs are more likely to have been home to CAA intermediate airfields, political capital cities, and to have a land grant college. They are more likely to have larger amounts of other transportation infrastructure such as roads, ports, or river access, and to be larger in land area as well. In general, climate does not vary substantially between CBSAs with airports and those without. Finally, the distribution of airports and non-airport CBSAs across regions, access to a coast, and right-to-work state status are roughly similar. In what follows, controls for many of these characteristics will be included.

Table 1.1: Sample Means - Airport Characteristics

	All Airports ($n = 131$)	
Variable	Mean	SD
Activation Year	1940.66	(2.91)
Distance to nearest CBD (miles)	4.79	(2.53)
Land Area of Airport (acres)	2185.52	(1667.94)
Current length of longest runway (feet)	8894.42	(1730.72)
Distance to nearest comm. airport (miles)	87.60	(39.46)
Boardings/Enplanements [thousands] (1960)	103.22	(165.25)
Boardings/Enplanements [thousands] (1980)	369.78	(570.63)
Boardings/Enplanements [thousands] (2010)	869.20	(2091.69)
Flights/Operations [thousands] (1960)	6.04	(7.39)
Flights/Operations [thousands] (1990)	35.13	(56.23)
Flights/Operations [thousands] (2010)	35.98	(61.77)
Per Capita Boardings (1960)	0.29	(0.39)
Per Capita Boardings (1980)	0.95	(0.94)
Per Capita Boardings (2010)	1.13	(1.19)

Notes: Standard Deviations (SD) in parentheses. Boardings/enplanements and flights include air carrier, air taxi (on-demand) and commuter flights.

1.5 Case Study

This section presents two case studies illustrating the links between a region's airport and its economy: Springfield, Missouri (Springfield-Branson National Airport) and Elmira, New York (Elmira Corning Regional Airport). The Springfield case study illustrates how an airport, coupled with a vibrant local economy, can benefit a metropolitan area, while the Elmira case illustrates how an airport could fail to substantially impact a city's fortunes over the long term. Each case considers four outcomes: population, total employment, tradable employment and non-tradable employment, Additionally, I compare the airport city outcome to its match given by one-to-one caliper matching (Section 1.4.2.2) and its estimated synthetic control unit (Section 1.4.2.3).

Springfield–Branson National Airport (SGF) opened in 1945 and its metropolitan area has since boomed. A recent economic impact study finds that SGF generated 4,454 jobs, \$154 million in payroll, and \$402 million in total output as of 2012, accounting for 2.48 percent of total metropolitan area output.[19] A glance at Figure 1.3 reveals Springfield has experienced large levels of population and employment increase since 1950, with only the tradable sector seeing employment declines limited to more recent years. In comparison, Pittsfield, Massachusetts, a city with similar pre-1950 population and employment levels but no airport, experienced peak population during the 1960s with subsequent decline,

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[19] MO Statewide Airports Economic Impact Study:
http://www.modot.org/othertransportation/aviation/documents/Missouri-2012-Economic-Impact.pdf

and a relatively flat employment profile overall. It appears that Springfield's ability to attract and subsequently retain tradable sector jobs, coupled with its ability to capitalize on tourism and boost its non-tradable sector employment, was due in no small part to the presence of SGF. However, Springfield also benefited from its central location on the railroad network and position as a regional grain and dairy processor. In the post-war period, it would quickly diversify into manufacturing as well Kirkendall (1986).

In contrast to Springfield, Elmira, New York, always a heavily manufacturing based economy, has experienced continued population and employment decline since the 1960s, a trend that Elmira's airport was unable to help reverse. Elmira's county-owned airport, Elmira-Corning Regional (ELM), opened in 1945. A 2011 economic impact study estimates that ELM supported 1,669 direct jobs and 1,708 indirect jobs.[20] The airport also accounts for $208 million in payroll and $1.5 billion in output.[21] Danville, Ohio was similarly positioned to Elmira before 1950, sharing many similarities with Elmira. However, Danville never received an airport. In the past, both Danville and Elmira were major thoroughfares for rail freight. A look at Figure 1.4 reveals that in both places, total employment has been essentially flat since 1950. Additionally, tradable sector employment, driven by manufacturing increased, then declined starting in the 1950s, never to recover. Both places were positioned similarly before Elmira's airport opened, and have followed similar trajectories since, indicating that ELM did not have a substantial effect on its local economy. In fact, a look at the synthetic control unit relative to each outcome shows that Elmira may have performed worse than what would be expected even in the absence of an airport. Unlike the case of Springfield, Elmira's airport was not able to stem the region's gradual decline. This was especially the case, as it was part of the Rust Belt, and also experienced a large flood in 1972 that would wipe out much of its manufacturing capacity. Even with the airport, Elmira would never recover.

1.6 Results

1.6.1 Long Differences, 1950-2010

Ordinary Least Squares. Table 1.2 gives the main OLS results for the various outcomes considered - long-differences estimating the growth in the working age population (comprised of individuals between ages 15 and 64), total employment, and employment in tradable, non-tradable, and transportation resulting from the presence of an airport

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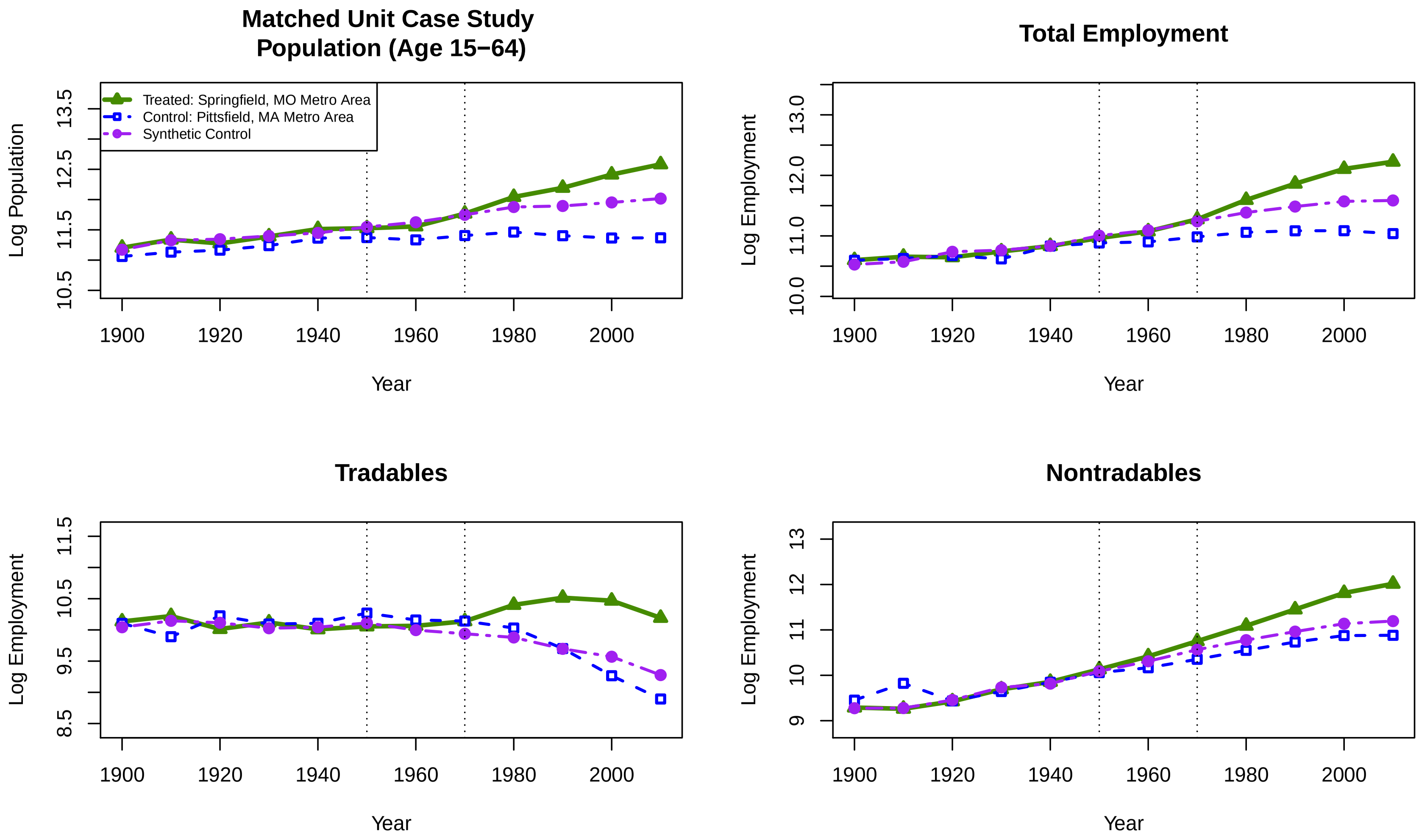
[20] https://www.dot.ny.gov/divisions/operating/opdm/aviation/repository/NYS%20Economic %20Study%202010%20Technical%20Report_0.pdf

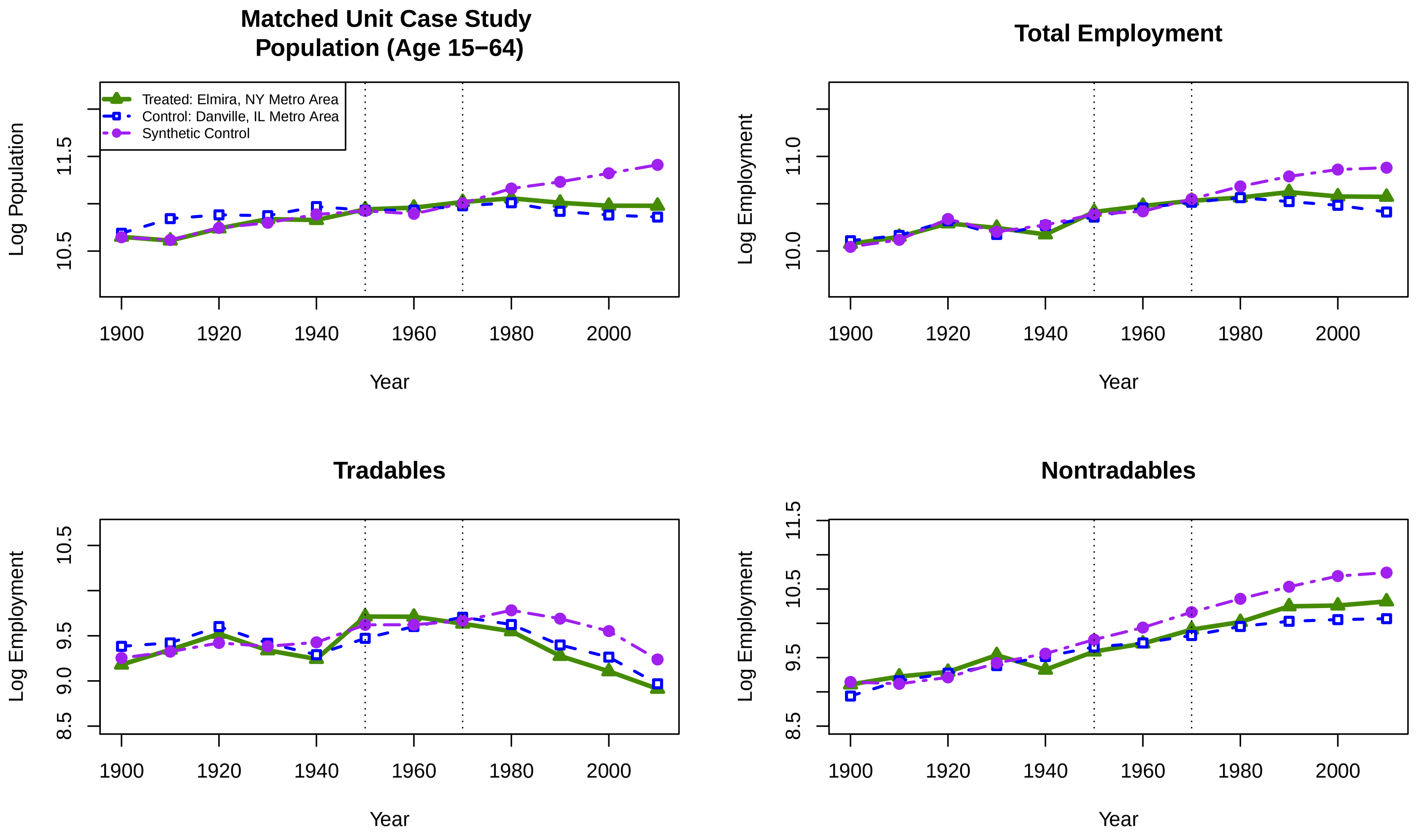
[21] Since the ELM economic impact figure included the now-defunct Sikorsky Aircraft Corporation's output in its totals, the case of nearby, slightly smaller Greater Binghamton Regional may provide a better idea of ELM's true economic impact. There, total payroll generated by the airport was estimated at $23 million, and total output was estimated at $52 million, with 483 jobs supported by the airport.

Figure 1.3: Case Study: Springfield, MO (SGF)



Notes: Graphs show sectoral employment and population outcomes for the treated airport CBSA, a control unit identified by caliper matching, and a synthetic control unit. Please see Section 1.4.2 for more details.

Figure 1.4: Case Study: Elmira, NY (ELM)



Notes: Graphs show sectoral employment and population outcomes for the treated airport CBSA, a control unit identified by caliper matching, and a synthetic control unit. Please see Section 1.4.2 for more details.

in a CBSA.[22] Panel A, controlling only for levels of pre-period population through 1950 and CBSA land area, gives an estimate of 0.364 (43.9 percent). Thus, it appears that in that initial specification, population grew 44 percent more in airport CBSAs than in non-airport CBSAs over the 1950-2010 study period. Controlling for regional effects via indicator variables for the nine Census divisions reduces the estimate to 0.246 (27.9 percent). Adding other controls in specification (3) – controls for 1887 straight-line rail mileage, planned 1947 highway mileage, having a port, being a political capital city, mean January temperature, having a coastal location, and for close proximity to a river – gives a very similar estimate of 0.252 (28.7 percent). In Panel B, estimates in the first three specifications ranges from 0.430 (52 percent) with only prior population controls included, to 0.292 (33.9 percent) with all controls, except for pre-period population, included. Specifications (4) through (6) replicate specifications (1) through (3), the only difference being the inclusion of controls for past population levels. The estimates change little, as the final estimate given in specification (6) of Panel B is 0.273 (31.4 percent).

Panel C shows the effects on tradable employment. Here, adding population controls has an interesting effect, reducing the magnitude of the estimated coefficients dramatically. This is puzzling. Economically, there is no reason to believe that tradable employment levels should respond much to city population. This is especially true since tradable employment, by definition, includes the production of goods and services that are sold on a national or international market, for consumption (in general) outside the borders of any single metropolitan area. Moreover, in Panel D, estimates of non-tradable employment remain stable across all six specifications, with a coefficient of 0.164 (17.8 percent) in specification (3), and 0.157 (17 percent) in specification (6). If, indeed something is happening here that is economically significant, we would expect the estimates for specifications (4) - (6) in Panel B to be substantially smaller and closer to their counterparts in Panel D, which is clearly not the case.

One plausible explanation is that the estimates for the tradable sector exhibits classical measurement error that worsens in the presence of multicollinearity (see, for example, Carroll, Raymond et al. (2006)). While the processes generating the data for tradable employment and total population differ, it is likely that any error in measurement is common to both. Moreover, the correlation coefficient between the two variables is 0.87 in 1950 and 0.86 in 2010, so multicollinearity could very well be a concern. The components that comprise tradable sector employment - agriculture and mining, manufacturing, and wholesale trade - exhibit higher levels of variability relative to the other study variables. The noise increases the bias in the tradable sector estimates. This, coupled with collinearity that accentuates attenuation of the coefficient on having an airport, leads to estimates that are subject to a significant amount of attenuation bias.[23]

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[22] Tradable goods are produced in the agriculture, mining, manufacturing, and wholesale trade sectors. Non-tradable goods are produced in the construction, retail trade, finance, insurance and real estate, public administration, and services sector. (The transportation, communications, and utilities sector is considered separately.)

[23] Following Carroll, Raymond et al. (2006), consider the general linear model $Y = \beta_0 + \beta_z^t Z + \beta_x^t X + \epsilon$.

Table 1.2: OLS Results: Effect of Airports on CBSA Outcomes, Long Differences 1950-2010

	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: Change in Population (All Persons, Ages 15 - 64), 1950-2010						
Airport	0.349***	0.223***	0.235***	0.349***	0.223***	0.235***
	(0.064)	(0.060)	(0.053)	(0.064)	(0.060)	(0.053)
R^2	*.335*	*.481*	*.549*	*.335*	*.481*	*.549*
n	508	508	506	508	508	506
Panel B: Change in Total Employment, 1950-2010						
Airport	0.430***	0.298***	0.292***	0.400***	0.262***	0.273***
	(0.067)	(0.064)	(0.056)	(0.064)	(0.062)	(0.057)
R^2	*.291*	*.439*	*.512*	*.358*	*.503*	*.548*
n	508	508	506	508	508	506
Panel C: Change in Tradable Sector Employment, 1950-2010						
Airport	0.479***	0.358***	0.311***	0.222***	0.160**	0.190***
	(0.069)	(0.072)	(0.065)	(0.067)	(0.070)	(0.067)
R^2	*.279*	*.374*	*.448*	*.416*	*.462*	*.491*
n	506	506	504	506	506	504
Panel D: Change in Non-Tradable Sector Employment, 1950-2010						
Airport	0.182***	0.144***	0.164***	0.164***	0.126***	0.157***
	(0.053)	(0.049)	(0.047)	(0.053)	(0.049)	(0.047)
R^2	*.435*	*.518*	*.549*	*.449*	*.533*	*.56*
n	496	496	494	496	496	494
Panel E: Change in Transportation Sector Employment, 1950-2010						
Airport	0.396***	0.287***	0.248***	0.238***	0.125**	0.124**
	(0.076)	(0.076)	(0.068)	(0.066)	(0.062)	(0.060)
R^2	*.215*	*.368*	*.475*	*.477*	*.571*	*.612*
n	420	420	419	420	420	419
Controls:						
Pre-period Employment	Y	Y	Y	Y	Y	Y
Pre-period Population	N	N	N	Y	Y	Y
Region	N	Y	Y	N	Y	Y
Geography/Transport	N	N	Y	N	N	Y

Notes: Table reports results of ordinary least squares (OLS) regressions of log population/employment outcomes given above on an indicator variable for whether a CBSA has an airport, with various controls as indicated. Cluster-robust standard errors in parentheses clustered at the CBSA level. Pre-period controls include employment controls specific to the sector being analyzed, in log levels, for 1900 -1950 in ten year increments. (Log population is substituted for log employment in Panel A.) Population controls include controls for pre-period 15-64 population, in log levels, for 1900-1950 in ten year increments. Region controls include dummy variables for each of the nine Census divisions and CBSA land area. Geography/transport includes controls for 1887 straight-line rail mileage, planned 1947 highway mileage, having a port, being a political capital city, mean January temperature, having a coastal location, and for close proximity to a river. Tradable sector employment is the sum of agricultural, mining, manufacturing, and wholesale trade sector employment. Non-tradable sector employment is the sum of retail trade, finance/insurance/real estate, business, professional and other services, construction, and public administration sector employment.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

In Panel E, specification (3) gives an estimate of transportation, communications and utilities (hereafter transportation) sector employment of 0.248 (28.1 percent), while specification (6) gives an estimate of 0.124 (13.2 percent). Given the discussion above, it appears likely that the transportation sector estimates also suffer from attenuation bias. Additionally, it follows that specifications (4) - (6) for the IV estimates that follow may also be biased for tradable sector employment and transportation employment.

Instrumental Variables. Table 1.3 gives the first stage of the IV estimation, which predicts whether or not a CBSA will have an airport in 1950 or after, relying on all instruments as described in 1.4.2.1. Across all six specifications, the instruments remain positive and in most cases significant. Of the three instruments, the location of 1938 air mail terminals consistently provides the largest contribution to the first stage. P-values from Hansen's J test are large, especially in specifications (3) and (6), indicating that the excluded instruments are appropriate and are independent of the error process. The smallest F-statistic of the six specifications is 28.30 and the R^2 statistics are between 0.45 and 0.50, indicating the instruments have reasonable explanatory power. In what follows, the first stage always uses all three instruments. Table A.6 in the Appendix shows that estimates on total employment are reasonably robust to the combination of instruments used.

Table 1.4 presents the IV counterparts to the estimates provided in Table 1.2. IV estimates on population growth in Panel A, specifications (3) and (6) are slightly larger than their OLS counterparts. In Panel B, total employment is estimated to increase by 0.312 (36.6 percent) before controls for population are included, or 0.235 (26.5 percent) once they are added. In Panel C, tradable sector employment experiences the most dramatic change between specifications once prior population is added in specifications (4) through (6), with the estimated effect going from 0.335 (40 percent) in specification (3) to 0.038 (3.9 percent) in specification (6). In contrast, estimates of non-tradable employment in Panel D actually increase somewhat and more likely to remain significant after controlling for population. Finally, Panel E shows that transportation sector estimates decrease from 0.433 (54.2 percent) in specification (3) to a non-significant 0.185 (20.3 percent) once population controls are applied.

As in the OLS case above, the dramatic influence of population controls on both tradable and transportation employment effects is puzzling. It is likely that the instrumental variables estimator was unable to correct for the attenuation bias in the original OLS estimates; hence the IV estimates in specifications (4) through (6) may not be valid. To determine whether these estimates are economically significant, or due to multicollinearity

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In the presence of classical measurement error, when $Z = 0$, it can be shown that regressing Y on X yields $\hat{\beta}^t_x = \beta^t_x \cdot \frac{\sigma^2_x}{\sigma^2_x+\sigma^2_u}$. Adding the set of covariates Z, in this case, log population, changes the attenuation factor. It becomes $\hat{\beta}^t_x = \beta^t_x \cdot \frac{\sigma^2_{x|z}}{\sigma^2_{x|z}+\sigma^2_u}$, where $\sigma^2_{x|z}$ is defined as the residual variance in the regression of X on the added covariates Z. In the presence of Z, $\sigma^2_{x|z} < \sigma^2_x$, implying that collinearity accentuates attenuation. Given the amount of noise in the tradable sector (and transportation sector) data, it is likely that measurement error has induced bias in the affected estimates.

Table 1.3: IV Regressions - First Stage Statistics

	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	Dependent Variable: Have Airport					
1922 Army Air Service Plan	0.234***	0.180***	0.156**	0.229***	0.163**	0.142**
	(0.0606)	(0.0628)	(0.0666)	(0.0611)	(0.0635)	(0.0668)
1938 Air Mail Route	0.443***	0.405***	0.391***	0.437***	0.389***	0.375***
	(0.0570)	(0.0591)	(0.0624)	(0.0582)	(0.0607)	(0.0636)
CAA Intermediate Airfield	0.0452	0.0567*	0.0717**	0.0424	0.0556*	0.0698**
	(0.0309)	(0.0312)	(0.0342)	(0.0311)	(0.0309)	(0.0338)
Constant	-0.925***	-1.438***	-1.332***	-0.785***	-1.302***	-1.187***
	(0.176)	(0.234)	(0.277)	(0.247)	(0.287)	(0.336)
Controls:						
Pre-period Employment	Y	Y	Y	Y	Y	Y
Pre-period Population	N	N	N	Y	Y	Y
Region	N	Y	Y	N	Y	Y
Geography/Transport	N	N	Y	N	N	Y
Observations	508	508	506	508	508	506
R-squared	0.451	0.480	0.486	0.459	0.492	0.497
F statistic	62.78	39.78	31.61	45.81	34.84	28.30
Overid (Hansen's J) P-Value	0.0839	0.726	0.906	0.0216	0.660	0.649

Note: Table reports the first stage regressions of CBSA airport status on whether the CBSA was on the 1922 Army Air Service Proposed Airways Systems of the United States, the 1938 Air Mail network, or on a CAA intermediate airfield. Cluster-robust standard errors given in parentheses, clustered on the CBSA level.
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 1.4: IV Results: Effect of Airports on CBSA Outcomes, Long Differences 1950-2010

	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: Change in Population (All Persons, Ages 15 - 64), 1950-2010						
Airport	0.571***	0.254*	0.255*	0.571***	0.254*	0.255*
	(0.127)	(0.139)	(0.134)	(0.127)	(0.139)	(0.134)
First Stage F	*69.245*	*43.176*	*33.617*	*69.245*	*43.176*	*33.617*
n	508	508	506	508	508	506
Panel B: Change in Total Employment, 1950-2010						
Airport	0.681***	0.339**	0.312**	0.653***	0.231	0.235*
	(0.130)	(0.139)	(0.130)	(0.126)	(0.144)	(0.138)
First Stage F	*62.777*	*39.775*	*31.612*	*45.806*	*34.844*	*28.295*
n	508	508	506	508	508	506
Panel C: Change in Tradable Sector Employment, 1950-2010						
Airport	0.719***	0.466***	0.335**	0.273**	0.032	0.038
	(0.119)	(0.128)	(0.137)	(0.131)	(0.154)	(0.164)
First Stage F	*52.589*	*32.095*	*28.475*	*48.698*	*34.804*	*30.582*
n	506	506	504	506	506	504
Panel D: Change in Non-Tradable Sector Employment, 1950-2010						
Airport	0.300***	0.157	0.178	0.301***	0.181	0.251*
	(0.111)	(0.124)	(0.123)	(0.114)	(0.127)	(0.130)
First Stage F	*76.203*	*46.382*	*35.998*	*51.121*	*38.247*	*31.745*
n	496	496	494	496	496	494
Panel E: Change in Transportation Sector Employment, 1950-2010						
Airport	0.773****	0.549****	0.433***	0.509****	0.235*	0.185
	(0.153)	(0.163)	(0.152)	(0.124)	(0.135)	(0.139)
First Stage F	*69.487*	*45.751*	*34.34*	*52.465*	*43.248*	*34.832*
n	420	420	419	420	420	419
Controls:						
Pre-period Employment	Y	Y	Y	Y	Y	Y
Pre-period Population	N	N	N	Y	Y	Y
Region	N	Y	Y	N	Y	Y
Geography/Transport	N	N	Y	N	N	Y

Notes: Table reports results of instrumental variables (IV) regressions of log population/employment outcome on an indicator variable for whether a CBSA has an airport, with various controls as indicated. Cluster-robust standard errors in parentheses clustered at the CBSA level. Pre-period controls include employment controls specific to the sector being analyzed, in log levels, for 1900 -1950 in ten year increments. (Log population is substituted for log employment in Panel A.) Population controls include controls for pre-period 15-64 population, in log levels, for 1900-1950 in ten year increments. Region controls include dummy variables for each of the nine Census divisions and CBSA land area. Geography/transport includes controls for 1887 straight-line rail mileage, planned 1947 highway mileage, having a port, being a political capital city, mean January temperature, having a coastal location, and for close proximity to a river. Tradable sector employment is the sum of agricultural, mining, manufacturing, and wholesale trade sector employment. Non-tradable sector employment is the sum of retail trade, finance/insurance/real estate, business, professional and other services, construction, and public administration sector employment.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

or perhaps noise in the data interacting with the past population levels, I next present results from two related, but different methods based on entirely separate sets of assumptions: one-to-one matching with caliper, and pooled synthetic controls. As these are not regression-based methods, they do not suffer from the possibility of attenuation bias. Hence, if in the matching and synthetic control estimates, specifications (4) - (6) are close to their respective counterparts in specification (1) - (3), it is extremely likely that attenuation bias is at play. Moreover, using these two alternative methods enables a general check on the soundness on the magnitudes and signs of the IV estimates presented in Table 1.4.

Caliper Matching. Caliper matching, along with the pooled synthetic control method, requires balance between treated and control units in the pre-period. Panel 3 of Figures 1.5 through 1.9 show the matching method was able to successfully balance the primary covariates of past population and employment across the pre-period. Turning to the results presented in Table 1.5, note that across all employment and population groups considered in panels A through E, there is very little difference in the estimates across specifications (1) - (3). Additionally, the inclusion of population controls makes little difference in the magnitude of the estimates, as expected. Taking specification (6) as the final specification for this method, we see that airports are responsible for growth in population of 0.194 (21.4 percent), overall employment growth of 0.275 (31.7 percent), and growth in transportation sector employment of 0.567 (76.3 percent). Importantly, in Panel C, it is clear that the estimate of growth in the tradable sector, 0.355 (42.6 percent), is much closer to the estimated growth in the tradable sector given by specification (3) of the IV Table 1.4, 0.335 (39.8 percent) than specification (6), 0.038 (3.9 percent). Moreover, the growth in the non-tradable sector of 0.149 (16.1 percent) estimated by caliper matching is closer to the IV specification (3) estimate of 0.178 (19.5 percent) than it is to the specification (6) estimate of 0.251 (28.5 percent). Effects on the transportation sector remain large and significant throughout all specifications, with estimated employment growth of 0.567 (76.3 percent) given by the final specification (6).

Pooled Synthetic Controls. Panel 4 of Figures 1.5 through 1.9 show the pooled synthetic control method was also able to successfully balance the primary covariates of past population and employment. Generally, the coefficients estimated by the synthetic control method are smaller than those obtained by matching. This is expected, as each synthetic case study is essentially providing a custom reweighted control estimate for each treated unit. In contrast, caliper matching only ensures balance on average, but not within individual matched pairs. In general, after all covariates are added to the model in specification (6), growth in population resulting from the airport is estimated to be 0.136 (14.6 percent). The change in total employment is estimated to be 0.160 (17.4 percent). Notably, even with the reduced magnitudes of those estimates, the change in tradable sector employment remains large at 0.255 (29 percent), again more in line with IV Table 1.4 specification (3) than specification (6). In contrast to the other methods, small and insignificant effects for non-tradable employment are obtained. Also, just as in the case with matching and IV specification (3), effects on the transportation sector remain large

Table 1.5: Caliper Matching Results: Effect of Airports on CBSA Outcomes, Long Differences 1950-2010

	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: Change in Population (All Persons, Ages 15 - 64), 1950-2010						
Airport	0.184***	0.176***	0.194***	0.166**	0.179***	0.194***
	(0.066)	(0.067)	(0.068)	(0.066)	(0.068)	(0.068)
Matched Cases n	76	76	76	76	76	76
Panel B: Change in Total Employment, 1950-2010						
Airport	0.272***	0.273***	0.265***	0.287***	0.256***	0.275***
	(0.050)	(0.053)	(0.053)	(0.050)	(0.054)	(0.053)
Matched Cases n	74	74	74	74	74	74
Panel C: Change in Tradable Sector Employment, 1950-2010						
Airport	0.362***	0.385***	0.355***	0.380***	0.388***	0.355***
	(0.060)	(0.058)	(0.055)	(0.059)	(0.058)	(0.056)
Matched Cases n	71	71	71	71	71	71
Panel D: Change in Non-Tradable Sector Employment, 1950-2010						
Airport	0.154***	0.163***	0.145***	0.122***	0.148***	0.149***
	(0.040)	(0.038)	(0.038)	(0.040)	(0.040)	(0.038)
Matched Cases n	54	54	54	54	54	54
Panel E: Change in Transportation Sector Employment, 1950-2010						
Airport	0.490***	0.538***	0.586***	0.422***	0.443***	0.567***
	(0.052)	(0.054)	(0.056)	(0.047)	(0.048)	(0.055)
Matched Cases n	28	28	28	28	28	28
Controls:						
Pre-period Employment	Y	Y	Y	Y	Y	Y
Pre-period Population	N	N	N	Y	Y	Y
Region	N	Y	Y	N	Y	Y
Geography/Transport	N	N	Y	N	N	Y

Notes: Table reports results of log population/employment outcomes given above on an indicator variable for whether a CBSA has an airport, with various controls as indicated, after employing one-to-one matching with caliper. The caliper is set such that observations outside of 0.3 standard deviations of 1900 - 1940 employment, and 0.2 standard deviations of 1950 employment, are dropped prior to employing standard one-to-one matching. Robust Abadie-Imbens standard errors are given in parentheses. Pre-period controls include employment controls specific to the sector being analyzed, in log levels, for 1900 -1950 in ten year increments. (Log population is substituted for log employment in Panel A.) Population controls include controls for pre-period 15-64 population, in log levels, for 1900-1950 in ten year increments. Region controls include dummy variables for each of the nine Census divisions and CBSA land area. Geography/transport includes controls for 1887 straight-line rail mileage, planned 1947 highway mileage, having a port, being a political capital city, mean January temperature, having a coastal location, and for close proximity to a river. Tradable sector employment is the sum of agricultural, mining, manufacturing, and wholesale trade sector employment. Non-tradable sector employment is the sum of retail trade, finance/insurance/real estate, business, professional and other services, construction, and public administration sector employment.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

and significant throughout all specifications, with a value of 0.333 (39.5 percent) obtained in the final specification (6).

Overall, it appears that with the inclusion of past population histories, matching and synthetic control estimates respond little to the additional information. The response of sectoral employment, particularly tradable and transportation, to the inclusion of past population values in the OLS and IV specifications is likely due to attenuation bias. This may result from measurement error, noise, and/or multicollinearity, and is not reflective of any critical structural trends in local economy employment not already captured by past employment level controls. As a result, I take model (3) as my final specification in the OLS and IV cases, and use the values from specification (6) when discussing the matching and synthetic control cases, since they appear to respond as expected – that is, not substantially – to the inclusion of population as a control. The top panel of Appendix Table A.2 summarizes these findings by method for each method's preferred specification. [24]

Considering the evidence presented thus far, I find that over the 1950-2010 period, the presence of airports in a CBSA has caused population growth ranging between 0.136 (14.6 percent) and 0.255 (29 percent), total employment growth of between 0.160 (17.4 percent) and 0.312 (36.6 percent), tradable sector employment growth of between 0.236 (26.6 percent) and 0.355 (42.6 percent), and non-tradable employment growth of between a non-statistically significant 0.027 (2.7 percent) and 0.149 (16.1 percent).

It is instructive to interpret the results in light of CBSA employment shares to understand these estimated responses in the broader context of other local economic trends. In 1950, the share of tradable sector employment in airport CBSAs was 40.5 percent, while the share in non-airport counties was 47.8 percent. By 2010, these shares had decreased to 16 and 20.5 percent, respectively. Even with the increase in tradable employment levels, relative to their 1950 levels, airports caused a decrease in tradable employment shares of between 0.142 (15.3 percent) and 0.234 (26.4 percent) while leading to their increase in the non-tradable sector by 0.038 (3.9 percent) to 0.083 (8.7 percent). Taken together, the job "growth" estimated for tradable sector jobs is essentially one of retaining existing tradable sector jobs, which through multiplier effects led to the creation of more non-tradable sector jobs. As the entire U.S. economy shifted from a manufacturing-based economy to a service-based one, airports played a key role in the transition.

Finally, in all the estimates, note the effect on population is less than that on employment in virtually all the specifications. Not only did airports contribute to increasing levels of employment among the existing labor force, but they appear to have intensified labor force participation as well, providing the jobs that would enable, for example, women to join the ranks of the employed in significant numbers. Figure A.3 shows how airports shifted the employment to population (EPOP) ratio on average as well, with much of the divergence occurring in the 1970s.

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[24] Appendix Table A.2 provides difference-in-difference estimates for reference as well, many of which are close to methods estimated by the other methods.

Table 1.6: Synthetic Control Results: Effect of Airports on CBSA Outcomes, Long Differences 1950-2010

	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: Change in Population (All Persons, Ages 15 - 64), 1950-2010						
Airport	0.091	0.171**	0.136**	0.091	0.171**	0.136***
	(0.075)	(0.067)	(0.067)	(0.075)	(0.067)	(0.067)
Matched Cases n	68	76	94	68	76	94
Panel B: Change in Total Employment, 1950-2010						
Airport	0.153*	0.238***	0.211**	0.146*	0.231***	0.160***
	(0.088)	(0.074)	(0.084)	(0.080)	(0.078)	(0.073)
Matched Cases n	63	75	81	70	70	84
Panel C: Change in Tradable Sector Employment, 1950-2010						
Airport	0.251***	0.282***	0.301***	0.196**	0.295***	0.255***
	(0.082)	(0.085)	(0.095)	(0.081)	(0.092)	(0.062)
Matched Cases n	56	65	76	63	65	78
Panel D: Change in Non-Tradable Sector Employment, 1950-2010						
Airport	0.018	0.114**	0.059	-0.021	0.085	0.027
	(0.069)	(0.074)	(0.071)	(0.071)	(0.071)	(0.067)
Matched Cases n	50	59	82	58	65	82
Panel E: Change in Transportation Sector Employment, 1950-2010						
Airport	0.761***	0.664***	0.318***	0.410***	0.493***	0.333***
	(0.142)	(0.151)	(0.114)	(0.100)	(0.114)	(0.106)
Matched Cases n	38	41	55	41	42	57
Controls:						
Pre-period Employment	Y	Y	Y	Y	Y	Y
Pre-period Population	N	N	N	Y	Y	Y
Region	N	Y	Y	N	Y	Y
Geography/Transport	N	N	Y	N	N	Y

Notes: Table reports results of log population/employment outcomes given above on an indicator variable for whether a CBSA has an airport, with various controls as indicated. First, a synthetic control unit was estimated for each of the above outcomes for each CBSA with an airport. Then, the treated/synthetic control units were pooled, and poorly fitting cases, defined here as cases where the mean squared prediction error (MSPE) of the synthetic unit was above 0.05, were removed. Next, a fully flexible difference-in-difference event-time model was employed, normalized such that the baseline year is 1950. The coefficients reported above are the 2010 outcomes from that model, representing the long difference outcome. Cluster-robust standard errors, clustered at the CBSA level, are given in parentheses. Pre-period controls include employment controls specific to the sector being analyzed, in log levels, for 1900 -1950 in ten year increments. (Log population is substituted for log employment in Panel A.) Population controls include controls for pre-period 15-64 population, in log levels, for 1900-1950 in ten year increments. Region controls include dummy variables for each of the nine Census divisions and CBSA land area. Geography/transport includes controls for 1887 straight-line rail mileage, planned 1947 highway mileage, having a port, being a political capital city, mean January temperature, having a coastal location, and for close proximity to a river. Tradable sector employment is the sum of agricultural, mining, manufacturing, and wholesale trade sector employment. Non-tradable sector employment is the sum of retail trade, finance/insurance/real estate, business, professional and other services, construction, and public administration sector employment.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Estimates of treatment effects for specific sector outcomes can be found in Appendix Table A.2. Additionally, more details on employment shares can be found in Appendix Table A.3.

1.6.2 Decade-By-Decade and Dynamic Effects

Table 1.7 gives IV estimates of the decade-by-decade effects of airports on employment since 1950.[25] In each specification, note that pre-period employment controls are included up to the base year. Significant growth in population and total employment occurred in two periods: 1950-1960 and 1970-1980. Estimated growth in population and employment, respectively, were 0.083 (8.7 percent) and 0.124 (13.2 percent) in the 1950s, and 0.081 (8.4 percent) and 0.0982 (10.3 percent) in the 1970s. Panel C shows that, as previously noted, the EPOP ratio diverged most dramatically in the 1970s, with roughly 3 percent higher labor force participation in airport CBSAs. Tradable employment grew in the 1950s, 1970s and 1980s, with the largest gain of 0.146 (15.7 percent) taking place in the 1950s. Non-tradable employment grew by 0.083 (8.7 percent) in the 1950s and 0.135 (14.5 percent) in the 1970s. Transportation sector employment, as expected, grew mostly in the early periods of airports, and would continue to grow through 1980, after which transportation sector employment levels would remain essentially constant.

Table 1.8 gives effects of airports, for each decade, on selected earnings and housing outcomes.[26] Panel A shows that airports had mostly insignificant effects on total CBSA payroll in each decade, with the exception of the 1970s. Panel B shows that per-worker payroll increased by roughly 4 percent in the 1960s; however, this was the only decade for which this would be true. Panel C, using earnings data from the Bureau of Economic Analysis, shows that earnings increased 13.9 percent between 1970 and 1980, with smaller increases thereafter. However, Panel D indicates that workers did not benefit from this; the additional payroll generated is almost entirely due to the additional jobs that the airports created. Finally, Panel E indicates that rents were unaffected by the airports.[27]

Figures 1.5 - 1.8 provide another perspective on the dynamic effects of airports over time. Each figure plots the evolution of the treatment effect for each year between 1950 and 2010. Note that the figures are normalized to 1940, so that effects on impact can be more easily seen. In general, the dynamic trends are similar to those already described above, and are similar across the various estimation methods. The estimated IV effects in the 1940s and 1950s are quite large, especially for tradable sector employment and transportation sector employment. Since the mean airport in the sample was open by 1940, it is not surprising that firms and individuals began to position themselves in locations with airports as the potential utility of aviation became clear to firms and individuals.

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[25] See Appendix Table A.9 for OLS estimates.

[26] See Appendix Table A.10 for OLS estimates.

[27] Rents are unavailable for 1960 and 1970; however they are available for 1950. Running a regression of change in rent between 1950 and 2010 on having an airport in the CBSA yielded a zero effect.

Table 1.7: IV Results: Decade-by-Decade Effect of Airports on CBSA Outcomes, Long Differences (Population and Employment Measures)

	(1)	(2)	(3)	(4)	(5)	(6)
Outcome by Decade	1950-60	1960-70	1970-80	1980-90	1990-2000	2000-10
Panel A: Change in Population (All Persons, Ages 15 - 64)						
Airport	0.0833*	-0.0106	0.0811**	0.00327	0.0114	-0.00530
($n = 506$)	(0.0471)	(0.0401)	(0.0364)	(0.0251)	(0.0199)	(0.0146)
First Stage F	33.62	33.17	32.46	31.42	30.54	29.61
Panel B: Change in Total Employment						
Airport	0.124**	-0.0142	0.0982***	0.00799	-0.0163	-0.00357
($n = 506$)	(0.0511)	(0.0357)	(0.0373)	(0.0297)	(0.0215)	(0.0226)
First Stage F	31.61	31.86	31.02	30.62	30.24	29.26
Panel C: Change in Total Employment to Population Ratio						
Airport	0.00985	-0.00429	0.0320***	0.00834	-0.00838	0.0117
($n = 506$)	(0.0143)	(0.0113)	(0.0108)	(0.00918)	(0.00844)	(0.00932)
First Stage F	27.59	26.53	25.76	24.91	24.76	24.01
Panel D: Change in Tradable Sector Employment						
Airport	0.146**	-0.0200	0.0853*	0.0667	-0.0443	0.0288
($n = 504$)	(0.0609)	(0.0537)	(0.0443)	(0.0429)	(0.0369)	(0.0423)
First Stage F	28.48	29.10	27.83	27.99	27.25	26.42
Panel E: Change in Non-Tradable Sector Employment						
Airport	0.0832**	-0.0494*	0.135***	-0.00896	-0.0416*	0.0171
($n = 494$)	(0.0351)	(0.0293)	(0.0416)	(0.0300)	(0.0248)	(0.0256)
First Stage F	36.00	35.38	34.11	33.00	31.85	30.67
Panel F: Change in Transportation Sector Employment						
Airport	0.225***	0.0579	0.0486	-0.0231	-0.00305	0.0313
($n = 419$)	(0.0535)	(0.0526)	(0.0525)	(0.0537)	(0.0613)	(0.0575)
First Stage F	34.34	33.84	33.96	33.75	33.44	33.57
Controls:						
Pre-period Employment	Y	Y	Y	Y	Y	Y
Region	Y	Y	Y	Y	Y	Y
Geography/Transport	Y	Y	Y	Y	Y	Y

Notes: Table reports results of instrumental variables (IV) regressions of log population/employment outcomes given above on an indicator variable for whether a CBSA has an airport, with various controls as indicated. Each specification represents one decade. Cluster-robust standard errors in parentheses clustered at the CBSA level. Pre-period controls include employment controls specific to the sector being analyzed, in log levels, for 1900 up to the base year, in ten year increments. For example, specification (3) includes log employment controls, by decade, through 1970 in ten year increments. (Log population is substituted for log employment in Panel A.) Region controls include dummy variables for each of the nine Census divisions and CBSA land area. Geography/transport includes controls for 1887 straight-line rail mileage, planned 1947 highway mileage, having a port, being a political capital city, mean January temperature, having a coastal location, and for close proximity to a river. Tradable sector employment is the sum of agricultural, mining, manufacturing, and wholesale trade sector employment. Non-tradable sector employment is the sum of retail trade, finance/insurance/real estate, business, professional and other services, construction, and public administration sector employment.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 1.8: IV Results: Decade-by-Decade Effect of Airports on CBSA Outcomes, Long Differences 1950-2010 (Income and Housing Measures)

	(1)	(2)	(3)	(4)	(5)	(6)
	1950-60	1960-70	1970-80	1980-90	1990-2000	2000-10
Panel A: Total Payroll (County Business Patterns Measure)						
Airport	-0.0188	0.0568	0.125*	0.0478	-0.0169	0.00768
	(0.138)	(0.0475)	(0.0652)	(0.0659)	(0.0454)	(0.0547)
First Stage F	33.62	33.17	32.46	31.42	30.54	29.61
Panel B: Per-Worker Payroll (County Business Patterns)						
Airport	0.00504	0.0395*	0.00515	0.0142	0.00589	-0.0106
	(0.0592)	(0.0202)	(0.0245)	(0.0256)	(0.0245)	(0.0312)
First Stage F	33.62	33.17	32.46	31.42	30.54	29.61
Panel C: Total Earnings (Bureau of Economic Analysis)						
Airport	-	-	0.130**	0.0464	-0.00153	-0.0261
			(0.0556)	(0.0468)	(0.0348)	(0.0421)
First Stage F			32.46	31.42	30.54	29.61
Panel D: Earnings Per Worker (Bureau of Economic Analysis)						
Airport	-	-	0.0239	0.00619	0.0188	-0.0190
			(0.0232)	(0.0266)	(0.0206)	(0.0268)
First Stage F			32.46	31.42	30.54	29.61
Panel E: Median Rent (Census)						
Airport	-	-	-	0.0166	-0.00559	0.00989
				(0.0418)	(0.0241)	(0.0220)
First Stage F				31.42	30.54	29.61
Observations	506	506	506	506	506	506
Pre-period Population	Y	Y	Y	Y	Y	Y
Region	Y	Y	Y	Y	Y	Y
Geography/Transport	Y	Y	Y	Y	Y	Y

Notes: Table reports results of instrumental variables (IV) regressions of logged outcomes above on an indicator variable for whether a CBSA has an airport, with various controls as indicated. Each specification represents one decade. Cluster-robust standard errors in parentheses clustered at the CBSA level. Pre-period controls include population (15-64) controls specific to the sector being analyzed, in log levels, for 1900 up to the base year, in ten year increments. For example, specification (3) includes log employment controls, by decade, through 1970 in ten year increments. (Log population is substituted for log employment in Panel A.) Region controls include dummy variables for each of the nine Census divisions and CBSA land area. Geography/transport includes controls for 1887 straight-line rail mileage, planned 1947 highway mileage, having a port, being a political capital city, mean January temperature, having a coastal location, and for close proximity to a river. Tradable sector employment is the sum of agricultural, mining, manufacturing, and wholesale trade sector employment. Non-tradable sector employment is the sum of retail trade, finance/insurance/real estate, business, professional and other services, construction, and public administration sector employment.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Effects for individual sectors are shown in Figures 1.9 and 1.10. Tradable sector employment appears to be driven by growth in agriculture and mining. Wholesale trade increased the largest anticipatory effect before 1950, but afterward the impact remained constant. Hence, aviation led to an early growth spurt, but no additional growth since. This is evidence that while air cargo may be driving some of the observed effects, it is not necessarily the sole source of these effects. Non-tradable sector employment has increased in construction, finance and real estate and services, but not in retail. Additional construction, increased financial sector activity and increased professional services as a result of the airport could rise solely on their own, or could be new demand resulting from the increase in tradable sector jobs.

1.6.3 Extensions

I now consider whether the average effects reported above, differ by city size, region, or service levels. Table 1.9 provides estimates of the main effects of interest by population quartile.[28] In the first quartile, that is, for airport cities with 1950 populations between 15,000 and 60,000 people, it appears that the airport had comparatively small and insignificant effects on all outcomes considered. In the second quartile, comprised of cities with populations between 60,000 and 120,000 people, the airports had large and significant effects on population and employment. This is true of cities in the third quartile (with populations between 120,000 and 250,000) and fourth quartiles as well (with populations between 250,000 and 1.24 million). Although the low F statistics shown in columns (1) - (3) may be of concern, it appears that the bottom 25 percent of cities, by population, may have had different outcomes from the remaining 75 percent.

Airports also appear to have affected different regions in slightly different ways. This can be seen in Table 1.10.[29] The Midwest has benefited dramatically from aviation, with a roughly 75 percent increase in population and total employment attributable to the airport. It also appears that the airports benefited the South by shifting EPOP ratios. Hence, it is possible that airports helped the South transition to a more modern service based economy during the 1970s and beyond. Finally, it appears that the West benefited from strong growth in its tradable sectors. Given the fact that the economies of the West are much younger than their counterparts in the rest of the U.S., airports seem to have played a role in allowing Western local economies to quickly catch up to those of the rest of the country.

Another way of examining the heterogeneity of the treatment effects is to examine the outcomes given by the synthetically created cases with the strongest fits.[30] Figures A.4 and A.5 shows that the Midwest benefited from its airports in a substantial way in terms of population and overall employment. Many of the airports at the top of the list are as-

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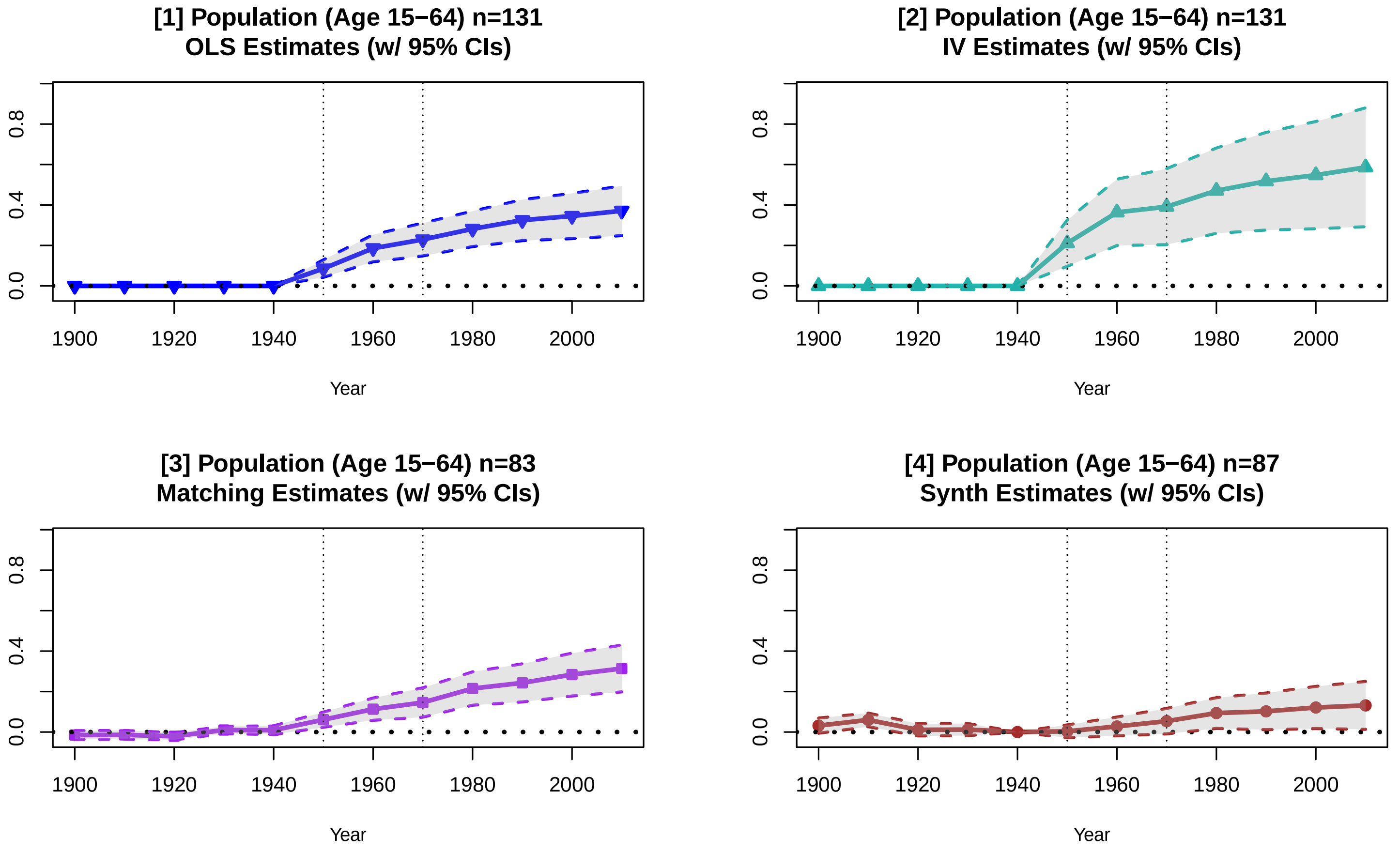
[28] See Appendix Table A.11 for OLS estimates.

[29] See Appendix Table A.12 for OLS estimates.

[30] MSPE $<$ 0.05 for the scatter plot (Figure **??**) and table; MSPE $<$ 0.01 for the bar charts (Figures A.4 and A.5)

Figure 1.5: Evolution of Treatment Effect: Log Population



[1] Population (Age 15−64) n=131
OLS Estimates (w/ 95% CIs)

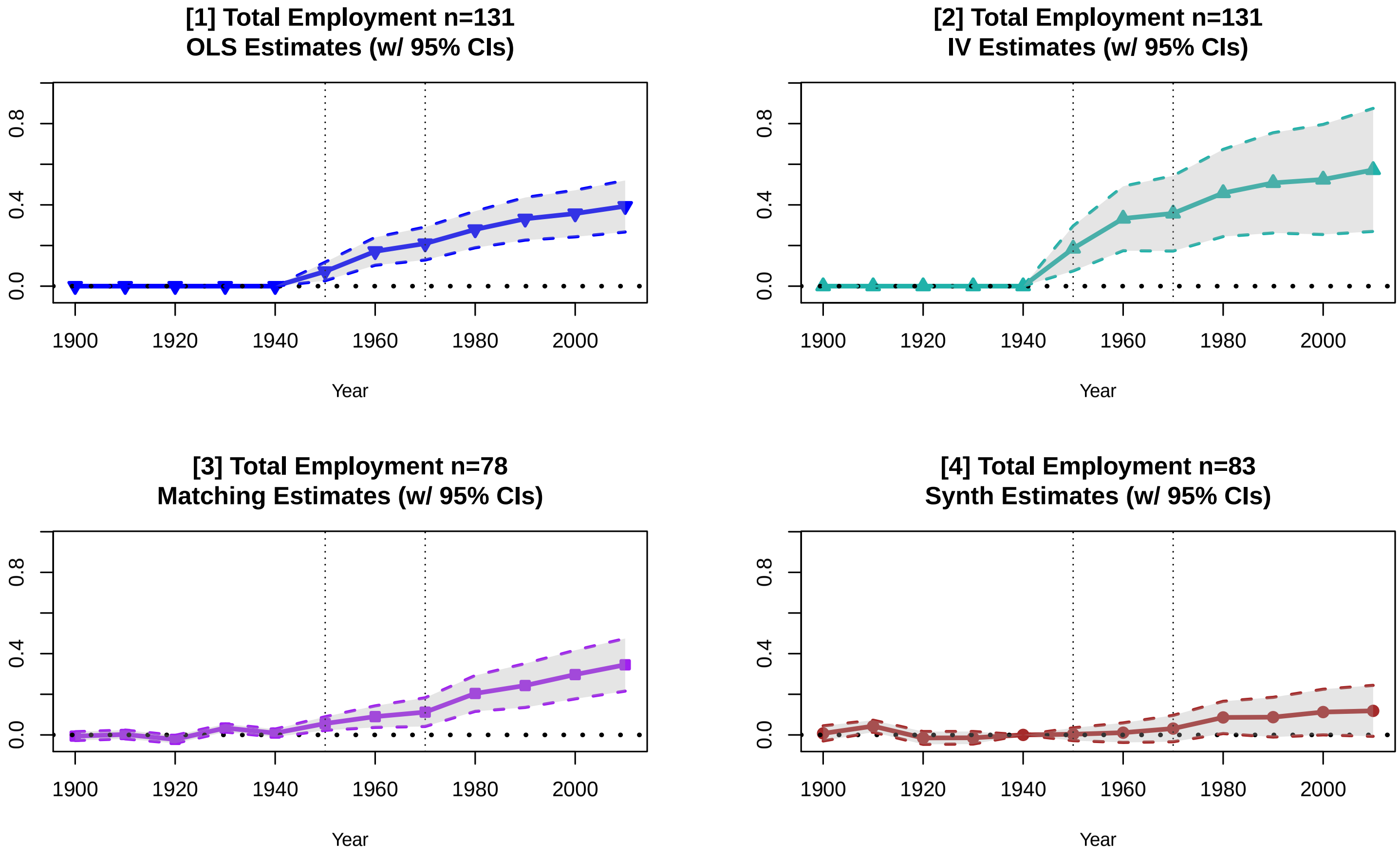
[2] Population (Age 15−64) n=131
IV Estimates (w/ 95% CIs)

[3] Population (Age 15−64) n=83
Matching Estimates (w/ 95% CIs)

[4] Population (Age 15−64) n=87
Synth Estimates (w/ 95% CIs)

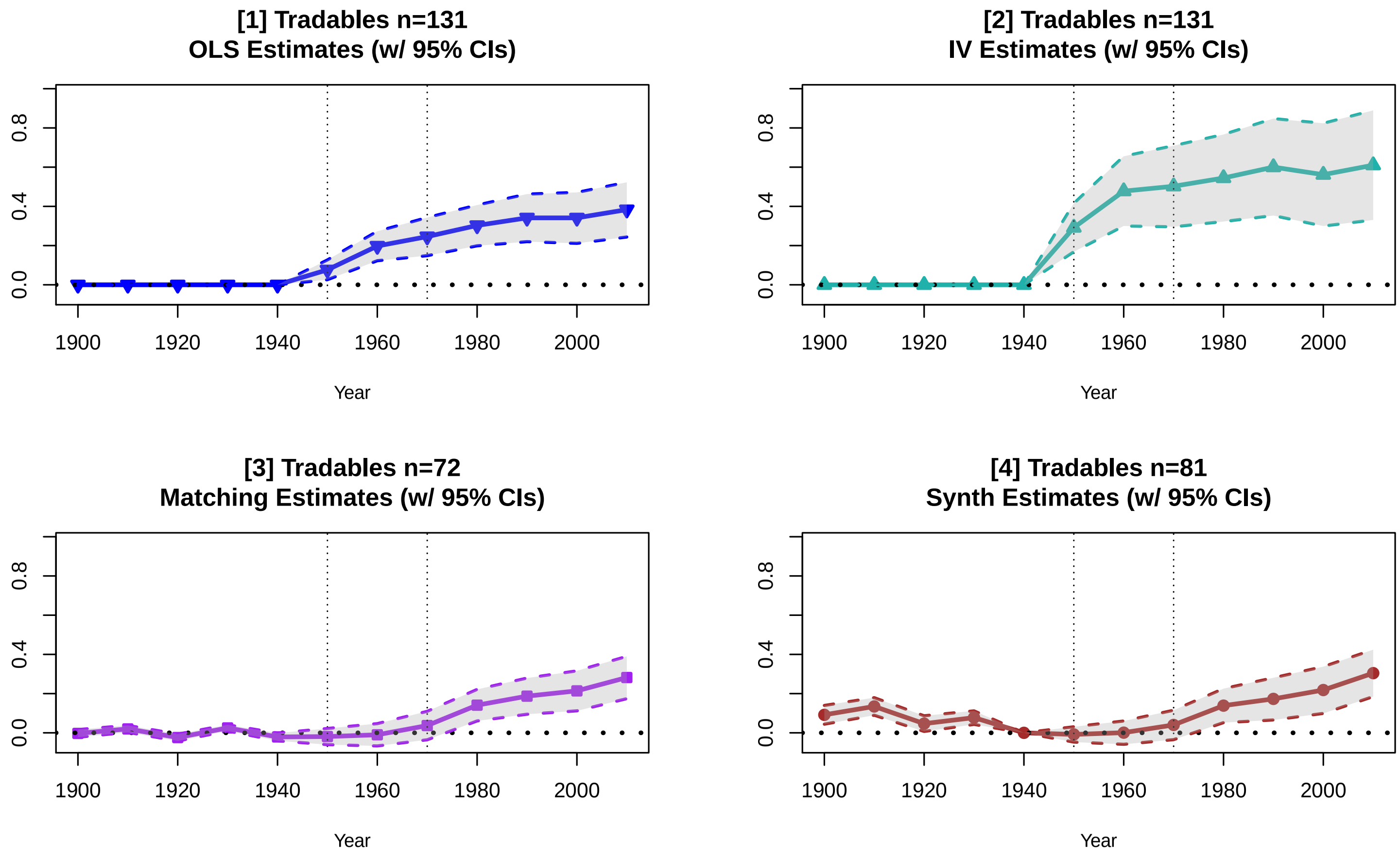
Notes: Figure shows the evolution of the airports' effects over time, relative to a normalization such that the 1940 outcome is normalized to zero. In each case, 95 percent confidence intervals are given by the dotted lines and shaded regions. Panel 1 gives OLS outcomes. Panel 2 gives the preferred instrumental variables (IV) outcome. Panel 3 gives the matched estimates from caliper matching, and Panel 4 gives the pooled synthetic control estimates. In panels 1, 2, and 4, standard errors are clustered at the CBSA level. In Panel 3, robust Abadie-Imbens standard errors are given. Please see section 1.4.2 for more details of the estimation and construction of each series.

Figure 1.6: Evolution of Treatment Effect: Log Total Employment



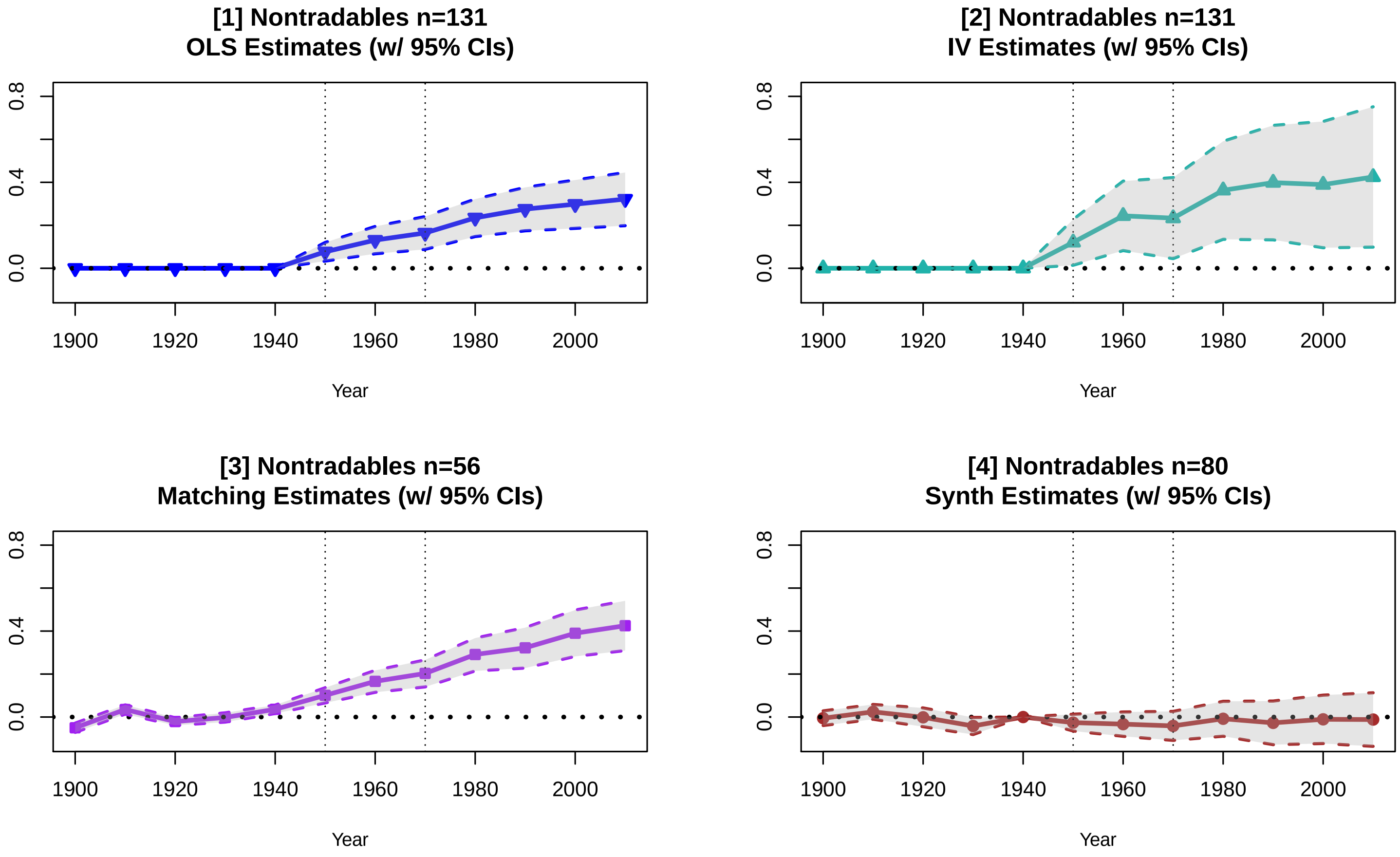
Notes: Figure shows the evolution of the airports' effects over time, relative to a normalization such that the 1940 outcome is normalized to zero. In each case, 95 percent confidence intervals are given by the dotted lines and shaded regions. Panel 1 gives OLS outcomes. Panel 2 gives the preferred instrumental variables (IV) outcome. Panel 3 gives the matched estimates from caliper matching, and Panel 4 gives the pooled synthetic control estimates. In panels 1, 2, and 4, standard errors are clustered at the CBSA level. In Panel 3, robust Abadie-Imbens standard errors are given. Please see section 1.4.2 for more details of the estimation and construction of each series.

Figure 1.7: Evolution of Treatment Effect: Tradable Sectors



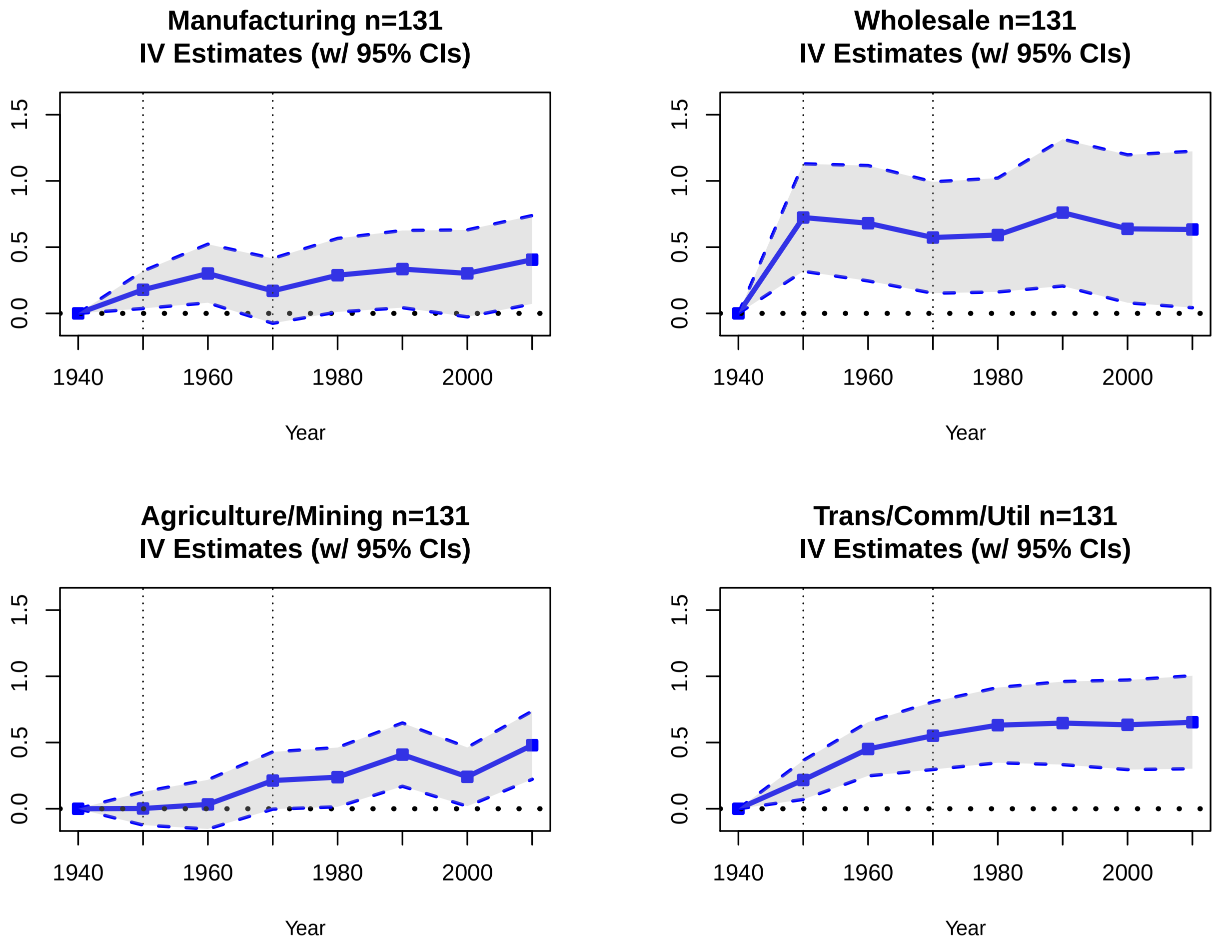
Notes: Figure shows the evolution of the airports' effects over time, relative to a normalization such that the 1940 outcome is normalized to zero. In each case, 95 percent confidence intervals are given by the dotted lines and shaded regions. Panel 1 gives OLS outcomes. Panel 2 gives the preferred instrumental variables (IV) outcome. Panel 3 gives the matched estimates from caliper matching, and Panel 4 gives the pooled synthetic control estimates. In panels 1, 2, and 4, standard errors are clustered at the CBSA level. In Panel 3, robust Abadie-Imbens standard errors are given. Please see section 1.4.2 for more details of the estimation and construction of each series.

Figure 1.8: Evolution of Treatment Effect: Non-tradable Sectors



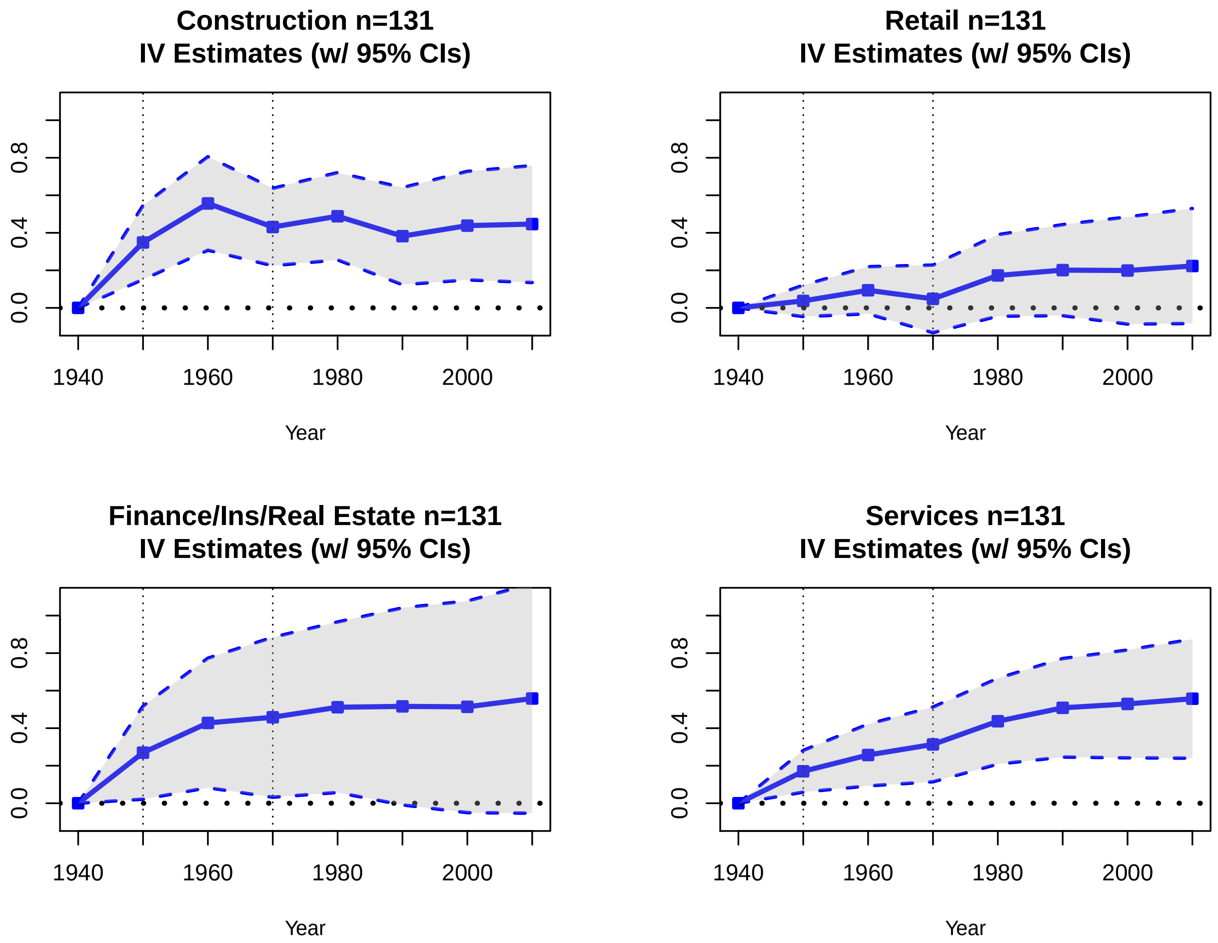
Notes: Figure shows the evolution of the airports' effects over time, relative to a normalization such that the 1940 outcome is normalized to zero. In each case, 95 percent confidence intervals are given by the dotted lines and shaded regions. Panel 1 gives OLS outcomes. Panel 2 gives the preferred instrumental variables (IV) outcome. Panel 3 gives the matched estimates from caliper matching, and Panel 4 gives the pooled synthetic control estimates. In panels 1, 2, and 4, standard errors are clustered at the CBSA level. In Panel 3, robust Abadie-Imbens standard errors are given. Please see section 1.4.2 for more details of the estimation and construction of each series.

Figure 1.9: Evolution of Treatment Effect: IV - Non-Tradable



Notes: Figure shows the evolution of the airports' effects over time, relative to a normalization such that the 1940 outcome is normalized to zero. In each case, 95 percent confidence intervals are given by the dotted lines and shaded regions. Standard errors are clustered at the CBSA level.

Figure 1.10: Evolution of Treatment Effect: IV - Non-Tradable



Notes: Figure shows the evolution of the airports' effects over time, relative to a normalization such that the 1940 outcome is normalized to zero. In each case, 95 percent confidence intervals are given by the dotted lines and shaded regions. Standard errors are clustered at the CBSA level.

Table 1.9: Results: IV Estimates of Airport Long Difference Effects By 1950 Population Quartile

	(1)	(2)	(3)	(4)
1950 Population Quartile	First	Second	Third	Fourth
Panel A: Population (All Persons, Age 15 - 64)				
Airport	0.0699	0.499*	0.348*	0.551*
	(0.374)	(0.299)	(0.204)	(0.305)
First Stage F	2.034	2.096	5.731	23.24
n	408	408	408	407
Panel B: Total Employment				
Airport	0.199	0.496*	0.381**	0.547*
	(0.346)	(0.294)	(0.192)	(0.310)
First Stage F	2.006	2.070	5.662	23.59
n	408	408	408	407
Panel C: Tradable Sector Employment				
Airport	0.113	0.407	0.377*	0.431
	(0.384)	(0.331)	(0.227)	(0.348)
First Stage F	1.974	2.117	5.289	22.44
n	406	406	406	405
Panel D: Non-Tradable Sector Employment				
Airport	0.181	0.379	0.197	0.284
	(0.294)	(0.267)	(0.182)	(0.297)
First Stage F	1.979	2.074	5.693	23.32
n	396	398	398	397
Panel E: Transportation Sector Employment				
Airport	0.461	0.483	0.439**	0.682**
	(0.334)	(0.358)	(0.219)	(0.313)
First Stage F	2.679	2.169	6.483	20.51
n	323	330	331	329
Controls:				
Pre-period Employment	Y	Y	Y	Y
Region	Y	Y	Y	Y
Geography/Transport	Y	Y	Y	Y

Notes: Table reports results of instrumental variables (IV) regressions of log population/employment outcome on an indicator variable for whether a CBSA has an airport, with various controls as indicated, by quartile of 1950 population. Cluster-robust standard errors in parentheses clustered at the CBSA level. Pre-period controls include employment controls specific to the sector being analyzed, in log levels, for 1900 to 1950. (Log population is substituted for log employment in Panel A.) Region controls include dummy variables for each of the nine Census divisions and CBSA land area. Geography/transport includes controls for 1887 straight-line rail mileage, planned 1947 highway mileage, having a port, being a political capital city, mean January temperature, having a coastal location, and for close proximity to a river. Tradable sector employment is the sum of agricultural, mining, manufacturing, and wholesale trade sector employment. Non-tradable sector employment is the sum of retail trade, finance/insurance/real estate, business, professional and other services, construction, and public administration sector employment.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 1.10: Results: IV Estimates of Airport Long Difference Effects By Census Region

	(1)	(2)	(3)	(4)
Census Region	Northeast	Midwest	South	West
Panel A: Population (All Persons, Age 15 - 64)				
Airport	0.427	0.565**	0.262	0.163
	(0.377)	(0.238)	(0.357)	(0.294)
First Stage F	2.371	11.48	13.16	7.369
n	391	417	425	398
Panel B: Total Employment				
Airport	0.419	0.557**	0.363	0.234
	(0.369)	(0.221)	(0.347)	(0.298)
First Stage F	2.334	11.58	12.91	7.384
n	391	417	425	398
Panel C: Tradable Sector Employment				
Airport	0.0734	0.447	0.288	0.427*
	(0.472)	(0.275)	(0.401)	(0.255)
First Stage F	2.267	11.09	11.77	6.913
n	389	415	423	396
Panel D: Non-Tradable Sector Employment				
Airport	0.278	0.440**	0.295	-0.0565
	(0.325)	(0.218)	(0.291)	(0.293)
First Stage F	2.353	11.79	13.78	7.498
n	381	407	414	387
Panel E: Transportation Sector Employment				
Airport	0.340	0.661***	0.454	0.460
	(0.404)	(0.245)	(0.416)	(0.290)
First Stage F	2.653	12.05	12.09	10.05
n	314	338	343	318
Controls:				
Pre-period Employment	Y	Y	Y	Y
Region	Y	Y	Y	Y
Geography/Transport	Y	Y	Y	Y

Notes: Table reports results of instrumental variables (IV) regressions of log population/employment outcome on an indicator variable for whether a CBSA has an airport, with various controls as indicated, by region as given by the U.S. Census Bureau. Cluster-robust standard errors in parentheses clustered at the CBSA level. Pre-period controls include employment controls specific to the sector being analyzed, in log levels, for 1900 to 1950. (Log population is substituted for log employment in Panel A.) Region controls include dummy variables for each of the nine Census divisions and CBSA land area. Geography/transport includes controls for 1887 straight-line rail mileage, planned 1947 highway mileage, having a port, being a political capital city, mean January temperature, having a coastal location, and for close proximity to a river. Tradable sector employment is the sum of agricultural, mining, manufacturing, and wholesale trade sector employment. Non-tradable sector employment is the sum of retail trade, finance/insurance/real estate, business, professional and other services, construction, and public administration sector employment.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

sociated with universities (Bloomington-Normal Regional, Columbia Regional) or strong manufacturing and tourism industries (Springfield-Branson). A drawback of the synthetic control estimator is that it predicts negative growth in places with weak fundamentals. Manufacturing economies that experienced rapid population decline such as Syracuse and Elmira, New York, fall into this category. On balance, however, the synthetic control results confirm that the Midwestern and Southern regions of the U.S. benefited substantially from the rise of aviation. However, rust belt cities such as Dayton, OH and Erie, PA would experience population declines despite having airports. In general, though, more cities experienced tradable employment gains then tradable employment losses. Yet, there is generally, no relationship between initial level of population in 1950 and the airport treatment effect.[31] From this, it appears that the contribution of an airport, while on average positive, is (1) highly variable, (2) is heavily dependent on local level fundamentals such as having a university, good tourist attractions, and/or a solid local employment base independent of the airport, and (3) does not vary much, relative to the size of a community. Thus, policy makers should be careful to cite transportation investments in cities with strong fundamentals in order to yield the highest return. It is also instructive to consider the interaction of region and initial city size on employment effects. Table A.13 examines this, again using the synthetic control estimator.[32] This exercise confirms and summarizes the existence of heterogeneity in individual city outcomes as described above. Interestingly, airports in the South and West were most effective for the largest cities, while those in the Midwest were most effective for the smallest cities.

I next consider how traffic flows may affect sectoral employment outcomes. Figure A.1 shows the air traffic levels for the various sample groups of airports over time. “Enplanements” measures the number of people who have boarded an aircraft at a particular airport, while “operations” refers to the number of departing and arriving flights.[33] It is immediately evident that enplanements have increased over time, with flight operations increasing at an even faster rate (this is due to air carriers’ desire to capture market share in the 1990s and part of 2000s). For the airports in this study, enplanements as a share of total commercial traffic enplanements have remained relatively constant over time. Enplanements per capita have increased sharply over the period for primary airports (i.e. airports for which traffic data is available from 1964 on), from 0.5 enplanements per capita in 1964 to almost two enplanements per capita in 2000 (but then falling to 1.5 enplanements per capita in 2010). A similar pattern emerges for the non-primary airports (which have traffic data from 1980 on). These airports collectively have a much smaller share of

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[31] However, Austin, TX and Colorado Springs, CO are notable outliers in this regard.

[32] The IV estimates become inconsistent with so few airports in each case.

[33] Technically, “enplanements” refers to the number of passengers boarding a flight at a given airport that was classified by the Federal Aviation Administration as an air carrier, air taxi, or commuter flight. “Operations” refers to the number of flights taking off from a given airport that were classified as itinerant air carrier or itinerant air taxi operations. While many of the airports in the sample also have significant activity classified as general aviation, I do not count these flights, as many of these are operations by private pilots or for flight instruction.

air traffic, and, also have, on a per capita basis, between 0.5 and 0.75 enplanements per capita since 1980. Taken together, this means that air traffic has (1) been increasing over time, which could potentially explain, for example, why there has not been a decrease in any of the observed employment effects; (2) the sample airports' role in the aviation network has remained relatively constant over time, as measured by the share of passengers serviced by them; and (3) enplanements per capita has been increasing, meaning that the intensity with which the airports have been used has increased, at least through 2000.

The question then becomes whether there might be any evidence that this change in traffic may have affected one industry more so than another. To address this question, I use industry-specific fixed effects regressions to see how the intensification of air traffic might affect these economies. The specification, for each industry j and CBSA i, is:

$$y_{ijt} = \alpha_i + \beta_1 Log(T)_{ijt} + \gamma_t + \mu_{it} + \epsilon_{ijt} \tag{1.7}$$

where y_{ijt} is log employment in the industry of interest, $log(T)$ refers to log per capita traffic as measured by log enplanements, γ_t is a year fixed effect, μ_{it} is a CBSA fixed effect, and ϵ_{ijt} is an error term. The regression includes traffic data from 1980 through 2010.

Generally, it appears that non-tradable employment responds more to increasing air traffic, with an elasticity of per capita traffic to CBSA employment 0.067, versus a non-significant elasticity of 0.035 for tradable employment. Within the nontraded industries, the strongest impacts are on the construction and financial, insurance, and real estate services industry, with elasticities of 0.121 and 0.102, respectively. The effect on construction is likely a response to the increased economic vitality that airports bring to many of the regions where they are situated, while the effects on the finance and service industries could be indicative of the role that face-to-face contact plays in ensuring success in information-based industries such as finance and certain types of services, such as consulting. Thus, it appears that just as airports provided key links allowing for a thriving tradable sector in their early years, the importance of aviation has now increased for the non-tradable sector as well. As the service sector is where the vast majority of modern jobs are located, there may be some justification for cities to advocate for high levels of air service. See Table A.5 in the Appendix for more details.

1.6.3.1 Airports and Job Creation

Using the estimates of job growth presented for the 1970-80 period in Tables 1.7 and 1.8, I recover the amount of additional earnings and payroll, as well as the number of jobs created by the average airport in the sample, during that period. In the treated airport communities, payroll growth of 0.125 (13.3 percent) and earnings growth of 0.130 (13.9 percent) translates into added payroll generated of \$83.8 million (\$74.0 million if measured in earnings rather than payroll) in 2010 dollars. After accounting for multiplier effects, the average airport is estimated to generate over 3,350 jobs, of which roughly 950 are in the tradable sector.[34]

As a reference case, consider Branson Airport, the first all-new major commercial airport to open in the United States in 2009. The airport cost $155 million to build in 2010 dollars.[35] Estimates on the expected payroll and number of jobs to be generated by the airport are extremely close to the figures given above.[36] It appears that Branson Airport can pay for itself in little over three years, the costs of environmental externalities and federally provided services such as air traffic control notwithstanding. It must be stressed that these are averages, and that a particular airport may generate little if any economic boost for its local economy, if, as in the Elmira case study (Section 1.5), macroeconomic forces and/or local level fundamentals are such that the airport fails to have a stimulative effect.

1.6.4 Additional Robustness Checks

Robustness to alternative methods. It has already been shown that the main estimates presented here are generally robust to estimation with alternative estimators. Additionally, as a check on the instruments used, I carry out regressions of airports on the change in total employment, but with various combinations of instruments. Table A.6 shows that IV estimates are generally consistent, providing evidence that estimates are robust to various combinations of the potential instruments given in Section 1.4.2.1, as long as the Air Mail instrument is included in the set of instruments. The two remaining instruments are too weak to be useful on their own.

Non-towered GA airports. Table A.7 shows the estimated effect of the small general aviation airports on the economy. The sample size is small ($n = 14$). These are small airports that are not equipped for commercial service, but otherwise meet conditions for inclusion in the sample. The IV estimator finds no significant effects. However, the matching estimator picks up a negative effect on population and transportation sector employment. Given the small sample size and fact that the matching coefficient on total employment is 0.014, it is unlikely that those are much more than statistical noise.

Neighboring CBSAs. Table A.8 considers the effect of neighboring CBSAs on airports. While the IV estimates remain noisy, the other methods indicate employment effects close to zero. This indicates that spillovers of airports on neighboring CBSAs is not an issue in the analysis. Moreover, removing neighboring CBSAs from the analysis does not affect the IV estimates substantially.

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[34] Recovering the number of transportation sector and other sector jobs is complicated by the fact that the coefficient on 1970-1980 transportation sector employment is small and not statistically insignificant.

[35] Branson Airport Fact Sheet, http://flybranson.com/docs/BransonAirportFactSheet.pdf

[36] Branson airport is estimated to generate $77.5 million in payroll and 3,299 jobs for the Branson Lakes Regional Economy.

1.7 Conclusion and Policy Implications

This paper has considered the effects of small and mid-size commercial airports opened before 1950 on their local economies over the post World War II period, specifically over the period 1950-2010. I used a rich, detailed data set of CBSA-level employment outcomes, geographical, transportation, and city background characteristics, as well as previously unexploited historical aviation events to estimate these effects. Using an instrumental variables approach, as well as caliper matching and pooled synthetic control methods, I showed that airports have had substantial effects on population and employment. Specifically, I found that relative to non-airport CBSAs, the presence of an airport in a CBSA has caused population growth ranging between 14.6 percent and 29 percent, total employment growth of between 17.4 percent and 36.6 percent, tradable sector employment growth of between 26.6 percent and 42.6 percent, and non-tradable employment growth of between a non-statistically significant 2.7 percent and 16.1 percent. These effects vary by region, city size, and traffic levels. The growth in the effects happen over two periods: from 1950-1960 and 1970-1980, after which the effect of aviation remains relatively constant on local economies. Evidence indicates that airports stimulate this employment and population increase via a direct effect on employment in tradable sectors, which through multiplier effects leads to higher employment in nontradables. The estimated effects for the 1970-1980 period translate into $83.8 million in added payroll and 3,300 jobs for a local economy generated by an airport, of which roughly 950 are in the tradable sector. It is important to note that the contribution of an airport, while on average positive, appears to be heterogeneous in the following respects: (1) it is highly variable, (2) it is heavily dependent on local level fundamentals such as having a university, good tourist attractions, and/or a solid local employment base independent of the airport, and (3) it does not vary much relative to the size of a community.

Taken together, I have shown that, on balance, infrastructure investment stimulates growth in the economy. Cities that were able to find a place for themselves in the network early on have, on average, benefited from their positioning. The lesson here is not that cities should rush to open new airports. Rather, it is crucial for cities to maintain their competitive edge by sometimes being willing to take intelligent risks in nascent technologies, and that if successful, cities benefit. Moreover, it appears that the effects are highly dependent upon local level fundamentals and are quite heterogeneous, but, with the exception of all but the smallest of cities, are independent of city size. Hence, some small airports have contributed to positive outcomes; others have not. At a minimum, service should be maintained to existing airports, at least at current levels. Whether an increase in service might intensify these observed effects overall is unclear, but there is some evidence that higher utilization of airports is associated with higher service sector employment, so perhaps increased air service could stimulate further growth in local economies. Investment and implementation of next-generation air traffic control capability, which would allow aircraft to fly more closely together and to operate more efficiently has the opportunity to positively affect airport communities. Finally, it appears worthwhile to continue to invest in airports, to ensure that firms and individuals who can benefit from the aviation system can do so, at least until the next innovation in long-distance transportation infrastructure comes along.

Chapter 1 Bibliography

Abadie, Alberto, Alexis Diamond, and Jens Hainmueller, "Synthetic Control Methods for Comparative Case Studies: Estimating the Effect of Californias Tobacco Control Program," *Journal of the American Statistical Association*, June 2010, *105* (490), 493–505.

_ , _ , and _ , "Synth: An R Package for Synthetic Control Methods in Comparative Case Studies," *Journal of Statistical Software*, June 2011, *42* (13), 1–17.

_ and Javier Gardeazabal, "The Economic Costs of Conflict: A Case Study of the Basque Country," *American Economic Review*, March 2003, *93* (1), 113–132.

American Air Mail Society, *American air mail catalogue*, Airpost Journal, 1939.

Aschauer, David Alan, "Is Public Expenditure Productive?," *Journal of Monetary Economics*, March 1989, *23* (2), 177–200.

Baum-Snow, Nathaniel, "Did Highways Cause Suburbanization?," *The Quarterly Journal of Economics*, 2007, *122* (2), 775–805.

Bednarek, Janet R. Daly, *America's Airports: Airfield Development, 1918-1947*, 1st ed., Texas A&M University Press, September 2001.

Bel, Germa and Xavier Fageda, "Getting there fast: globalization, intercontinental flights and location of headquarters," *Journal of Economic Geography*, July 2008, *8* (4), 471–495.

Blonigen, Bruce A. and Anca D. Cristea, "Airports and Urban Growth: Evidence from a Quasi-Natural Policy Experiment," Working Paper 18278, National Bureau of Economic Research August 2012.

Boustan, Leah Platt, Devin Bunten, and Owen Hearey, "Urbanization in the United States, 1800-2000," Working Paper 19041, National Bureau of Economic Research May 2013.

Brueckner, Jan K, "Metropolitan Airline Traffic: Determinants and Effects on Local Employment Growth," 1982. BEBR No. 894, College of Commerce and Business Administration, Bureau of Economic and Business Research, University of Illinois at Urbana-Champaign.

_ , "Airline Traffic and Urban Economic Development," *Urban Studies*, July 2003, *40* (8), 1455–1469.

Carroll, Raymond, Ruppert, David, Stefanski, Leonard, and Crainiceanu, Ciprian, *Measurement Error in Nonlinear Models*, 2 ed., Chapman and Hall, 2006.

_ **and Matthew A. Turner**, "Urban Growth and Transportation," *The Review of Economic Studies*, October 2012, *79* (4), 1407–1440.

_ **, Peter M. Morrow, and Matthew A. Turner**, "Roads and Trade: Evidence from the USÂ§," *The Review of Economic Studies*, November 2013, p. rdt039.

Eberts, Randall W. and Daniel P. McMillen, "Chapter 38 Agglomeration economies and urban public infrastructure," in Paul Cheshire and Edwin S. Mills, ed., *Handbook of Regional and Urban Economics*, Vol. Volume 3 of *Applied Urban Economics*, Elsevier, 1999, pp. 1455–1495.

Giroud, Xavier, "Proximity and Investment: Evidence from Plant-Level Data," *The Quarterly Journal of Economics*, May 2013, *128* (2), 861–915.

Green, Richard K, "Airports and Economic Development," *Real Estate Economics*, March 2007, *35* (1), 91–112.

Hovhannisyan, Nune and Wolfgang Keller, "International Business Travel: An Engine of Innovation?," Working Paper 17100, National Bureau of Economic Research May 2011.

Kirkendall, Richard S., *A History of Missouri*, Vol. 5, University of Missouri Press, 1986.

Michaels, Guy, "The Effect of Trade on the Demand for Skill: Evidence from the Interstate Highway System," *Review of Economics and Statistics*, 2008, *90* (4), 683–701.

Moretti, Enrico, "Local Labor Markets," Handbook of Labor Economics, Elsevier 2011.

Munnell, Alicia, "How Does Public Infrastructure Affect Regional Economic Performance?," in "Is There a Shortfall in Public Capital Investment?," Federal Reserve Bank of Boston, June 1990. Conference Proceedings, No. 34.

_ **and** _ , "The Bias Due to Incomplete Matching," *Biometrics*, March 1985, *41* (1), 103–116.

Ruggles, Steven, J. Trent Alexander, Katie Genadek, and Matthew Schroeder, "Integrated Public Use Microdata Series: Version 5.0 [Machine-readable database]," 2010.

Sekhon, Jasjeet S., "Multivariate and Propensity Score Matching Software with Automated Balance Optimization: The Matching Package for R," *Journal of Statistical Software*, 2011, *42* (7), 1–52.

Severnini, Edson, “The Power of Hydroelectric Dams: Agglomeration Spillovers.” PhD dissertation, UC Berkeley, UC Berkeley November 2012.

_ , “Airports and urban sectoral employment,” *Journal of Urban Economics*, March 2014, *80*, 133–152.

U.S. Army Air Service, “Airways and Landing Facilities,” *Air Service Information Circular*, March 1923, *5* (404), 1–13.

VanDerLinden, Robert, *Airlines and Air Mail: The Post Office and the Birth of the Commercial Aviation Industry*, Lexington: University Press of Kentucky, 2002.

Wittman, Michael and William Swelbar, “Trends and Market Forces Shaping Small Community Air Service in the United States,” White Paper ICAT-2013-02 May 2013.

Chapter 2

Causal Effect of Airport Hubs on Urban Growth

2.1 Introduction

In an era of high fuel prices, high operating costs and increased competition, airlines have found themselves culling their networks to maximize efficiency and reduce costs. Over the past decade, a number of large mergers in the domestic airline industry, such as United Continental, Delta Northwest, American and U.S. Airways, and Southwest and AirTran. According to the U.S. Department of Transportation, these mergers have led these four combined carriers to have just under 70 percent of market share.[1]

Post-deregulation, airlines moved quickly to establish hubs, seeking to establish a market share advantage at various airports, hoping that this would drive profitability. While this drove operational efficiency, competitive pressures kept pricing advantages in check for the most part (Button, 2002). For travelers, hubs are also popular as they allow access to most domestic destinations with no more than one connection. Time-sensitive business travelers appreciate the ability to travel non-stop to a variety of destinations. Various studies suggest cities may benefit from these hub airports. For example, Giroud (2013) has shown that new non-stop air routes have the potential to increase plant level investment by 8 percent and productivity by 1.3 percent. to headquarter companies because of the availability of direct flights. Similarly, Bowen (2010) notes that airline hubs have facilitated the consolidation of corporate headquarters and, additionally, job growth. Button et al. (1999) argue that high-technology companies also have a clear preference for locating in cities with hub airports.

However, since it is costly to establish and maintain hub airports, air carriers have a strong incentive to minimize the number of hubs they operate. With recent changes to the system, cities such as St. Louis, Memphis, Cleveland, and to a lesser extent, Cincinnati, all have experienced hub closures as a result of merger reorganizations. While the popular press has made much of the potential harm these losses might cause on their local communities, to date little empirical research has been conducted to substantiate those claims. The purpose of this paper is to fill that void, and, by extension, use these semi-exogenous changes to service to examine the effect that hub airports have on their economies, over and above those of a typical non-hub airport.

This study is the first to use data from the entire post-deregulation period of aviation to assess the (relatively) exogenous change in hub status of major cities, resulting from airline mergers or bankruptcies, on economic outcomes such as population and employment within a city. Specifically, I create a database of hub openings and closings, and also define a set of "hub potential" airports - airports that carried similar amounts of traffic, but did not become hubs. I exploit the temporal variation in hub openings and closings – for example, there were seven hubs from seven hubs in 1979 and 14 hubs in 2012. However, in peak-hub periods, there were 24 hubs in 1988 and an average of 22 hubs through the 1980s and 1990s.

Using panel regression and event-study techniques, I show that airline hub airports

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[1] U.S. Department of Transportation, Bureau of Transportation Statistics: http://www.transtats.bts.gov/

do have a causal effect on city economic outcomes. Namely, I show that hubs increase personal income and establishment counts by 2 to 3 percent, with virtually all of the growth in establishments in the non-traded sector. I also show that positive employment outcomes are limited mostly to related industries, such as air travel and hotels and lodging. The effect of hubs on a city's employment is estimated to be practically zero. However, hub airports do create spillovers on employment overall within a 3 to 7 mile radius of the hub. These effects operate through the changes in air traffic, especially through a variety of frequent flights offered, many non-stop.

The rest of this paper proceeds as follows: Section 2 reviews the literature on air hubs and provides some background. Section 3 presents a basic model of hub formation. Section 4 presents case studies to illustrate how a hub might affect a local economy in practice. Section 5 provides information about the data, section 6 presents the results and discussion, and section 7 concludes.

2.2 Background

Airports in general have been shown to be important contributors to the health of their local economies. As I showed in Chapter 1, cities with airports grew, on average, 0.5 percent per year more since 1950 than cities without one. I also demonstrated that the effects are roughly similar for airports regardless of city size; however, they were not identical. Sheard (2014), in a study examining the linkages between airport size and urban growth, finds that while airport size has some effect on employment in tradable sectors, it has no effect on employment in manufacturing or other non-tradable services. He also finds that airport size has practically zero effect on overall local employment. If this is true, than one might expect the loss (or gain) of a hub airport to matter little to a city's economy.

However, another strand of literature finds that hub airports, specifically, have characteristics that may prove to be unique to cities with hub airports. Button et al. (1999) examines employment data between hub and non-hub cities by year. They find an overall increase in high-tech, high paying jobs in hub cities. They also find a possible link between rapid growth in high-tech employment in cities that are hubs compared to those that are not, further suggesting that having a hub airport might be beneficial to a city's economy, at least when it comes to the technology sector. Neal (2011) finds that urban growth is driven by a city's "centrality" in business networks. However, this finding relies on a lagged dependent variable model which does not necessarily prove causality. Giroud (2013) shows that new non-stop air routes have the potential to increase plant level investment by 8 percent and productivity by 1.3 percent. This implies that companies are much more likely to establish headquarter and other operations in cities partly based on the availability of direct flights to a city. Bowen (2010) notes that airline hubs have facilitated the consolidation of corporate headquarters and, correspondingly, job growth in cities, the majority of which have an airline hub. Neal (2012) and Neal (2014b) examine the potential effects hubs may have on urban creative economies. He categorizes hubs into various types: closeness hubs that offer non-stop services, betweenness hubs that offer intermediate connections, and degree hubs, or terminal destination hubs. He finds that only the latter type can substantially impact economic development and attract creative workers to a city.

In terms of hub location, O'Kelly (1998) finds that an optimal hub has few direct links between hubs, suggesting a motive for airlines to keep their number of hubs as small as possible. Others propose that location might be the most important factor in an airline's choice of hub. Jaillet et al. (1996) argues that candidacy for hubs depends more on geographic position than local demand level, leading to the conjecture that at least some hubs were created independent of city characteristics. As noted by Button and Lall (1999), business travelers are time-sensitive rather than price-sensitive, caring more about the frequency of flights, ease of rescheduling, and the services offered at airports than the price of a flight. Redding et al. (2011) provide a model and empirical analysis of the shift in Germany's main hub from Berlin to Frankfurt following the reunification of East and West Germany in 1990. They conclude that the location of an air hub is not uniquely determined by fundamentals; that is, multiple steady states exist. The chosen location likely has more to do with airlines' sunk costs than city fundamentals.

It is important to note that there is no single definition of a hub airport. For example, the U.S. General Accounting Office classifies an airport as a hub if more than 60 or 85 percent of its traffic is controlled by one or two dominant carriers, respectively. (In some studies, the respective numbers used change, such as 50 to 75 percent). The Federal Aviation Administration, by contrast, divides airports into large hub and medium hub subcategories based on the share of passenger traffic (enplanements) at an airport.[2] Academic research often defines a hub as an airport such that carriers feed three or more banks of traffic daily through it from 40 or more cities (Button, 2002).

Given these considerations, particularly the differing definitions of a hub, and the goal of this study, I will define a hub simply by the label given to it by air carriers. If, in its annual report or other documentation, an airline considers a particular airport to be a hub in a particular year, then it will count as a hub for the purposes of this paper. This paper will utilize the salient features of a hub - large, located primarily based on airline sunk costs and operational needs, and operated for the sake of maximizing airport profit, not local city outcomes - to study the effect of hub closings and openings on economic development in hub cities. This will help to provide credible causal evidence on the relationship between an airport hub and local economic development.

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[2] A large hub has one percent or more of domestic passenger enplanements. A medium hub has 0.25 - 1.00 percent. A small hub has 0.05 - 0.249 percent, and a non-hub airport has less than 0.05 percent enplanements.

2.3 Conceptual Framework

To better understand the effect that a hub may have on a local economy, and to clarify the mechanisms through which those effects might occur, I adapt a model of hub location from Redding et al. (2011), and modify it to account for two distinct types of travelers: connecting passengers and terminating passengers.

As in Redding et al. (2011), consider a model with three locations or cities. A monopoly airline would have the choice to fly point-to-point (bi-directional flights from point A to B, B to C, and C to A), or to offer flights with a hub. For example if C becomes the hub, then there would be flights from A to C and B to C. Passengers who wanted to travel between A and B would have to connect at point C. Intuitively, the airline now requires one fewer set of flights to serve all its customers, but would have to incur the fixed costs F of establishing and maintaining a hub. Additionally, there would be inconvenience to passengers traveling between points A and C relative to the point-to-point system, meaning that discounts would be offered on connecting itineraries to compensate them for their inconvenience. Profitability would determine the airline's choice; that is if $\pi_H = R - (F + D) > \pi_{PP}$, where π_H is the airline's profit under the hub system, R is revenue generated, and π_{PP} is that under the point-to-point system, then the airline will choose the hub system.

Suppose an airline now has to choose between various locations for a hub. In this setup, the choice of city A, B, or C is purely due to factors that comprise F and D. Given the demand for travel, airlines face a downward sloping demand curve for travel between each pair of cities. As shown in Redding et al. (2010), this demand is a function of opportunities for passengers to consume nontraded goods in the destination city, say, for example, by renting a hotel room or performing business transactions over a meeting, or a visit to a tourist destination and travel costs. The airline's goal in hub placement, however, is not to necessarily place the hub in the most desirable locations from a passenger's perspective. Of course, an airline will do so if profits are maximized in such a setup, but in general it is most profitable to establish hubs in a variety of cities, that based on characteristics of the airline's network, will minimize F and D. Hence, hub location is not a function of local demand factors, but rather, network-wide cost minimization properties.

Now suppose there are two airlines - West and East. Both are monopoly airlines that have located their hubs in such a way as to minimize cost. The airlines decide to merge (or, without loss of generality, one buys the other). Due to newly realized network synergies, certain hubs will no longer be required. Hence, it will be profitable for the airline to close certain hubs. The loss of the hub, in this model, is entirely due to airline profitability and not to local labor market conditions. Will this loss affect the local economy? Not necessarily. Spillovers from the hub depend on both aggregate passenger traffic levels and the percentage of passengers whose final destination is the hub airport city. The first type would affect air travel employment, and potentially, hotels and lodging employment, if such a hub requires itineraries with layovers. Thus, the expectation is that employment in those sectors would correlate most strongly with the increased passenger traffic that hubs bring. Other jobs within close vicinity of the airport would also follow the same pattern.

The hub's effect on the local economy, however, is an entirely different story. If passengers are connecting, then they do not consume any nontraded goods in the connecting city. In fact, only the share of destination passengers, α, would be relevant. Empirical estimates of connecting passengers $(1-\alpha)$ range from a low of 10 percent to a high of 80 percent, with a median of around 60 percent in 2000 (Lee and Luengo-Prado, 2005). For reference, roughly 10 percent of passengers traveling through a non-hub airport connect. It is thus entirely possible that, depending on the actual traffic levels, a city may benefit more from a non-hub airport than a hub airport, or that the relative benefits would be roughly equalized. Which of these ultimately is the case is an entirely empirical question, and is the subject of the analysis to follow.

2.4 Case Studies

This section presents four case studies of hub airports and their effects on their local economies: St. Louis, Cincinnati, Charlotte, and Dayton. The four airports were selected to illustrate the diversity of mechanisms through which a hub may influence local economic activity.

2.4.1 Lambert-St. Louis Airport (STL)

Since the late 1920's, Transcontinental and Western Airlines (TWA) was associated with the St. Louis airport (STL) in some capacity. Ozark Airlines, a rising regional player, began serving St. Louis in 1950. The Airline Deregulation Act of 1978 gave TWA power to expand, and its ties with STL for over 50 years led the airline to establish St. Louis as its main hub. With a duopoly at St. Louis with more than 80 percent of its traffic, TWA and Ozark Airlines, a regional airline operating out of STL, merged in 1986 – a year after Southwest entered the market. During the 1990s, TWA's financial situation worsened, leading it to file for bankruptcy three times: 1993, 1995, and 2001, when American Airlines purchased it. By 2003, American had halved more than 400 of STL's daily flights, and gradually reduced flights until it retired the hub in 2010. Once the prominent name in American aviation history, STL was turned into a regional airport dominated by Southwest almost as fast as it became hub (Harty, 2014). By 2010, non-stop market access had been halved.

Figure 2.1 provides information on employment in the St. Louis metropolitan area. The first signs of trouble began to appear around 1999, when rumors of the TWA and American merger began circulating. Interestingly, this anticipatory decline in employment was most noticeable within a 10-mile radius of the airport. There was virtually no effect on metropolitan area employment. Aviation sector employment decreased, but the hotel industry boomed until 2004. Moreover, only a couple Fortune 500 firms left the area as a result. In all cases, the declines in employment were small. While the metropolitan area emerged relatively unscathed, jobs were lost in the immediate vicinity of the airport.

Within 5 miles of the airport, the second significant drop in employment rate started around 2007, as American gradually downsized St. Louis. By 2010, the job losses would continue, but at a much slower rate. In all cases, it appears the adjustment process was rapid; there is little evidence of a lag between the loss of hub traffic and employment levels.

2.4.2 Cincinnati/N. Kentucky International Airport (CVG)

Trends in aviation changed the airline industry in many ways after the events of September 11th. As passenger traffic was down overall, Delta made the decision to downsize Cincinnati/Northern Kentucky International Airport (CVG). By the end of 2005, CVG had lost 30 percent of its flights, half its passenger traffic and one third of its jobs (Pilcher, 2010). After Delta's merger with Northwest Airlines in 2008, the situation became more dire. Officially, Cincinnati still remains a Delta hub, but in practical terms it has essentially been de-hubbed.[3]

Turning to Figure 2.2, it becomes clear that passenger traffic has been steadily increasing, while flight traffic peaked in the late 1990s. Much of that peak was due to increased service for the Summer Olympics, which took place in Atlanta in 1996.[4] The 2005 downsizing resulted in a sizable decrease in market access, with a 40 percent reduction in non-stop destination access. While there were some decreases in employment near the airport, those were in the 5 to 10 percent range. Metropolitan area employment dropped from its peak but by no more than 10 percent, and even rebounded after the first round of service cuts, until the Great Recession occurred in 2008. There was a marked decline in air travel sector employment. Additionally, up to four Fortune 1000 firms had closed their headquarters by 2014, though those firms had headquarters located more than 20 miles from the airport. Compared to St. Louis, which lost its hub status and subsequently rebounded, it does not appear that CVG's continued designation as a "hub" will be as beneficial to the fortunes of Cincinnati as might otherwise be believed.

2.4.3 Charlotte-Douglas International Airport (CLT)

While the CVG case indicated that simply labeling an airport a "hub" will not improve an economy's fortunes, especially in the absence of the necessary service, the Charlotte case illustrates that becoming a hub can, in some cases, be transformative. Just after deregulation, Piedmont Airlines needed a hub to expand its network, and the prospering city of Charlotte was its first choice. Dubbed "the city deregulation built", usage of Charlotte's airport facilities went from 7 percent to 79 percent within six years (Eller, 2008).

In 1989, Piedmont Airlines merged with US Air. US Air would continue to grow the hub. CLT survived and thrived, even after American West Airlines acquired US Airways

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[3] To be clear, however, for this analysis, CVG is still considered an open hub as of 2012.

[4] Atlanta is Delta's largest hub. Connecting traffic accounted for the increase in CVG's traffic.

Figure 2.1: Case Study: St. Louis Area Airport Employment

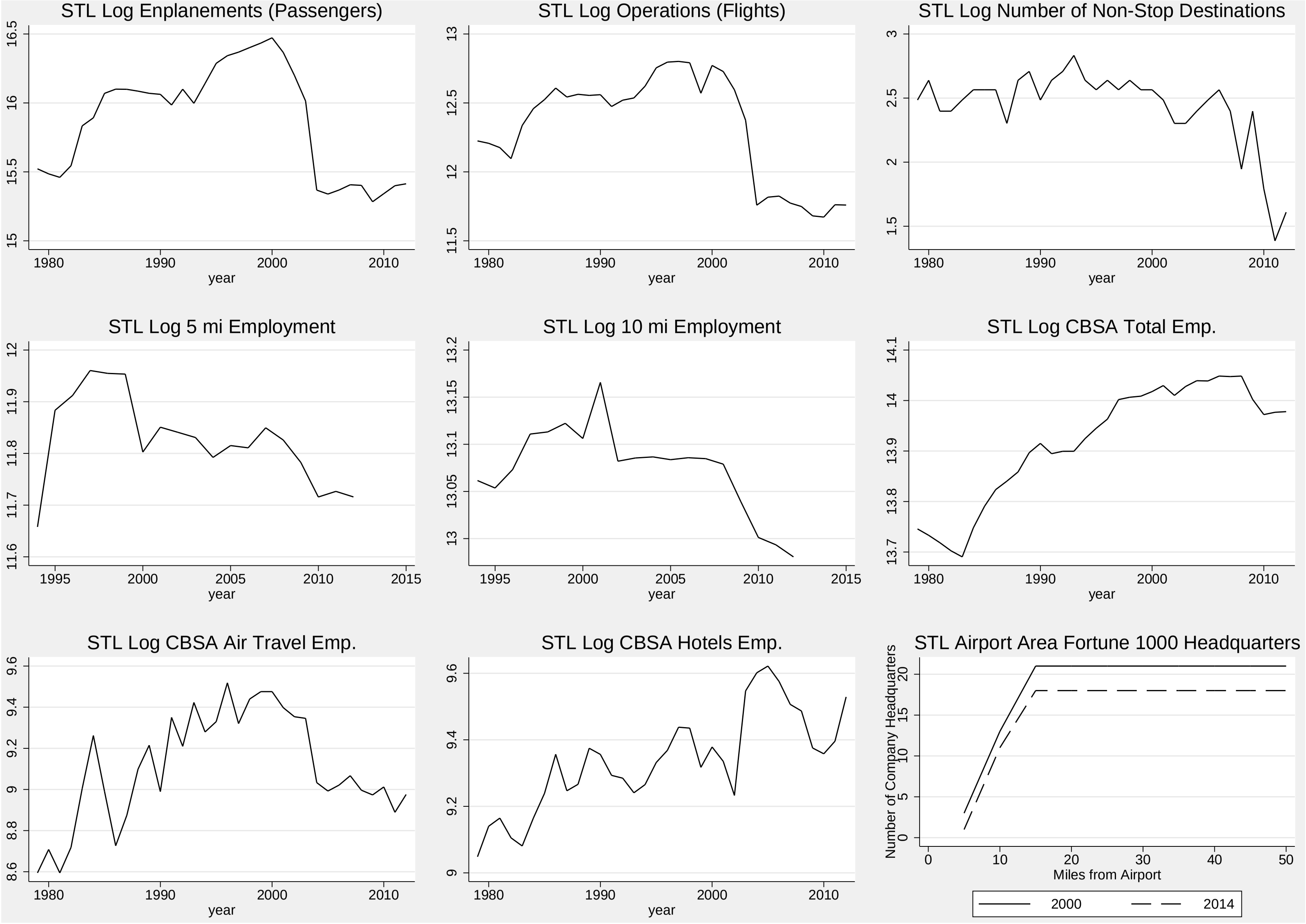
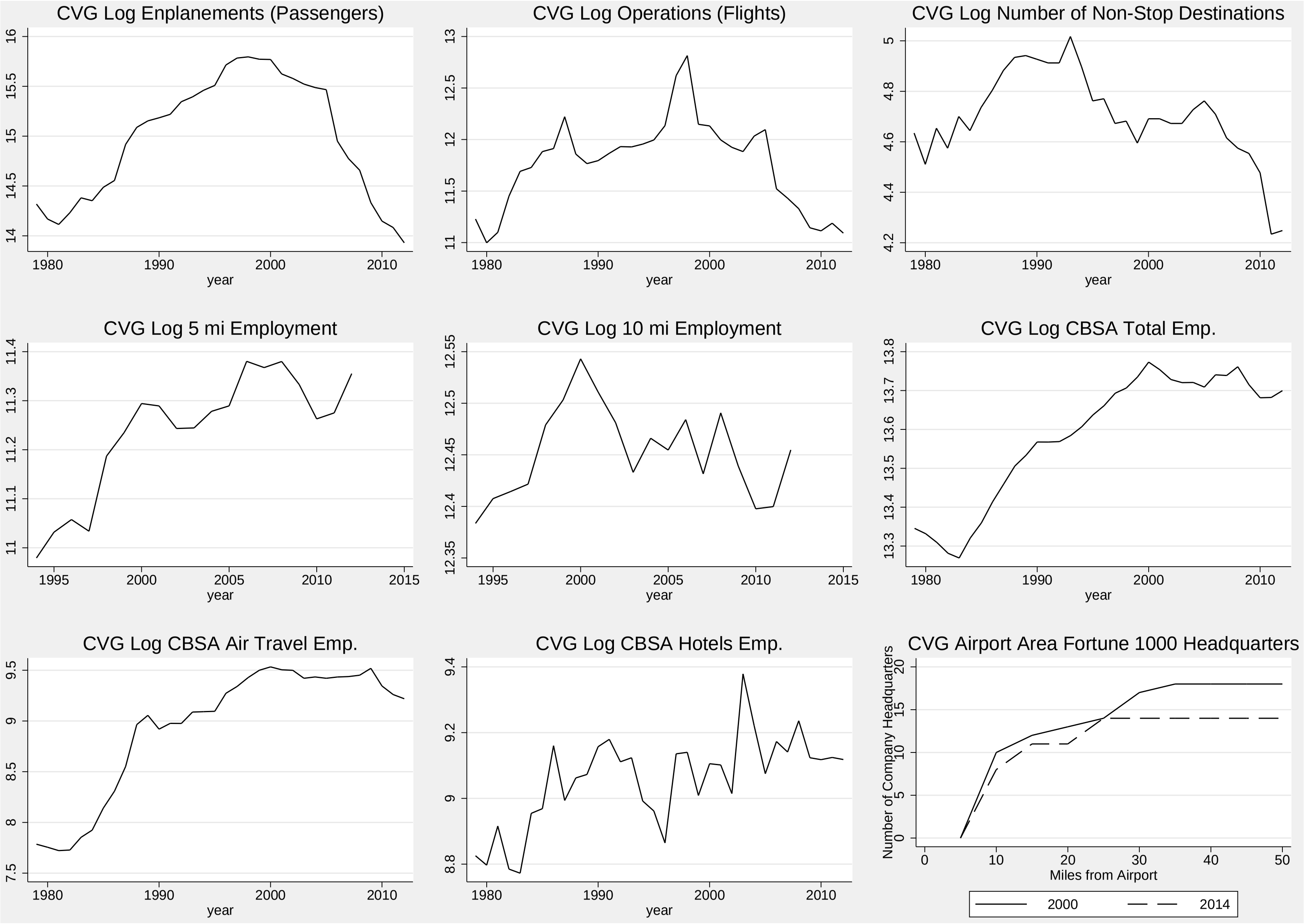


Figure 2.2: Case Study: Cincinnati/Northern Kentucky Airport Employment



in 2005. Five years later, CLT was US Airways' largest hub.[5] The most recent merger in Charlotte Douglas' history was in 2013 between American Airlines and US Airways (McLaughlin and Zajac, 2014). For now, CLT remains a major hub in the American air transportation industry. On all metrics considered in Figure 2.3, it is clear that CLT has had a large impact on its local economy. Of the case studies considered so far, it has retained much of its non-stop market access, and clearly has retained virtually all its passenger traffic. It is also the only case considered thus far that has gained Fortune 1000 company headquarters between 2000 and 2014. The lesson here is that for some cities, hubs can be a transformative force.

2.4.4 Dayton, Ohio (DAY)

Finally, consider an early case in hub closings: that of Dayton, Ohio (DAY). In 1982, after its success with the hub at Charlotte, Piedmont Airlines turned Dayton into its Midwest hub. The following decade saw another of Piedmont's success of building and maintaining a hub, as Dayton was crucial in connecting major western cities such as San Francisco and Los Angeles to the Midwest and the East Coast . However, Dayton's success was short lived. After its merger with Piedmont Airlines, US Air had an abundance of hubs. Dayton's proximity to Pittsburgh meant that US Air was also hurting that hub as well. As a result of those financial issues, Dayton was closed as a hub in 1993.

While the Charlotte hub continued to prosper (see section 2.3), Dayton suffered. As shown in Figure 2.4, employment declines began in the 1990s and continued through the present. Metropolitan area employment did not immediately decline, however. For a time, it actually continued to increase. Perhaps most interestingly is that within the air travel industry, the effect of the hub closing in the early 1990's was not accompanied by a corresponding decrease in sector employment until post-2000. Ultimately, the combined effects of the hub loss and industry changes post-September-11th led to the region's ultimate decline. Still, considering solely the isolated effect of the hub loss itself, as in the other cases considered, we see that did not in and of itself lead to immediate declines in employment except within the immediate area of the airport.

Taken together with previous case studies, the graphs of employment in Dayton after US Air closed the hub seem to reiterate the general finding that hub losses do not appear to have dramatic effects on the local economy.

2.5 Data and Methods

The analysis in this project is based on a panel data set that was constructed consisting of a city's airport hub status, passenger enplanements and operations, market access, employment and payroll data. To select the airports included in this study, I began with

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[5] US Airways Chronology:
http://www.usairways.com/en-US/aboutus/pressroom/history/chronology.html

Figure 2.3: Case Study: Charlotte-Douglas (CLT) Airport Employment

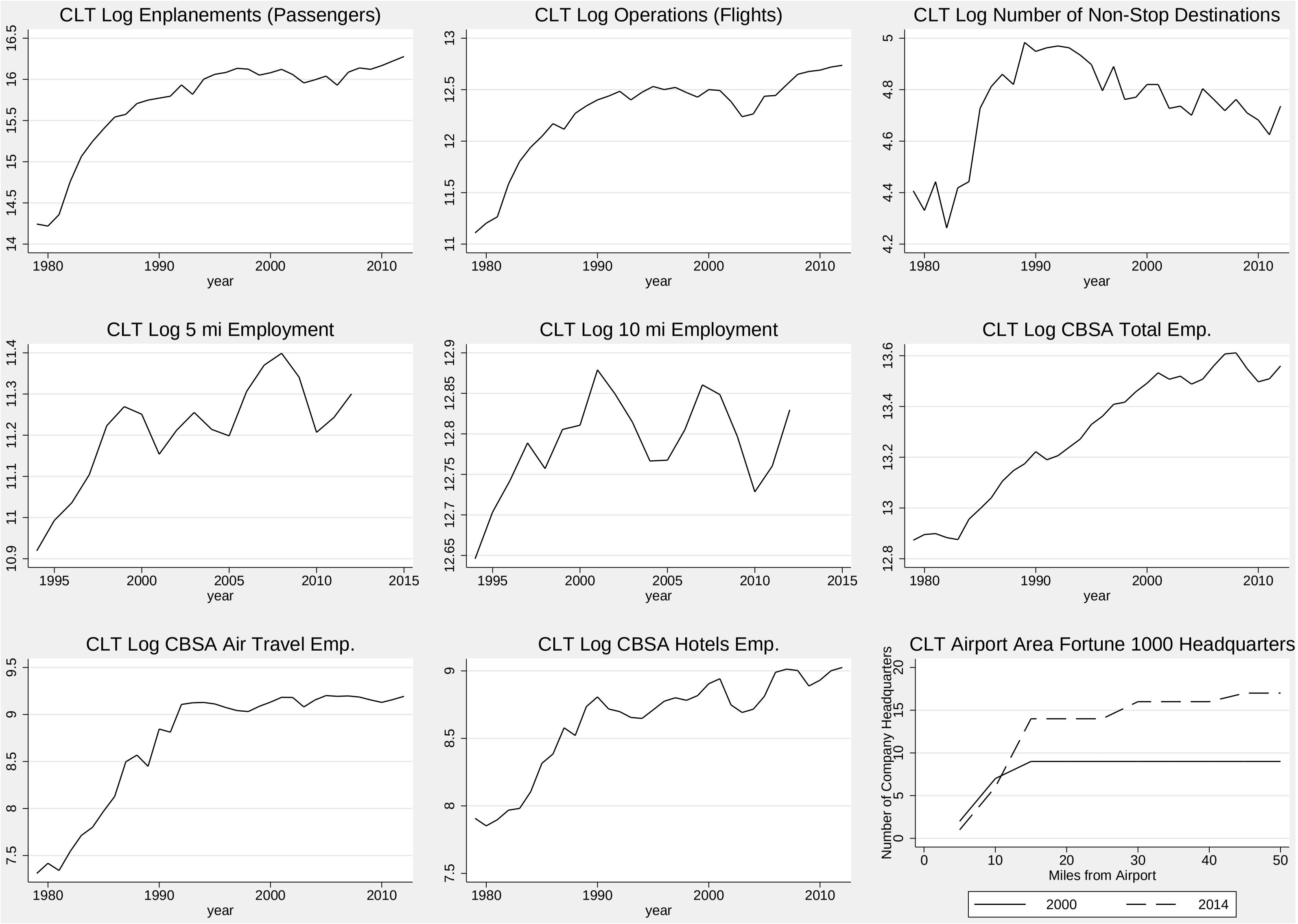


Figure 2.4: Case Study: Dayton, OH (DAY) Airport Employment

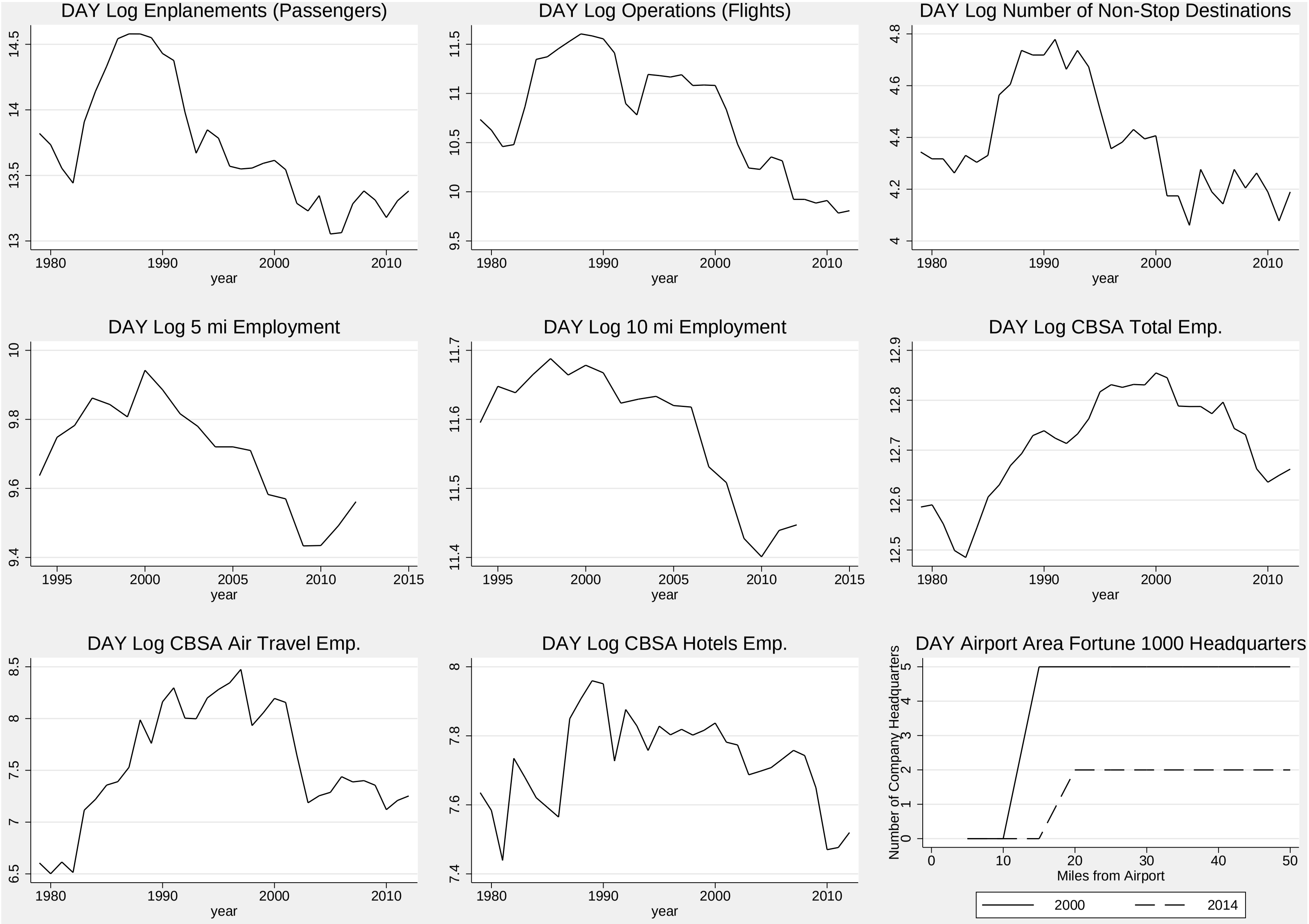
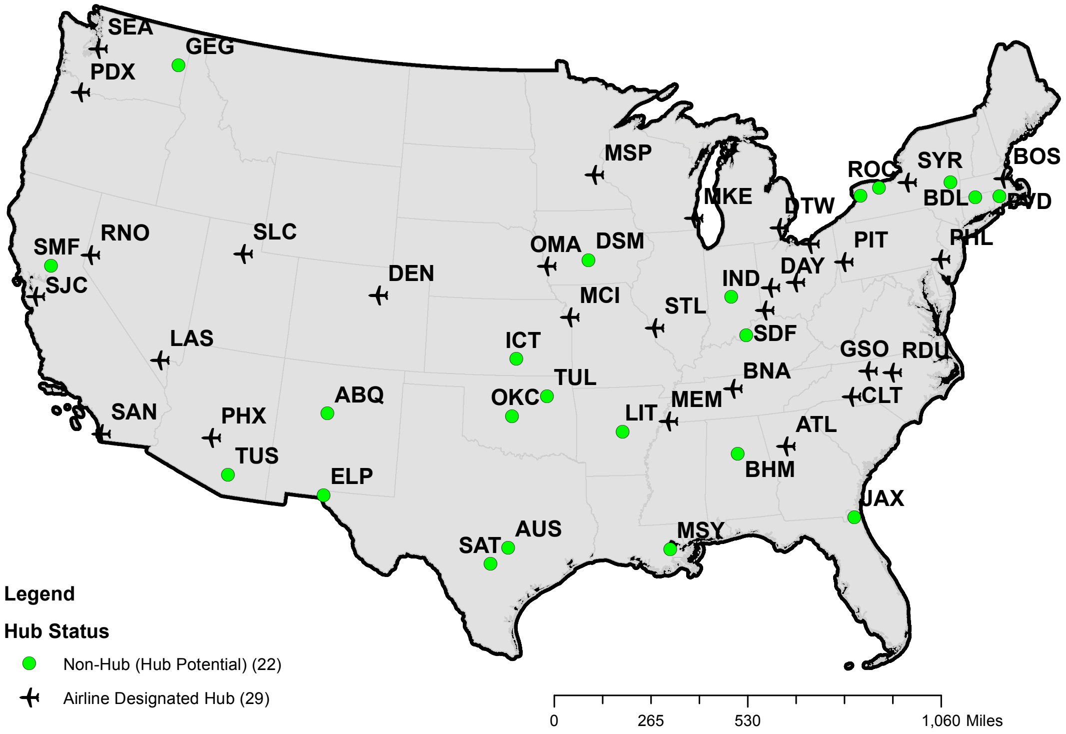


Figure 2.5: Map of Hub and Hub Potential Airports in Study



the sample of 157 airports from the 1964 *FAA Statistical Handbook*.[6] After eliminating airports in cities with multiple airports, I keep those that in 1977 carried at least 0.2 percent of air traffic, and/or that would ever become airport hubs.[7] This yields a sample of 51 airports - 29 that were hubs for some part of their history, and 22 that were never designated as hub airports. The map below shows the locations of the airports in this analysis.

Details of each hub airport are given in Table B.1, while those for hub potential airports are given in Table B.2 in the Appendix.

For each airport, I obtain air traffic data - enplanements (passenger counts) and operations (flights) from 1964, 1970, and 1976 - 2012 from the Federal Aviation Administration.[8] Given the importance of non-stop flights to business travelers, I use U.S. Department of Transportation DB1B market data to generate two simple measures of market access - the number of cities one can travel to or from an airport without any stops, and the number of cities that can be reached with no more than one connection. I also use this to generate

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[6] To the best of my knowledge, this is the earliest comprehensive classification of hub cities in the United States by a governmental entity.

[7] This cutoff was chosen after examining the traffic levels of hub airports in the study, and noting that the smallest airport at the time to become a hub, San Jose (SJC), had 1977 traffic levels of 0.2 percent. 1977 was chosen as this was just prior to deregulation in 1978.

[8] FAA Terminal Area Forecast, https://aspm.faa.gov/main/taf.asp

a measure of one-way fares by originating airport.[9]

Primary data on city employment outcomes are derived from the County Business Patterns.[10] Data were obtained for each year from 1964 to 2012 for total employment and industry employment in a variety of sectors - tradable and non-tradable, mining, manufacturing, construction, transportation, air transportation, wholesale trade, retail trade, eating and drinking places, finance, insurance, and real estate, services, hotels and lodging, amusement and recreation, and museums, zoos, and other similar establishments. I also obtain the data for establishments by sector, and total payroll. I use the Standard Industrial Classification (SIC) categories as a baseline.[11] Where necessary, data were converted from NAICS groups to SIC groups.[12][13] Finally, all county-level data was aggregated to the Census Based Statistical Area (CBSA) metropolitan area level.[14]

Data on population and personal income are obtained from the U.S. Bureau of Economic Analysis.[15] for each of the industries listed above, at the metropolitan area level.[16] I also obtain this data for personal income, earnings, earnings per worker and per-capita personal income.[17]

Finally, to assess whether hub airports might have any local spillover effects on the economy, I use Zip Code Business Patterns (ZBP) data from the U.S. Census Bureau.[18] This data is available from 1994 to 2012. Using zip code centroids and GIS software, I compute the distance from the airport's FAA-computed latitude and longitude to each centroid. This enables me to examine employment outcomes within various radii of the

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[9] I am grateful to Severin Borenstein for providing this data. https://sites.google.com/site/borenstein/airdata

[10] U.S. Census Bureau, Obtained from the National Historical Geographic Information System (NHGIS), www.nhgis.org..

[11] These industries correspond to the following SIC codes: 10-14 (Mining), 15-17 (Construction), 20-39 (Manufacturing), 45 (Air Travel), 50-51 (Wholesale Trade), 52-59 (Retail Trade), 58 (Eating and Drinking Places), 60-67 (Finance, Insurance and Real Estate), 70-89 (Services), 71 (Hotels and Lodging), 79 (Amusement & Recreation Services), 84 (Museums, Botanical, Zoological Gardens). Tradable sector employment is defined as the sum of mining, manufacturing, and wholesale trade employment. Non-tradable sector employment is defined as the sum of construction, retail trade, finance, insurance and real estate, and services employment.

[12] SIC to NAICS conversions were accomplished using the fixed point equations provided by the U.S. Department of Housing and Urban Development: http://socds.huduser.org/CBPSE/note.htm

[13] Missing data was imputed using establishment counts and the midpoint for the number of employees at each establishment. Missing data affected substantially fewer than one percent of the data points in the analysis.

[14] As a robustness check, I repeated the analysis at the Commuting Zone and County levels, and found the results to be virtually indistinguishable.

[15] Tables CA5 and CA5N, Regional Economic Accounts, Bureau of Economic Analysis, U.S. Department of Commerce: http://www.bea.gov/regional/

[16] Service industries were excluded, as numerous changes were made to the taxonomy of component industries in 2000.

[17] Census Based Statistical Areas, based on 2010 definitions, are the primary unit of observation in this analysis.

[18] https://www.census.gov/econ/cbp/historical.htm

airport, and also to verify how much (if any) information is lost in standard metropolitan-area level analyses of airports and employment. The ZBP data provides total employment and payroll, establishment counts for each industry, and indicators for the number of establishments within an employment size class. I use the midpoint of these employment size classes, multiplied by the number of establishments in each class, to generate estimates of industry-specific employment. As most of the establishments are relatively small, the employment estimates should be fairly accurate on an aggregated level.

2.5.1 Methodology

As noted in Section 2.2, there are a variety of definitions of hub airports. In this study, I consider the consequences of an airline labeling an airport as their hub. To create the database of airline hubs, we culled airline web sites, annual reports, newspaper articles, aviation trade publications and other historical sources. As the baseline for the events affecting hub benefits, e.g. mergers, bankruptcies, and acquisitions, I use the list compiled by Airlines for America, the aviation industry trade group.[19] Relevant events (post-1978, affecting a major U.S. hub airport) were compiled into a timeline shown in Figure 2.6. The timing of resulting hub openings and closings is summarized in Appendix Table B.1.

Identification is based on the assumption that hub closures were due to plausibly exogenous changes in the network structure resulting from industrial organization-related activity. Hub closures and downsizings that were made for other reasons (such as the reduction in size of the Cincinnati hub considered in Section 2.4.2) are not included. I use both fixed effects regression as well as event-study methods to identify the effects of these airports on their cities. I run the following specifications:

$$Y_{it} = \alpha + \beta(H = 1) + \kappa \boldsymbol{X} + \gamma_i + \tau_t + \epsilon_{it} \tag{2.1}$$

where β identifies the (log) change in the employment, payroll, population or aviation-related outcome of interest Y_{it}; γ_i is a city fixed effect and τ_t is a year fixed effect. The primary unit of observation is the metropolitan area, also referred to as a Census Based Statistical Area (CBSA). In the specifications that follow, controls that may be included in the vector of X include the possibility of a time trend (linear and quadratic), and city-specific time trends where allowed by the data, Standard errors are clustered at the CBSA (airport) level.

As a check on the values given by equation 2.1, I also use an event-study methodology. After normalizing the data to the time of airport opening or closing, I run the following event-time specification:

$$Y_{it} = \alpha + \gamma_i + \tau_t + \sum_{k=-4}^{4} \beta_{k,it} + \epsilon_{it} \tag{2.2}$$

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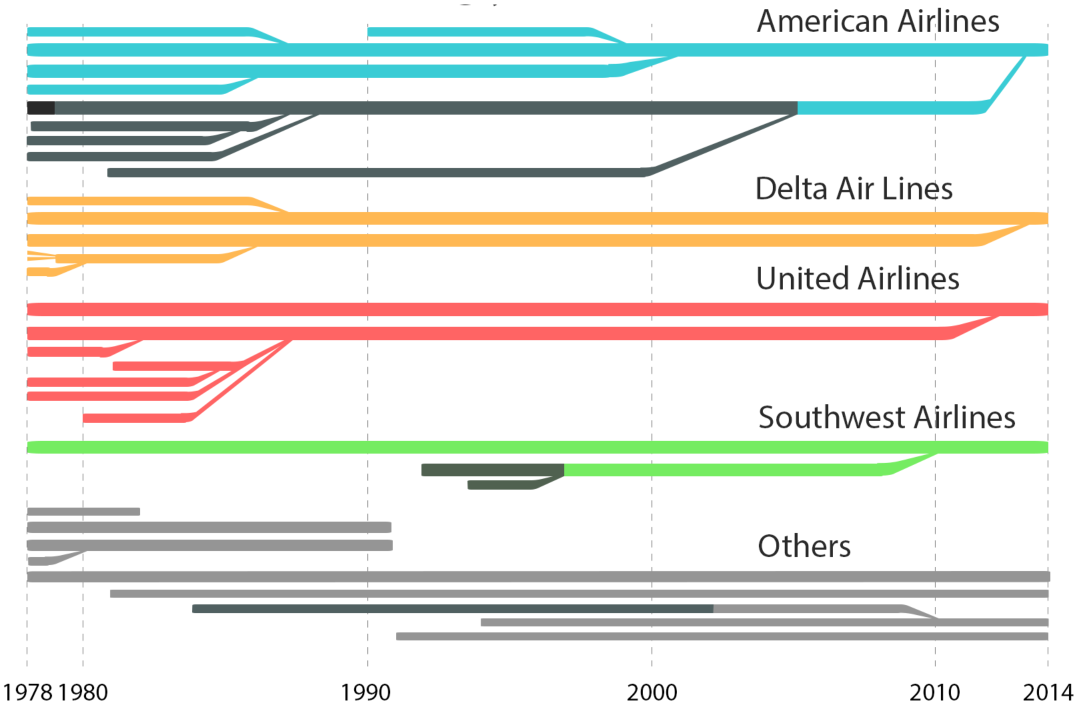
[19] http://airlines.org/data/u-s-airline-mergers-and-acquisitions/

Figure 2.6: Airline Genealogy: Summary Timeline of Mergers and Bankruptcy Activity



Individual genealogies for each airline group are provided in figures given in the Appendix. Shading correstponds to the eventual airline individual airports would merge into.

where I incorporate a series of dummy variables indicating time relative to the year of certification. In the results reported here, the time-since-hub-change dummies are capped at $k_{min} = -4$ and $k_{max} = 4$, respectively. The omitted category is the last year prior to the hub opening or closing. Cluster-robust standard errors are estimated, clustered at the CBSA (airport) level. In both cases, city-specific trends are accounted for in the final specifications.

2.6 Results and Discussion

2.6.1 Panel Evidence (Entire Sample)

First, to ensure that the measure of hub openings and closings I consider here captures changes in the aviation system as expected, Table 2.1 provides information on how airport hubs affect air service. In Panel A, I consider passenger boardings/enplanements. Specification 1 includes only airport (city) fixed effects, and gives a value of 0.486. Adding a linear and quadratic time trend reduces this value to 0.304 in specification 2. Swapping out the time trends for year fixed effects does not change the estimation much, giving an estimate of 0.305 in specification 3. After controlling for city-specific trends in specification 4, my preferred specification, we see that hubs increase air passengers by approximately 25 percent.[20] Similarly, after accounting for trends, hubs have roughly 21 percent more flights, but do not necessarily allow access to significantly more destinations non-stop. The same is true for destinations reachable with one connection, and ticket prices. In fact, Panel E provides absolutely no evidence that hubs lead to airline monopoly pricing power.

Table 2.2 considers population and wage measures. In Panel A, it is clear that hubs have effectively a zero effect on population. It also appears that hub airports do not substantially increase payroll, either overall or on a per-worker basis. Yet, measures of personal income, which essentially proxy for a city's gross domestic product and output, are significant, both on an aggregate and per-worker basis, as shown in Panels B and C. In Table 2.3, I find that, as expected, employment increases in the air travel sector by roughly 20 percent as a result of hub airports. However, there is no corresponding increase in wholesale trade employment or eating and drinking places. However, in Panel D, we see that hotel employment increases substantially, by roughly 8 percent. Is this increase due to tourism? Panels E and F suggest otherwise. Hubs actually appear to decrease amusements and recreation sector employment.[21] In contrast, while noise in the

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[20] I include the comparison between Specification 2 and 3 to assess the amount of variation there might be between including year fixed effects (preferred) and a linear and quadratic time trend. While I would prefer to include city by year fixed effects in the final model, this is impractical given the number of regressors that would ultimately be required, hence I opted not to include year effects in the final, preferred specification.

[21] It is difficult to measure tourism-related employment. SIC 79, Amusements and Recreation, is likely not the best measure of the tourism sector's activity, as it includes employment in categories such as

Table 2.1: Results: Panel Regressions - Air Access Factors

	(1)	(2)	(3)	(4)
Panel A				
Log Boardings	0.486****	0.304****	0.305****	0.247****
	(0.083)	(0.083)	(0.086)	(0.048)
N	1734	1734	1734	1734
R-Sq	0.885	0.917	0.922	0.968
Panel B				
Log Flights	0.374****	0.267***	0.262***	0.207****
	(0.079)	(0.082)	(0.084)	(0.042)
N	1734	1734	1734	1734
R-Sq	0.898	0.911	0.916	0.962
Panel C				
Log Non-Stop Destinations	0.110**	0.073**	0.038	0.058
	(0.051)	(0.030)	(0.028)	(0.037)
N	1724	1724	1724	1724
R-Sq	0.946	0.963	0.975	0.970
Panel D				
Log One-Stop Destinations	-0.005	0.020	0.022	0.018
	(0.029)	(0.020)	(0.021)	(0.014)
N	1734	1734	1734	1734
R-Sq	0.986	0.993	0.994	0.995
Panel E				
Log Average One-Way Ticket Price	0.070	0.016	0.004	-0.002
	(0.043)	(0.033)	(0.031)	(0.039)
N	1734	1734	1734	1734
R-Sq	0.441	0.727	0.797	0.764
City (Airport) FE	Y	Y	Y	Y
Time Trend (Linear and Quadratic)	N	Y	N	Y
Year FE	N	N	Y	N
City-Specific Trends	N	N	N	Y

Cluster robust standard errors in parentheses, clustered at the city (airport) level.
*** p<0.01, ** p<0.05, * p<0.1

data precludes any judgment of significance, the coefficients on all four specifications of Panel F (Museums, Zoos, and Botanical Gardens) are substantial relative to those of the other employment categories.

Turning to Table 2.4, I find no significant effects on total employment (in fact, just as noted by Sheard (2014), it is practically zero). I also find no significant employment effects on the aggregate groups of tradable and non-tradable employment, services, finance, insurance and real estate, or retail trade. In Table 2.5, we see that there are no significant effects of hubs on the classes of aviation-related employment sectors considered earlier, including Hotels, Amusements and Recreation, and Museums, Zoos, and Botanical Gardens. The small coefficients on the coefficients in Panels E and F relative to their counterparts in Table 2.3 suggest that tourism-related employment is likely not responsible for the employment increase in hotel employment. Table 2.6, on the other hand, shows an overall 1.4 - 2 percent increase in establishments, with all of the increase coming from the nontraded sector. Coupled with the finding of virtually zero change in employment, this implies that the number of workers per establishment is smaller in cities with airport hubs, which based on previous research (see, for example, Chatterji et al. (2013)) could indicate higher levels of entrepreneurial activity which is also correlated with city growth. This finding also corroborates with the work of Button, Lall, Stough and Trice (1999) who find that hub airports have a causal positive effect on employment in presumably more innovative high-technology industries.

I also find evidence that (log) employment shares increase by 20 percent in airport employment, by 7 percent in hotel employment, but decrease by up to 8 percent in amusements and recreation employment, consistent with the employment findings above. I find no additional significant effects on employment shares. Additionally, using industry payroll data from the Bureau of Economic Analysis, I find evidence (at the 10 percent level) of a 4 percent increase in income for eating and drinking places, but otherwise no significant effects on industry-level payroll.

2.6.2 Extensions: Zip Code Business Patterns

Given the findings above, it is interesting to explore how airports might generate spillover effects, and, more importantly, how the magnitude of these employment effects might change with distance from the airport. It is important to bear in mind that ZBP data is only available from 1994 on, so these estimates differ from those presented in Section 2.6.1 above. In Figure 2.7, I consider nine outcomes: total employment, total establishments, total payroll, airport employment, hotels employment, amusement and recreation employment, museums and botanical gardens, wholesale trade, and services.[22] For virtually all the industries affected by airports, the size of the effect peaks between 3

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dance studios, theatrical services, bowling centers, commercial sport franchises, physical fitness facilities, and amusement parks. Many of these types of establishments would exist even without an airport in the city.

[22] ZBP employment for industries estimated - see Section 2.5.

Table 2.2: Panel Regression Results: Population, Output and Wage Measures

	(1)	(2)	(3)	(4)
Panel A				
Log Population	0.053	0.014	0.016	-0.002
	(0.033)	(0.031)	(0.032)	(0.007)
N	1734	1734	1734	1734
R-Sq	0.935	0.972	0.972	0.999
Panel B				
Log Personal Income	0.270*	0.038	0.039	0.024**
	(0.146)	(0.031)	(0.031)	(0.011)
N	1734	1734	1734	1734
R-Sq	0.584	0.984	0.985	0.998
Panel C				
Log Per-Capita Personal Income	0.217*	0.024**	0.023**	0.026**
	(0.123)	(0.011)	(0.010)	(0.011)
N	1734	1734	1734	1734
R-Sq	0.077	0.990	0.992	0.993
Panel D				
Log Earnings Per Worker	0.168	0.011	0.014	0.005
	(0.105)	(0.012)	(0.011)	(0.007)
N	1734	1734	1734	1734
R-Sq	0.072	0.987	0.989	0.994
Panel E				
Log Payroll	0.277*	0.039	0.047	0.014
	(0.145)	(0.036)	(0.036)	(0.015)
N	1734	1734	1734	1734
R-Sq	0.640	0.978	0.979	0.996
Panel F				
Log Payroll Per Worker	0.153	0.016	0.016	0.006
	(0.098)	(0.014)	(0.013)	(0.008)
N	1734	1734	1734	1734
R-Sq	0.107	0.980	0.984	0.992
City (Airport) FE	Y	Y	Y	Y
Time Trend (Linear and Quadratic)	N	Y	N	Y
Year FE	N	N	Y	N
City-Specific Trends	N	N	N	Y

Cluster robust standard errors in parentheses, clustered at the city (airport) level.
*** p<0.01, ** p<0.05, * p<0.1

Table 2.3: Panel Results: Sectoral Employment (1)

	(1)	(2)	(3)	(4)
Panel A				
Air Travel Employment	0.534****	0.280***	0.298***	0.208***
	(0.101)	(0.091)	(0.092)	(0.077)
N	1734	1734	1734	1734
R-Sq	0.796	0.897	0.901	0.940
Panel B				
Wholesale Trade Employment	0.103**	0.014	0.019	0.027
	(0.049)	(0.040)	(0.042)	(0.018)
N	1734	1734	1734	1734
R-Sq	0.941	0.961	0.963	0.991
Panel C				
Eating and Drinking Places	0.119*	0.002	-0.002	0.006
	(0.065)	(0.024)	(0.026)	(0.012)
N	1734	1734	1734	1734
R-Sq	0.828	0.973	0.974	0.994
Panel D				
Hotels and Lodging	0.179***	0.094*	0.093*	0.080**
	(0.066)	(0.050)	(0.052)	(0.031)
N	1734	1734	1734	1734
R-Sq	0.926	0.959	0.961	0.979
Panel E				
Amusements and Recreation	0.121	-0.062*	-0.026	-0.068**
	(0.140)	(0.033)	(0.037)	(0.030)
N	1734	1734	1734	1734
R-Sq	0.622	0.936	0.947	0.972
Panel F				
Museums, Zoos, Parks	0.373*	0.065	0.077	0.089
	(0.216)	(0.106)	(0.107)	(0.092)
N	1729	1729	1729	1729
R-Sq	0.662	0.881	0.887	0.933
City (Airport) FE	Y	Y	Y	Y
Time Trend (Linear and Quadratic)	N	Y	N	Y
Year FE	N	N	Y	N
City-Specific Trends	N	N	N	Y

Cluster robust standard errors in parentheses, clustered at the city (airport) level.
*** p<0.01, ** p<0.05, * p<0.1

Table 2.4: Panel Results: Sectoral Employment (2)

	(1)	(2)	(3)	(4)
Panel A				
Total Employment	0.125**	0.023	0.032	0.009
	(0.053)	(0.028)	(0.029)	(0.013)
N	1734	1734	1734	1734
R-Sq	0.902	0.972	0.975	0.995
Panel B				
Tradables	0.018	-0.015	0.029	-0.035
	(0.052)	(0.048)	(0.042)	(0.038)
N	1734	1734	1734	1734
R-Sq	0.880	0.885	0.962	0.913
Panel C				
Nontradables	0.154**	0.014	0.020	0.007
	(0.068)	(0.023)	(0.025)	(0.012)
N	1734	1734	1734	1734
R-Sq	0.846	0.979	0.980	0.995
Panel D				
Services	0.190**	-0.004	0.002	-0.002
	(0.090)	(0.023)	(0.025)	(0.012)
N	1734	1734	1734	1734
R-Sq	0.773	0.980	0.981	0.996
Panel E				
Finance, Insurance, Real Estate	0.141**	0.036	0.043	-0.012
	(0.055)	(0.032)	(0.031)	(0.021)
N	1734	1734	1734	1734
R-Sq	0.905	0.971	0.974	0.991
Panel F				
Retail Trade	0.109**	0.016	0.015	0.013
	(0.045)	(0.023)	(0.025)	(0.012)
N	1734	1734	1734	1734
R-Sq	0.903	0.973	0.974	0.995
City (Airport) FE	Y	Y	Y	Y
Time Trend (Linear and Quadratic)	N	Y	N	Y
Year FE	N	N	Y	N
City-Specific Trends	N	N	N	Y

Cluster robust standard errors in parentheses, clustered at the city (airport) level.
*** p<0.01, ** p<0.05, * p<0.1

Table 2.5: Panel Results: Sectoral Establishment Counts (1)

	(1)	(2)	(3)	(4)
Panel A				
Air Travel Establishments	0.234**	0.058	0.060*	0.055
	(0.092)	(0.035)	(0.035)	(0.034)
N	1734	1734	1734	1734
R-Sq	0.713	0.936	0.937	0.959
Panel B				
Wholesale Trade	0.111**	0.005	0.003	0.018
	(0.047)	(0.038)	(0.039)	(0.014)
N	1734	1734	1734	1734
R-Sq	0.949	0.970	0.973	0.994
Panel C				
Eating and Drinking Places	0.119**	0.009	0.000	0.006
	(0.054)	(0.030)	(0.031)	(0.009)
N	1734	1734	1734	1734
R-Sq	0.860	0.974	0.976	0.996
Panel D				
Hotels and Lodging	0.091**	0.027	0.028	0.017
	(0.039)	(0.033)	(0.033)	(0.020)
N	1734	1734	1734	1734
R-Sq	0.875	0.953	0.956	0.985
Panel E				
Amusements and Recreation	0.174**	0.007	0.012	0.001
	(0.082)	(0.031)	(0.032)	(0.013)
N	1734	1734	1734	1734
R-Sq	0.762	0.973	0.975	0.994
Panel F				
Museums, Zoos, Parks	0.146	-0.053	-0.039	-0.050
	(0.139)	(0.055)	(0.057)	(0.059)
N	1701	1701	1701	1701
R-Sq	0.589	0.920	0.926	0.953
City (Airport) FE	Y	Y	Y	Y
Time Trend (Linear and Quadratic)	N	Y	N	Y
Year FE	N	N	Y	N
City-Specific Trends	N	N	N	Y

Cluster robust standard errors in parentheses, clustered at the city (airport) level.
*** p<0.01, ** p<0.05, * p<0.1

Table 2.6: Panel Results: Sectoral Establishment Counts (2)

	(1)	(2)	(3)	(4)
Panel A				
Total Establishments	0.128***	0.024	0.019	0.018**
	(0.044)	(0.025)	(0.025)	(0.008)
N	1734	1734	1734	1734
R-Sq	0.910	0.978	0.980	0.997
Panel B				
Tradables	0.086*	-0.011	0.000	-0.001
	(0.045)	(0.036)	(0.035)	(0.018)
N	1734	1734	1734	1734
R-Sq	0.942	0.959	0.976	0.980
Panel C				
Nontradables	0.139***	0.022	0.020	0.012*
	(0.051)	(0.024)	(0.025)	(0.006)
N	1734	1734	1734	1734
R-Sq	0.883	0.979	0.980	0.998
Panel D				
Services	0.169**	0.015	0.009	0.010
	(0.067)	(0.024)	(0.025)	(0.008)
N	1734	1734	1734	1734
R-Sq	0.836	0.980	0.981	0.998
Panel E				
Finance, Insurance, Real Estate	0.132*	0.023	0.035	-0.003
	(0.067)	(0.028)	(0.028)	(0.014)
N	1734	1734	1734	1734
R-Sq	0.818	0.972	0.976	0.992
Panel F				
Retail Trade	0.085***	0.021	0.012	0.014*
	(0.028)	(0.025)	(0.025)	(0.007)
N	1734	1734	1734	1734
R-Sq	0.954	0.978	0.979	0.997
City (Airport) FE	Y	Y	Y	Y
Time Trend (Linear and Quadratic)	N	Y	N	Y
Year FE	N	N	Y	N
City-Specific Trends	N	N	N	Y

Cluster robust standard errors in parentheses, clustered at the city (airport) level.
*** p<0.01, ** p<0.05, * p<0.1

and 7 miles away from the airport, and subsequently decreases from there. These effects for total employment, air travel, amusements and recreation, museums, wholesale trade, and service sector employment are significant at the 10 percent level for at least one point within that range. We see, however that virtually all the effects, save for the hotel sector, shrink in size and become non-significant past the 15 mile mark. Given that the average area of a metropolitan area is 5,390 miles (corresponding to an average radius of 37 miles from an airport), it could simply be the case that some effects of the hub were too small to be detected at the level of the CBSA, but could be detected closer to the airport. As a robustness check, I repeated the analysis presented in Section 2.6.1 and found nearly identical results to those presented here.

2.6.3 Event Study

As a check on the primary findings, I also use an event-study design to separately estimate the effects of hub openings and hub closings on the local economy. In each specification, I control for four years prior to and after hub opening (three years in the case of more limited Zip Code Business Patterns (ZBP) data). Each specification includes city and year fixed effects, as well as city-specific linear time trends. For each event study, I focus on four air-travel related factors: passenger and aircraft traffic, non-stop market access, and average ticket price. I focus on nine measures of the local economy: total employment, total establishments, per capita personal income, air travel employment, hotels employment, amusements and recreation employment, museums, zoo and botanical garden employment, wholesale trade employment, and service sector employment.

I normalize such that all estimates are relative to $t = -1$; that is, one year prior to the hub opening or closing. Because most hubs were opened in the 1980s and 1990s, this set was restricted to the set of hubs that opened and remained open to this day. This is to reduce the potential of contaminating the estimates of hub openings via hub closings, though downsized hubs might still pose an issue for identification.[23] Similarly, hub closing events were included only if prior to 2004, to ensure that event studies of at least 4 lags could be run. This also helps mitigate the fact that the competitive dynamics of the airline industry began to change substantially in the early 2000s. It is important to note that given the event studies are working with fewer data points than the panel regressions, these results may be biased.

To establish a baseline for the CBSA-level effects, Figure 2.8 shows the result of the event study for hub openings on four air travel characteristics: boardings, flights, non-stop destinations, and average ticket prices. While the estimator shows an increase in passenger boardings, it fails to show a significant increase in flights. This is troubling, as it is clear from the previous section that boardings and flights must move together. In terms of non-stop market access, this provides evidence that easier access to markets may not be the primary driver of any observed employment effects. Rather, it may

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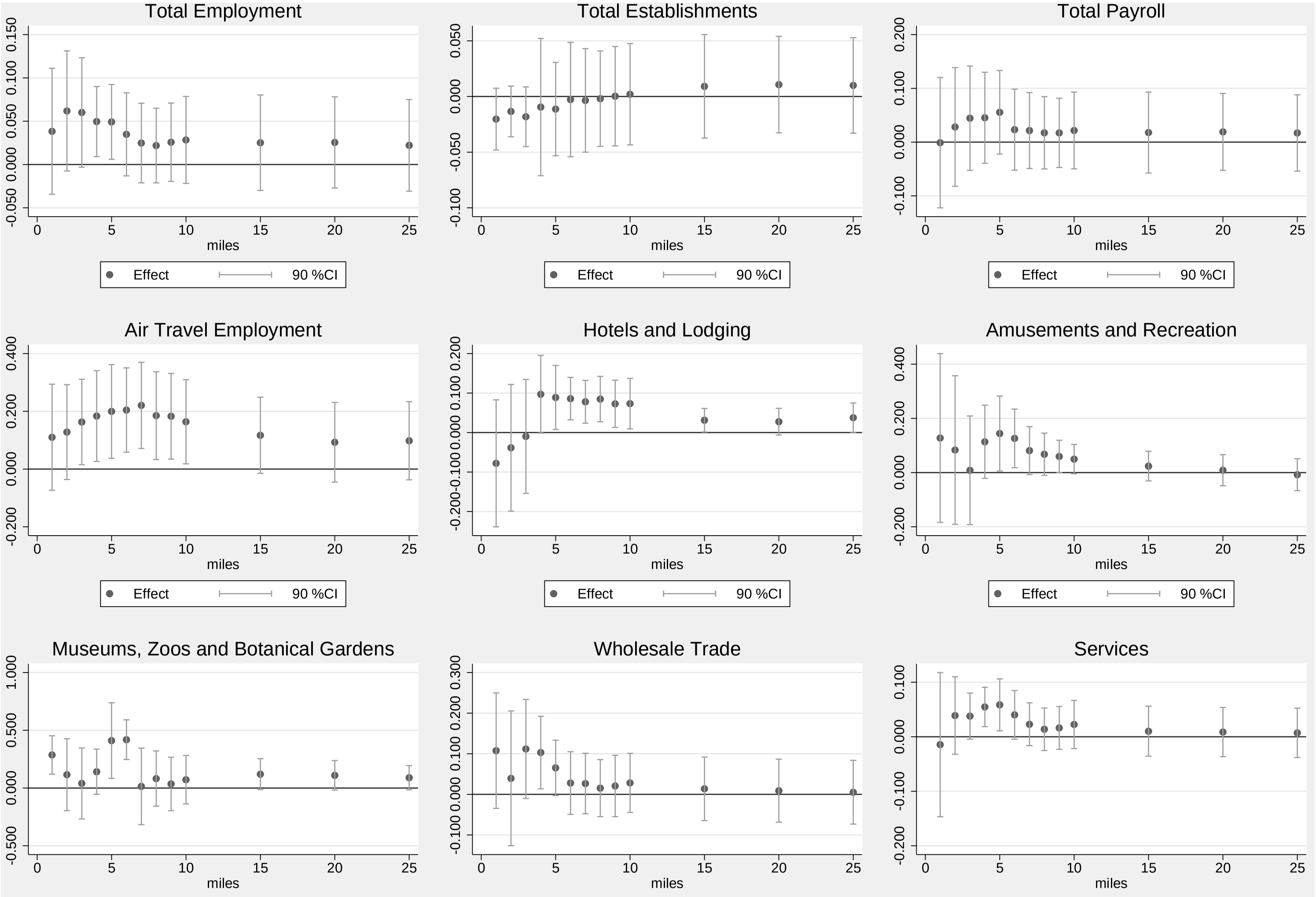
[23] City-by-year trends are included in the specifications, to reduce the potential severity of this issue.

Figure 2.7: Treatment Effect of Hubs by Distance from Airport- Zip Code Sample



Figures generated using Zip Code Business Patterns data. Each data point plots the coefficient of interest (indicator variable for having a hub) for a fixed-effects regression which includes airport (city) and year fixed effects, city-specific trends, similar to Specification (4) of the regressions presented previously.. Standard errors clustered at the city level. 90 percent (not 95 percent) confidence intervals shown. Miles represent cumulative distance from airport - for example, 5 miles out includes employment between 0-5 miles from the airport.

be the frequency of flights that drives their effects on employment. Estimates of the employment, establishment and income outcomes considered in Figure 2.9 do change as expected. The estimates are noisy, and few are significant for even a single year at the 5 percent significance level. The only exception is the estimates for hotels and lodging, which increase as expected. These estimates could be as they are simply because hub openings are additions to existing airports, which may have already been large enough to impact their local economies before their labeling as airline hubs.

On the other hand, CBSA level effects for hub closings do show the expected effects. Figure 2.10 presents the results of the event studies for hub closings. We see a significant decline in boardings and flights, with the effect on boardings greater than that on flights. In contrast to the estimates of Figure 2.11, the hub closing employment results parallel much of what was seen in the panel regression analysis: a small decline in total employment; a slightly more pronounced decline in total establishments; a borderline-significant decline in per-capita personal income; a decline in air travel employment; and a decline in wholesale trade employment. There are no significant changes in hotels and lodging employment or in other related sectors. These findings corroborate somewhat with the estimates shown in Tables 2.3 - 2.6. Moreover, they offer some indication that the negative values observed in Panel E of Table 2.3, are not robust, but it also offers evidence that tourism is likely not the cause of most of the observed effects. That is, there appears to be no reason to expect that hub airports lead to a decline in sectors such as amusement and recreation, but there is no evidence that hubs boost employment in these sectors either. If nothing else, the implication is that tourist destinations may have the potential to turn a destination airport into a hub (though it is unlikely), but that hub airports alone should not be viewed as catalysts for tourism on their own.

As a final method of assessing the effects of hubs on cities, I consider the role distance may play in the occurrence of those effects. That is, are there additional effects of hubs occurring closer to the airport that may be lost at the CBSA level? Since the ZBP data is only available from 1994 to 2012, only hub closings could be considered. Given the need for sufficient years of prior data, the sample of hubs included was restricted to those that closed in year 2000 or after. I present the ZBP outcomes for employment outcomes 5 miles and 10 miles away from the airport.

First, I consider the effects of hubs on air travel factors. Changes in boardings, flights, and average ticket prices are not significant, as shown in Figure 2.12. Changes in nonstop destinations are negative and significant. This indicates that any changes we find in employment could potentially be driven more by market access factors than traffic. Figure 2.13 considers effects at five miles. We see a decline in total employment, and to a lesser extent, payroll. There is a significant decline in air travel employment, amusements and recreation, museums, zoos, and botanical gardens, and service sector employment. There is no significant change in hotels and lodging employment or wholesale trade employment. This indicates that, perhaps a hub airport may not be a huge driver of employment for a city as a whole, but hub airports do generate localized spillovers, especially in some of the more tourist-oriented sectors. Moving to 10 miles out, as shown in Figure 2.14, the

Figure 2.8: Hub Opening Event Study: CBSA - Air Travel Indicators

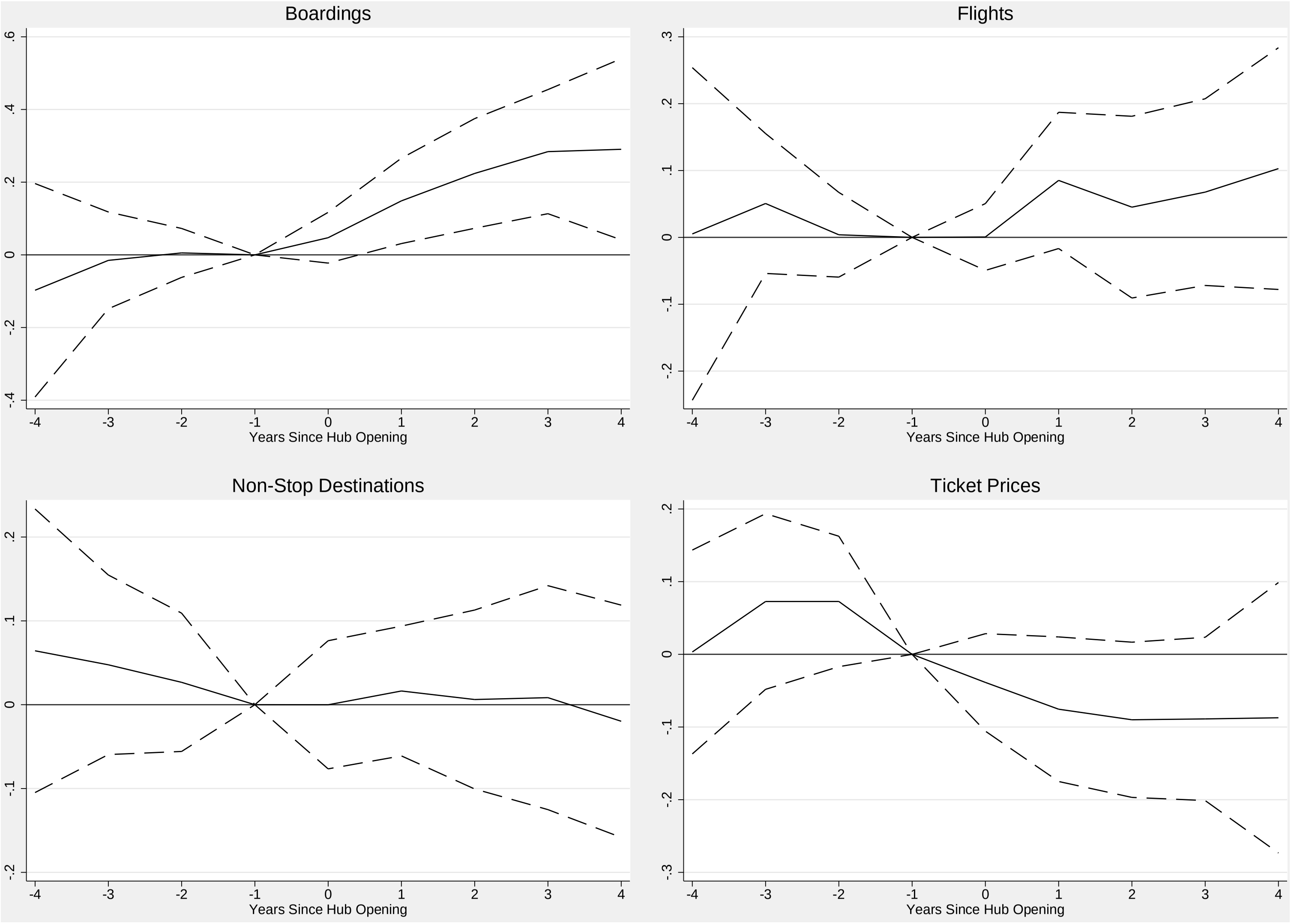


Figure shows event study outcomes on the quantities indicated above. Event studies include airport (city) and year fixed effects, as well as city specific trends. Standard errors are clustered at the city level. Dotted lines indicate 95 percent confidence intervals.

Figure 2.9: Hub Opening Event Study: CBSA - Local Economy Indicators

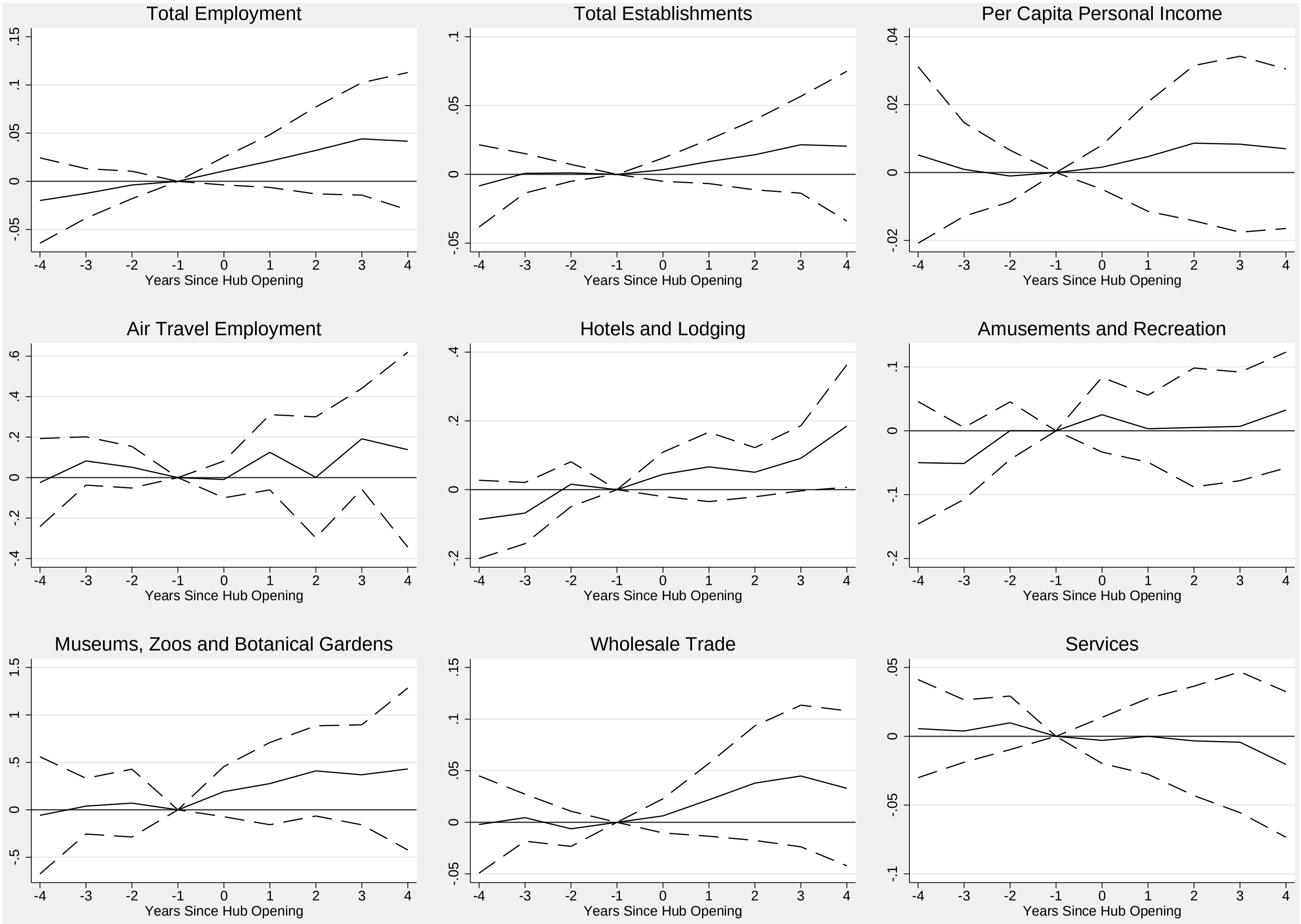


Figure shows event study outcomes on the quantities indicated above. Event studies include airport (city) and year fixed effects, as well as city specific trends. Standard errors are clustered at the city level. Dotted lines indicate 95 percent confidence intervals.

Figure 2.10: Hub Closing Event Study: CBSA - Air Travel Indicators

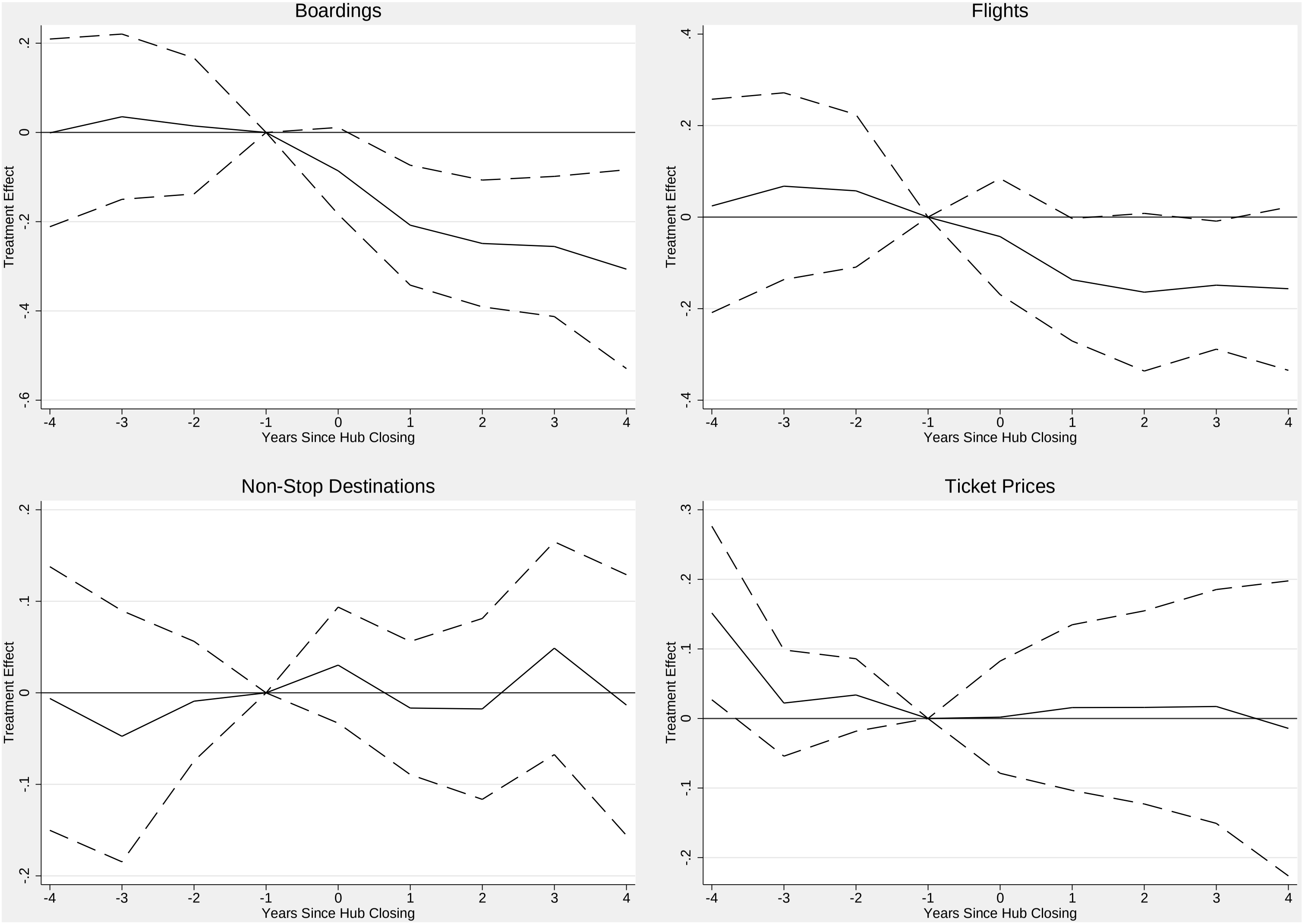


Figure shows event study outcomes on the quantities indicated above. Event studies include airport (city) and year fixed effects, as well as city specific trends. Standard errors are clustered at the city level. Dotted lines indicate 95 percent confidence intervals.

Figure 2.11: Hub Closing Event Study: CBSA - Local Economy Indicators

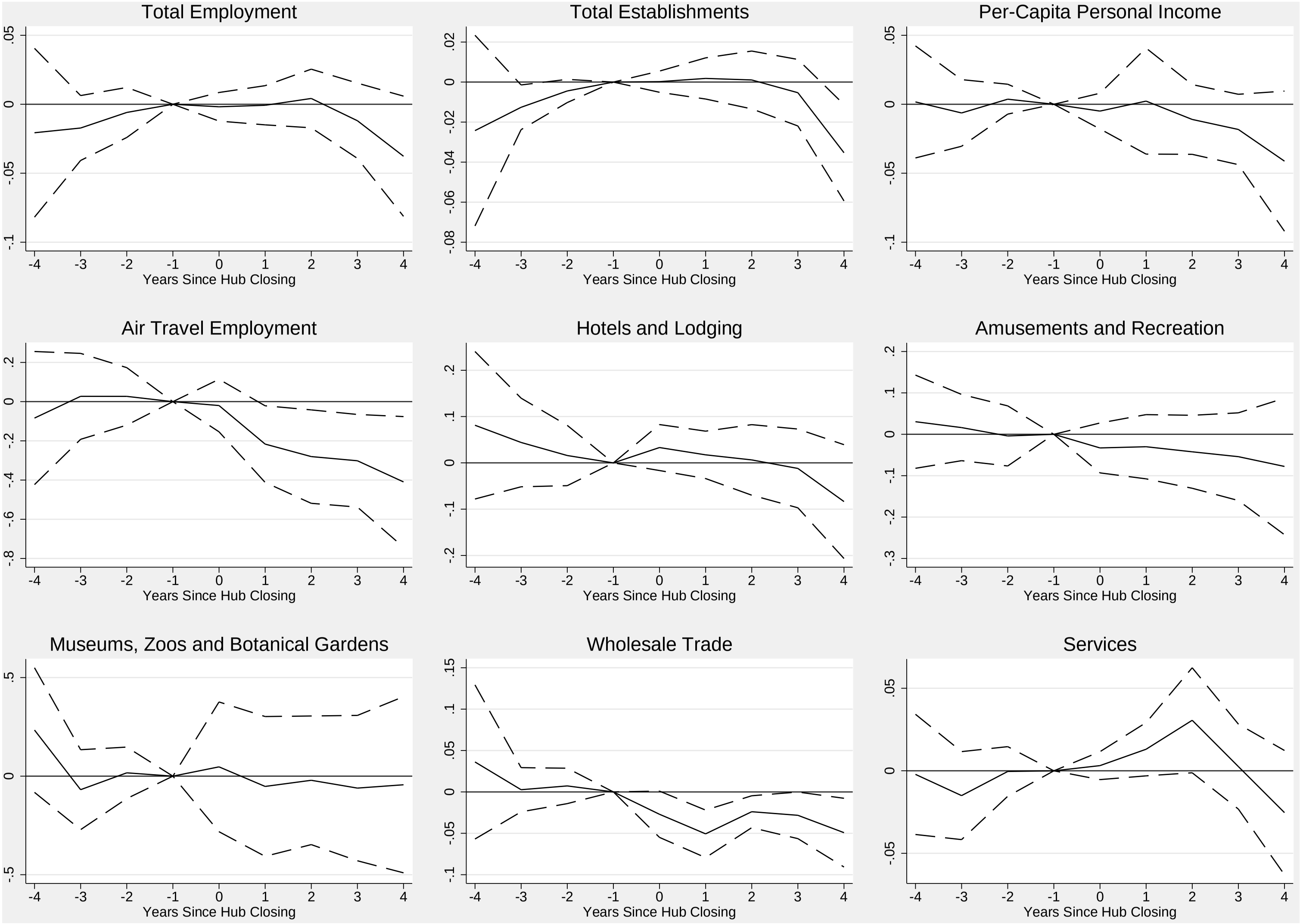


Figure shows event study outcomes on the quantities indicated above. Event studies include airport (city) and year fixed effects, as well as city specific trends. Standard errors are clustered at the city level. Dotted lines indicate 95 percent confidence intervals.

negative effect on hotels becomes more pronounced, but the effects on all other outcomes becomes flat.

2.6.4 Mergers and Acquisitions - Robustness

So far, the effects considered have involved all hub openings and hub closings that occurred in aviation history. The majority of these closings were made as a result of airline operational optimization. In some cases, hubs were considered duplicative and so were removed. In others, behavior of rivals may have made the costs of operating a hub too large. Still, others may have failed to lure enough traffic to make them worthwhile. In order to understand how these factors might affect identification of the effects presented above, I consider a model where only hub closures as a result of mergers and acquisitions are included. Of the 29 hub airports considered in the study, 14 experienced closures prior to 2012. Of those, only five could be said to be solely a result of M&A activity. These are: Dayton (DAY), Syracuse (SYR), San Jose (SJC), Reno (RNO), and San Diego (SAN). Dayton and Syracuse were both shut in the early 1990s as a result of Piedmont and American Airlines' merger in 1989. Reno Air had a hub at RNO during the mid-1990s, but was acquired by American in 1998, leading to subsequent hub closures at Reno. Also, with its absorption of Reno Air, American's San Jose hub became redundant and was de-hubbed. San Diego was a hub for Pacific Southwest Airlines (PSA) prior to its merger with USAir in 1988. Although the number of airports considered is small, identification is still possible given the long timeline considered in this analysis.

In general, specifications (1) - (3) differ greatly from the final specification in which city-specific trends are accounted for. As the number of hubs is small, I consider specification 4 as my preferred specification. Turning to Table B.3, we see that hubs still lead to increases in boardings and flights. The size of the increase is slightly larger than that shown in the main specifications. As in the main analysis, non-stop market access is no longer significant, and ticket prices fail to significantly change as well. Table B.4 shows no increase in population. However, in contrast to the result in Table 2.2, personal income and per-capita income increases by 4 to 5 percent, substantially larger than the main effect of roughly 3 percent. Additionally, earnings per worker increases by roughly 3 percent in this model. This confirms the main result, that air hubs lead to personal income growth. As before, payroll remains insignificant, but payroll per worker appears to increase by almost 3 percent. In Table 2.3, air travel retains its significance, with a magnitude of roughly 50 percent larger than those in the main result. The effect of hotels is indistinguishable from that in the main model. There remains no significant effect on employment by sector as considered in Table 2.4, except in the case of services. The non-significant coefficient on total employment provides evidence that hub status does not substantially affect total employment. The coefficient of -0.019 implies that the true effect is close to zero, as does the effect of 0.009 estimated in the main table. There are differences in establishment counts: the M&A model shows a roughly 5 perent increase in hotels and amusement and recreation establishments due to hubs. The magnitude of the

Figure 2.12: Hub Closing Event Study: Zip Code Level - Air Travel Indicators

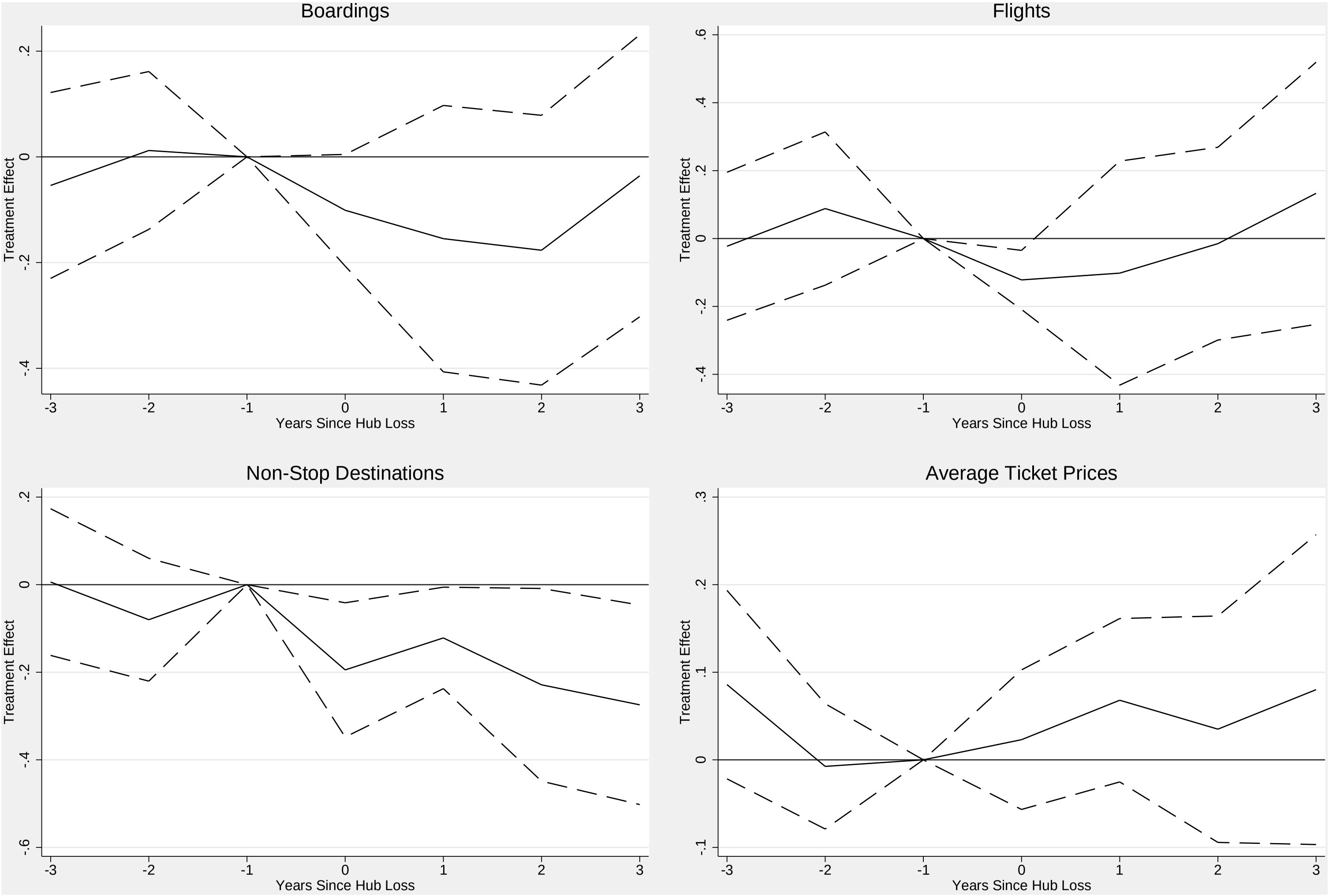


Figure shows event study outcomes on the quantities indicated above. Event studies include airport (city) and year fixed effects, as well as city specific trends. Standard errors are clustered at the city level. Dotted lines indicate 95 percent confidence intervals.

Figure 2.13: Hub Closing Event Study: Local Economy Indicators at 5mi from Airport

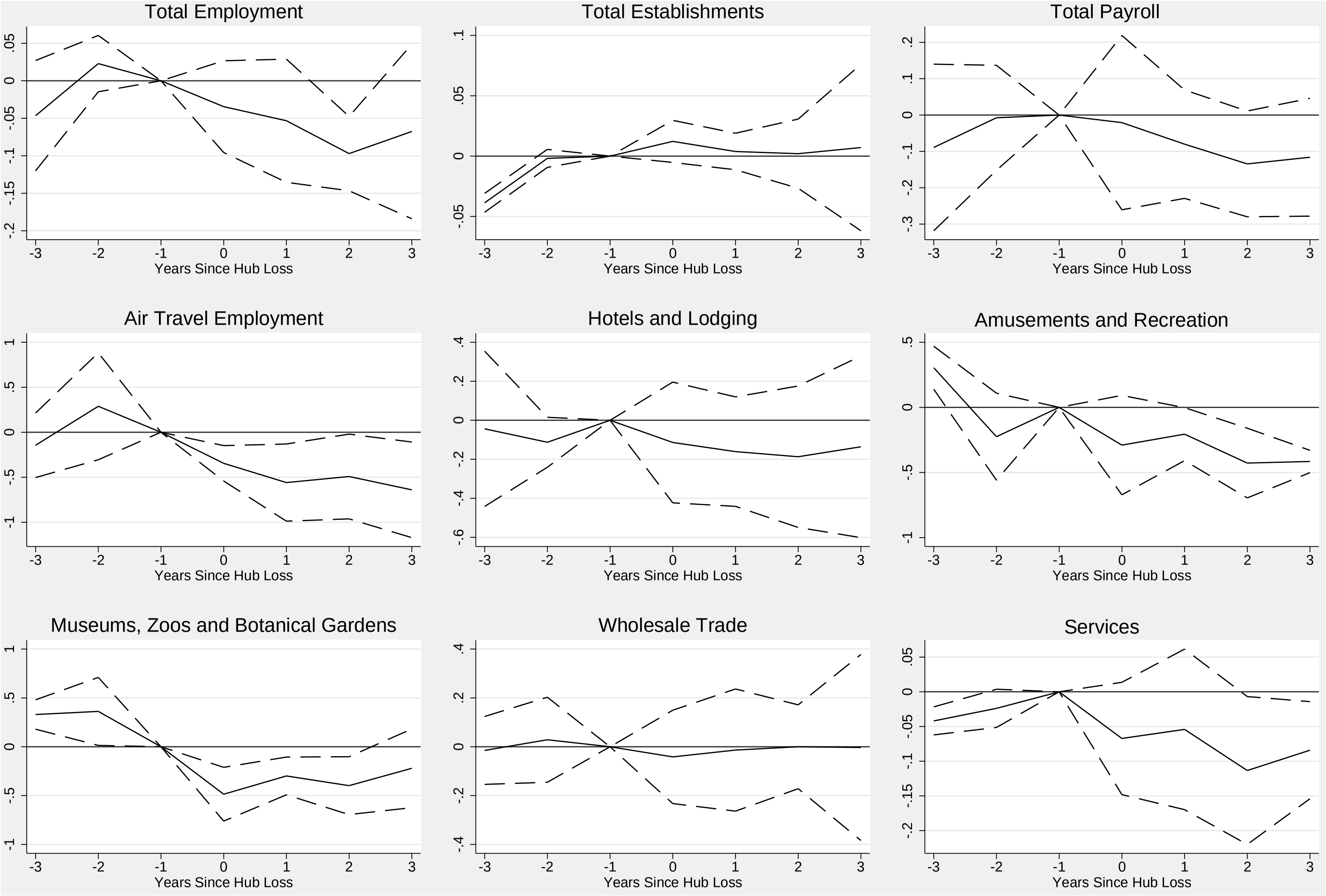


Figure shows event study outcomes on the quantities indicated above. Event studies include airport (city) and year fixed effects, as well as city specific trends. Standard errors are clustered at the city level. Dotted lines indicate 95 percent confidence intervals.

Figure 2.14: Hub Closing Event Study: Local Economy Indicators at 10mi from Airport

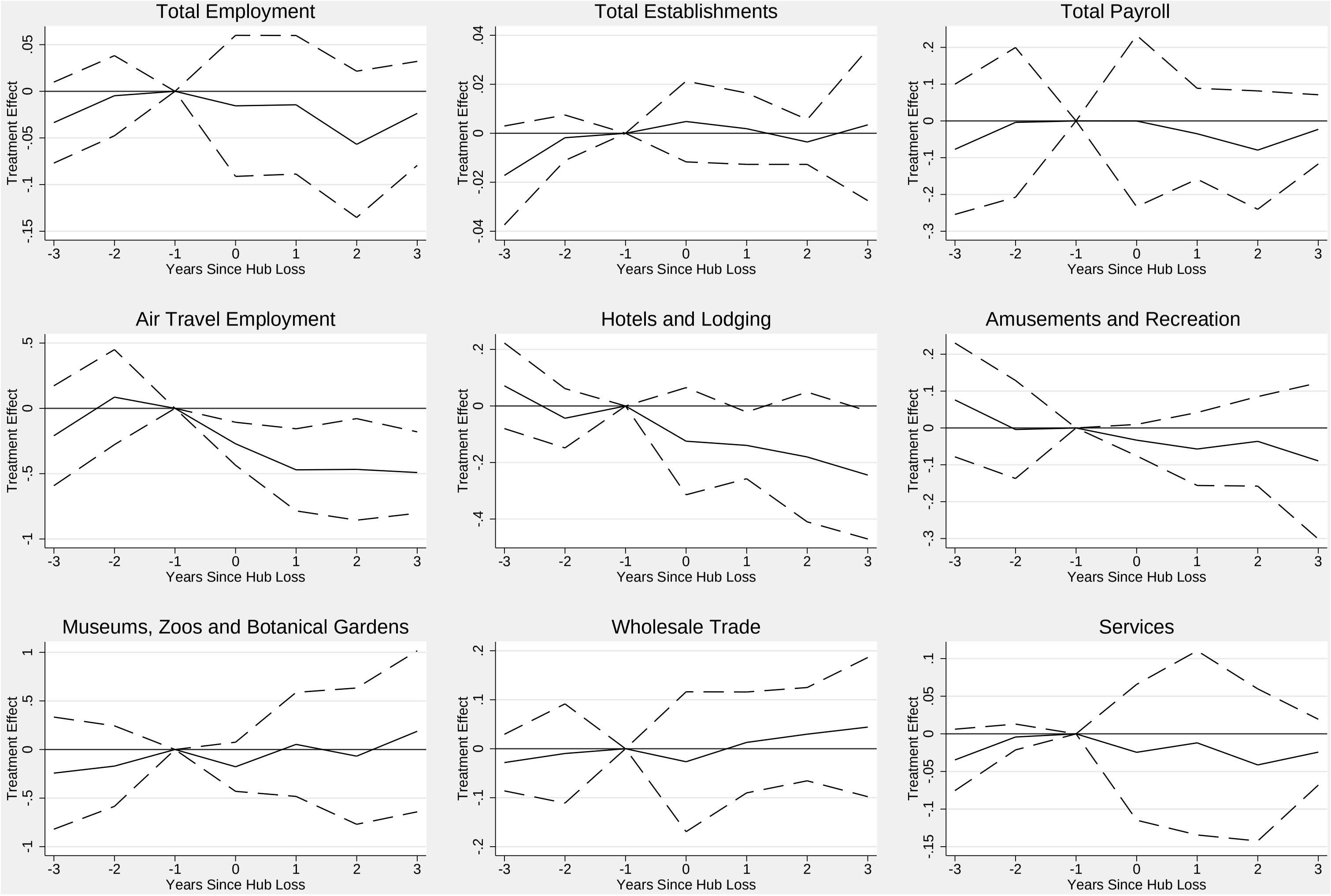


Figure shows event study outcomes on the quantities indicated above. Event studies include airport (city) and year fixed effects, as well as city specific trends. Standard errors are clustered at the city level. Dotted lines indicate 95 percent confidence intervals.

increases for other establishment outcomes generally mirror those estimated in the main analysis.

In summary, the estimates of this model line up with those shown in Section 2.6.1. Event studies are also estimated and are shown in Figures B.1 and B.2. However, these models appear suspect, as they fail simple checks in consistency. For example, the effect on boardings and flights should be similar, but are not. Given the small sample of air hubs that are available for this analysis, and the fact that the event study, by design takes into account substantially less information than the panel regressions, these should be viewed with caution, and only for reference.

2.6.5 Hub Effects: Traffic, Market Access, or Labeling?

The effects estimated here could be due to air traffic, market access as proxied by the number of destinations reachable, or even the hub designation itself. Generally, non-stop destinations does not appear to be driving the observed effects. So, is there a hub premium? I consider this to be a question for further research. One way to disentangle this effect could be to rescale the local traffic from the hub airports (by passengers) to something that is comparable for non-hub airports; for example, a measure of only destination traffic. To do so, I would compute the shares of connecting passengers at each hub, from baseline DOT ticket data, for each year, and then net out those passengers. From there, city-level outcomes can be estimated and compared. I hypothesize that it is less the label and more the market access (number of destinations) driving this outcome. With additional data, it is possible to examine the travel behavior of high-value business travelers and how they respond in the context of a hub system. Another way to examine this effect might be to consider Southwest's service, which I didn't consider here. At this point in their history they have built a robust network of focus cities that mimic hubs in function to some degree, but that do not carry the "hub" designation. If the Southwest focus city hubs are affecting their economies similarly to the legacy hubs, then we can conclude that it is not the label driving this. Again, I leave this for further research.

2.7 Conclusion

This paper is the first to use the data from the entire post-deregulation period of aviation to assess the causal effects of hub airports on local economies. Using panel regression and event-study techniques coupled with the plausibly exogenous changes in the labeling of hub airports by air carriers, I show that airline hub airports do have a causal effect on city economic outcomes. Namely, I show that hubs increase personal income by at least 2-3 percent, and also increase establishment counts by up to two percent, with virtually all of the growth in establishments in the non-traded sector. I also show that positive employment outcomes are limited mostly to travel related industries, such as air travel and hotels and lodging. The effect of hubs on a city's employment is estimated to be practically zero. However, hub airports do create spillovers on employment overall within a 5 mile radius of the hub. These effects operate through the changes in air traffic, and, to a limited extent, change in access to markets served by non-stop flights.

Considering the evidence presented, a few lessons emerge. (1) Hubs appear to be more important to a city's business climate than its tourism prospects, seconding Neal (2011)'s finding that only destination hubs are able to generate significant outcomes. (2) The effects of hubs appear to operate primarily through their ability to offer a high frequency of flights to a variety of destinations, many direct. (3) Hubs generate spillover effects, which peak somewhere at a radius of between 3 and 7 miles away from the airport. (4) Most of the effects on industries most likely to be linked to tourism are contained to these localized spillovers. (5) Hubs are not bad for cities, either, in that in every model considered, hubs had no significant effect on ticket prices, while improving options for consumers. In summary, having a hub downsized, or losing a hub, will definitely affect some jobs, and will definitely affect the prospect of those employees who work near an airport. However, the effects of losing a hub, outside of the air travel or hotel industries, is quite small, and need not be cause for alarm. Thus, it appears much of the fear surrounding recent hub losses is not necessarily justified. Hub airports do not make or break a city; rather, strong fundamentals such as business climate and, to a lesser extent, tourist attractions, are likely to be more critical.

In future work, I hope to delve into one of the primary questions that I was unable to adequately consider here: namely, has the role of a hub fundamentally changed in the post-September 11th world? Air carriers have changed their strategies from maximizing market share to maximizing profits, and with recent mergers, have consolidated hubs and flight operations. One benefit for the cities that benefit from this would be stronger hubs with increased market access. How will that affect cities that "win" one of these new super-hubs, such as Charlotte or Philadelphia? Additionally, as transportation investments tend to generate jobs in a small radius of the airport as shown, it is interesting to examine the role air hubs play in providing employment for minorities and/or those with limited job prospects. Finally, while the findings of this paper lead to the conclusion that the benefits of air hubs do exist, they are modest. What role do local level subsidies play in determining the success or failure of a hub? What is the optimal role for local government to play in aviation-related affairs?

Chapter 2 Bibliography

Bowen, John, *The economic geography of air transportation: space, time, and the freedom of the sky* number 81. In 'Routledge studies in the modern world economy.', London ; New York: Routledge, 2010.

Button, Kenneth, "Debunking some common myths about airport hubs," *Journal of Air Transport Management*, May 2002, *8* (3), 177–188.

_ **and Somik Lall**, "The Economics of Being an Airport Hub City," *Research in Transportation Economics*, 1999, *5*, 75–105.

_ **,** _ **, Roger Stough, and Mark Trice**, "High-technology employment and hub airports," *Journal of Air Transport Management*, January 1999, *5* (1), 53–59.

Chatterji, Aaron, Edward L. Glaeser, and William R. Kerr, "Clusters of Entrepreneurship and Innovation," Working Paper 19013, National Bureau of Economic Research May 2013.

Eller, Richard E., *Piedmont Airlines: A Complete History, 1948 - 1989*, Jefferson, North Carolina: McFarland & Company, Inc., Publishers, 2008.

Giroud, Xavier, "Proximity and Investment: Evidence from Plant-Level Data," *The Quarterly Journal of Economics*, May 2013, *128* (2), 861–915.

Harty, Jack, *Weekend Rewind: A Look Back Into The Archive of Airchives Vault Of Aviation History* February 2014.

Jaillet, Patrick, Gao Song, and Gang Yu, *Airline Network Design and Hub Location Problems* 1996.

Lee, Darin and Maria Jose Luengo-Prado, "The Impact of Passenger Mix on Reported Hub Premiums in the US Airline Industry," *Southern Economic Journal*, 2005, *72* (2).

McLaughlin, David and Andrew Zajac, *American Airlines - US Airways Merger Settlement Approved* April 2014.

Neal, Zachary, "Creative Employment and Jet Set Cities: Disentangling Causal Effects," *Urban Studies*, January 2012, p. 0042098011431282.

Neal, Zachary P, "The Causal Relationship Between Employment and Business Networks in U.s. Cities," *Journal of Urban Affairs*, May 2011, *33* (2), 167–184.

_ , "Types of Hub Cities and their Effects on Urban Creative Economies," 2014.

O'Kelly, M. E., "A Geographer's Analysis of Hub-and-Spoke Networks," *Journal of Transport Geography*, 1998, *6* (3), 171–186.

Pilcher, James, *Why CVG Lost Half of All Flights* May 2010.

Redding, Stephen, Daniel M. Sturm, and Nikolaus Wolf, "Web-Based Technical Appendix for History and Industry Location: Evidence from German Airports," 2010.

Redding, Stephen J., Daniel M. Sturm, and Nikolaus Wolf, "History and Industry Location: Evidence from German Airports," *The Review of Economics and Statistics*, 2011, *93* (3), 814–831.

Sheard, Nicholas, "Airports and urban sectoral employment," *Journal of Urban Economics*, March 2014, *80*, 133–152.

Chapter 3

Energy-Efficient Public Schools: Nationwide Diffusion Patterns and Effects on Student Achievement in California

3.1 Introduction

Over the past 15 years, sustainability has increasingly become an important factor in the construction and design of buildings of all types. While different from airports, train stations, roads, pipelines and other types of infrastructure, the design of buildings has been shown to play an important role in the productivity of their inhabitants, as well as an important determinant of the rents that can be charged for the space (see, for example, Eichholtz et al. (2013)).

As natural resources such as fossil fuels become increasingly more scarce and costly, building operators have sought to reduce the impact that their buildings have on the environment. In so doing, building managers have adopted a variety of practices such as, among others: adding larger windows designed to retain indoor heat, installing better ventilation systems that not only reduce energy costs but improve air quality, and adding solar panels to generate electricity. Many of these improvements might be expected to not only reduce energy consumption, but also to improve the overall environment. Hence, going "green" can also be good for increasing the productivity and happiness of a building's users.

Much of the previous research in this area has focused primarily on commercial real estate (see, for example, Eichholtz et al. (2013), Kok, McGraw and Quigley (2012), and Simcoe and Toffel (2012)). However, one particular class of buildings have failed to receive as much attention: public school buildings. Public school buildings are one of America's oldest forms of public infrastructure. According to a 1999 report commissioned by the National Center for Education Statistics, the mean age of a U.S. public school building is approximately 57 years, with 90 percent of those built prior to 1985.[1] Older buildings are more likely to be in disrepair, and also to suffer from issues such as poor insulation or indoor air quality that lead to increased operating costs, and perhaps decreased student and staff performance.

Currently, there are two certification options for public schools – the U.S. Environmental Protection Administration's Energy Star Program and the Leadership in Energy & Environmental Design (LEED) Green Schools certification program sponsored by the U.S. Green Building Council. While LEED ratings have become the gold standard in higher education green building programs, the plurality of "green" schools have been certified through the U.S. Environmental Protection Administration's Energy Star for Buildings program.[2] Thus, in this paper I focus on schools certified by the Energy Star program. As suggested by its name, the Energy Star program labels school buildings based on their energy performance relative to comparable school buildings.

There is anecdotal evidence that green school renovations may result in positive impacts on student outcomes via improvements to indoor building quality. These arise through an improvement of the learning environment, by adding windows and natural

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[1] Cassandra Rowand, How Old are America's Public Schools? National Center for Education Statistics, 1999; http://nces.ed.gov/pubs99/1999048.pdf

[2] Based on author's analysis of data used in Kok, McGraw and Quigley (2012).

sunlight, allowing users better control over classroom temperatures, improving air quality via efficient ventilation systems, and additional improvements that are part of the sustainable building toolkit. For example, a survey of green schools by McGraw-Hill Construction indicates that 70 percent of green schools had improved test scores. Case studies summarized by Gordon (2010) posit that green schools led to up to a 15 percent reduction in absenteeism and can add up to a 5 percent increase in student test scores. Beyond these cases, however, there has been little large-scale empirical work to date on the topic. Because school buildings are public infrastructure, funds expended on renovations and green labeling are taken from scarce budgetary resources. Furthermore, when making decisions on whether to join such a program, administrators may share this popular belief that sustainable buildings can enhance student performance. Thus, from a policy perspective, it is imperative to understand what the benefits of these green renovations are, especially from the perspective of students, schools, and districts.

Given the paucity of research to date specifically on green schools as infrastructure, this study seeks to answer the following questions: (1) What factors are associated with school districts that have chosen to adopt green buildings? and (2) What are the benefits, if any, of green schools on academic achievement? As this is the first paper to comprehensively examine the effects of this program in the schools context, I begin by exploring the factors that correlate with the presence of these schools in U.S. school districts. Then, I turn to the case of California to examine the causal effect of labeling a school building "Energy Star Certified" building on school completion rates and student achievement. Using panel regression and event-study techniques, I find, on balance, that the effect of green schools appears to be quite small, if not negligible. Thus, decisions of whether one should "green" a school should be based solely on engineering costs, and not on expected improvements in student achievement.

The outline of the remainder of this chapter is as follows. First, I present background on the Energy Star Program and review the relevant literature on green buildings. Then, I discuss the data used in the study. Next, I present results from the examination of the nationwide Energy Star program. Then, I present results from the California case. Finally, I conclude and discuss implications for future research.

3.2 Background

Since 2000, the U.S. Environmental Protection Administration (EPA) has offered annual Energy Star Certification for buildings and manufacturing plants. Compared to similar buildings, these certified facilities use less energy, are less expensive to operate, and cause fewer greenhouse gas emissions. To qualify for an Energy Star certification, a building must earn a 75 or higher on the EPA's rating scale, indicating that the facility performs better than at least 75 percent of similar buildings nationwide.[3] This program

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[3] US EPA: http://www.energystar.gov/index.cfm?c=business.bus_bldgs

is touted as a way for building managers to reduce their energy usage and carbon footprint, reduce their buildings' energy costs, affect the bottom line, and demonstrate an organization's commitment to reduce its impact on the environment.

With certification of energy efficient buildings a relatively recent occurrence, various studies have focused on different determinants of their spread, ranging from city demographics to regional legislation. A few stylized facts emerge. Green buildings tend to cluster in metropolitan regions of the United States, particularly along the coastlines (Kaza et al., 2013). These areas typically have larger populations, higher educational attainment, younger populations, and higher incomes (Cidell (2009); Kontokosta (2011); Lee and Koski (2012); Lubell et al. (2009)). They are typically (but not always) clustered in high income areas (Kahn and Vaughn, 2009).[4] Additionally, their presence is correlated with increased environmentalist sentiment, as measured by residents' political affiliation with the Green Party and voting on two statewide environmental initiatives, is significantly correlated with the number of LEED buildings (Kahn and Vaughn, 2009).

Public policy and legislative activities also appeared to have played a role in the concentration and construction of energy efficient buildings. Choi and Miller (2011) find strong effects of federal and state legislature promoting green construction on increased LEED buildings. They also saw a positive correlation between the political party of the state governor, specifically Democratic, and the concentration of LEED buildings. Cidell and Cope (2014) similarly find a significant relationship between having a municipal LEED-based green building policy and having more registered LEED buildings, which they interpreted as causal. Simcoe and Toffel (2012) shows municipal government procurement rules produce spillover effects that stimulate both private-sector adoption of the LEED standard and the proliferation of green building expertise. However, there is no clear consensus as to what the drivers of such policies are. Kontokosta (2011) found that the climate zone of the city (determined by number of heating days or cooling days per year as well as average humidity in the region), the mayor's political party affiliation, and the density of environmental nonprofits were negligible variables in determining the presence of green policy. In contrast, Lee and Koski (2012) concluded that higher numbers of environmental nonprofits and cities that had opted into a climate protection agreement were associated with increased green building activity.

The benefits of energy efficient buildings beyond energy savings have also been closely examined. Eichholtz, Kok and Quigley (2013) was one of the first papers to systematically examine the impact of environmentally sustainable buildings on the marketplace. They found that buildings with a "green" rating commanded higher rents – roughly 3 percent higher per square foot, and roughly 7 percent higher in terms of effective rents. Selling prices of these buildings were also 16 percent higher. Similarly, Fuerst and McAllister (2011) found 17 percent sale premiums and 3 percent rental premiums on labeled buildings; however, they also found that Energy Star labeling did not have an effect on

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[4] California differed in having LEED buildings clustered in the poorest and predominantly white zip codes while nationally, LEED buildings were located in the highest income zip codes with larger shares of Asians and blacks.

occupancy rates.

In the case of corporate buildings, there is evidence that the intangible effects of the label are also involved in determining the value of green buildings in the marketplace. For example, beliefs about worker productivity or improved corporate image may play a role. Eichholtz, Kok and Quigley (2010) examine the decisions of more than 11,000 tenants to choose office space in green buildings or in otherwise comparable, conventional buildings nearby. They find that corporations in the oil and banking industries, as well as non-profit organizations, are among the most prominent green tenants. They also show that firms in mining and construction and organizations in public administration, as well as organizations employing higher levels of human capital, are more likely to lease green office space. Part of this could be attributable to a "warm glow" or competitive altruism, which posits that individuals carry out altruistic actions to accrue reputation and other selective benefits (Hardy and Vugt, 2006).

In contrast to the well-developed literature on corporate real estate, there has been relatively little work done on the effects of energy-efficient schools, despite their proliferation over the past 15 years. Through the Energy Star program, the EPA offers opportunities for school buildings to achieve such certification. The EPA states that energy costs are the largest operating expense for school districts after salaries and benefits. Space heating, cooling, and lighting account for nearly 70 percent of school energy use.[5] With reductions in cost, schools may have the opportunity to funnel savings to other areas such as new technology, more staff, and improved facilities.

The U.S. Green Buildings Council (USGBC) defines a green school as "a school building or facility that creates a healthy environment that is conducive to learning while saving energy, resources, and money". A USGBC study argues that green schools may provide a range of benefits that traditional schools do not. For example, they cite reduced teacher sick days, reduced operations and maintenance costs, increased state competitiveness, reduced social inequity and educational enrichment as just a few of these benefits. They posit that while it costs an average of $3 per square foot to incorporate green design principles into construction, the total benefits are worth approximately $74 per square foot (Katz, 2006). Baker and Bernstein (2012) show the incidence of sick building syndrome decreased with better HVAC systems, and that teachers were better able to perform when they had more control over classroom temperatures.[6]

Recent work has examined the impact of school building quality on student academic achievement. Since green schools tend to include improvements to facilities, building quality may be expected to improve as well. Duran-Narucki (2008) examined the relationship between student attendance, school building conditions, and school performance

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[5] http://www.energystar.gov/sites/default/files/buildings/tools/EPA_BUM_CH10_Schools.pdf or http://www.energystar.gov/buildings/tools-and-resources/energy-star-building-upgrade-manual-chapter-10-k-12-schools

[6] Additionally, a 2010 Lawrence Berkeley National Laboratory study shows that demonstrated that substandard ventilation reduced student performance by five to ten percent. http://energy.lbl.gov/ied/sfrb/vent-school.html

as measured by English Language Arts (ELA) and Math test scores. Researchers scored building conditions based on 20 items that were either visible to students or vital to the condition of visible features of a building (ex: doors, windows, toilets, foundation walls, heaters). In lower-quality facilities, students attended fewer days and had lower grades in ELA and Math standardized tests. Maxwell and Schechtman (2012) examine building quality based on student-defined metrics. They showed that objective and perceived school building quality and self-efficacy were significantly related to GPA scores, but not to standardized test scores. Most directly related to this research, case studies summarized by Gordon (2010) states that green schools effected up to a 15 percent reduction in absenteeism and can add up to a 5 percent increase in student test scores.

While there is a popular belief that green buildings bring these productivity benefits, this has not been subjected to much scrutiny in the academic literature, particularly in the important context of schools. This paper aims to fill that gap. I hypothesize that converting an existing school to a green school could lead to improved outcomes in student completion and academic performance. These benefits could emanate from the fact that green schools incorporate improvements such as improved heating and ventilation systems, enhanced use of natural lighting and improved acoustics in order to save energy. In so doing, these systems may offer improved ventilation, better indoor air quality, thermal comfort, lighting and noise management. This, in turn, will enhance student learning outcomes, which should be reflected in higher test scores and lower dropout rates.

The goals of this paper are twofold. First, I seek to conduct a nationwide examination of the factors affecting green school placement, and to provide causal evidence that green schools reduce dropout rates *at the school district level.* Second, I seek to understand, within the special case of California, which schools are greened, and how this affects dropout rates and academic achievement *at the individual school level.* California is an ideal test case for this study, in that it has a substantial fraction of the green schools and also happens to have academic achievement data for schools standardized across schools.

3.3 Data and Methods

I compile two separate data sets for this analysis, one consisting of school district level data for districts nationwide, and another consisting of individual school-level data for California. In what follows, I will refer to the former as the U.S. data set and the latter as the California data set.

3.3.1 Energy Star Labeled Schools

Data on green schools were obtained from the Energy Star program's labeled buildings locator.[7] This database includes all Energy Star labeled public K-12 schools from 2000

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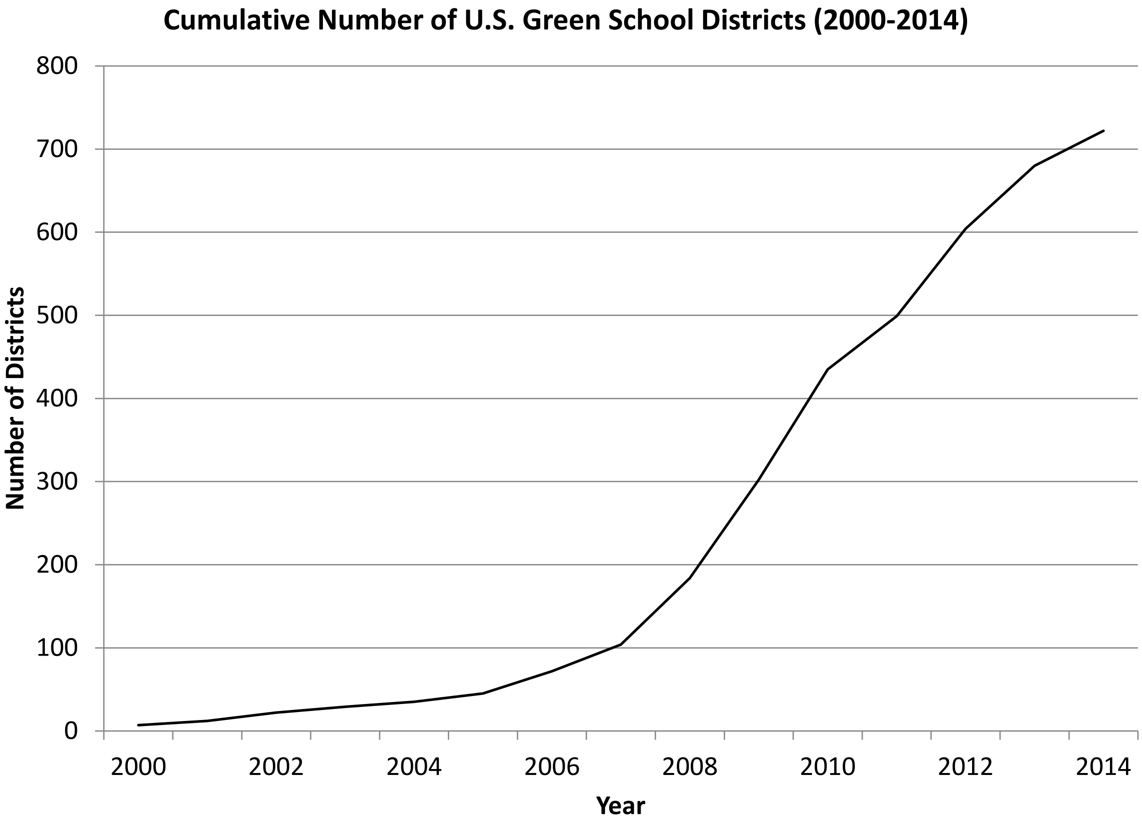
[7] Energy Star Labeled Buildings Locator:
http://www.energystar.gov/index.cfm?fuseaction=labeled_buildings.locator

Figure 3.1: Nationwide Diffusion of Energy Star Certified Schools via School Districts



until December 2014. It includes data on school characteristics, such as address, school district, year of construction, year of certification, square footage, and Energy Star rating score. Using school addresses, I match each school in the database to the National Center for Education Statistics database of currently operating schools. Figure shows the nationwide diffusion of such schools over the 2000 - 2014 time period. Note that it exhibits the classic “S” curve that accompanies the diffusion curves of many new technologies. Table also provides additional characteristics of the sample of treated schools.

Figure 3.2 shows the spread of green schools over time. In Panel A, green schools, as defined by the Energy Star program, are sparsely located. By 2005, roughly around the first inflection point of the “S” curve, there are more green schools - primarily located on the coastlines in clusters and areas of either extreme cooling or heating. This matches the results seen by Kaza et al. (2013). The growth in number of green schools began to drastically increase after 2007, and this can be seen in Panel C where in 2010, green schools can be found in almost every state. By 2014 (Panel D), the number of green schools had increased, but their pace of growth declined. In both 2010 and 2014, a clustering effect can be seen in which green schools are primarily located on the eastern and western edges of the U.S. and usually around other green schools. California has large concentrations of green schools in the urban San Francisco Bay Area and Southern California coastline

Table 3.1: Green Schools in Sample

	All US		California	
	Mean	SD	Mean	SD
Mean students per school	390	230	497	338
Fraction of Green Schools in District				
School Year 2004 - 2005	1.97	1.009	3.25	13.3
School Year 2009 - 2010	27.81	31.59	34.76	39.09
School Year 2012 - 2013	52.4	29.87	69	29
Green Schools Sample				
Year Constructed	1960	157	1929	270
First Labeled Year	2010	2.94	2010	3.49
Average Rating	88	7.57	94.2	6.15
Avg Size (1000 sq ft)	105	90	76.4	67.5

Note: SD: Standard Deviation.

regions, but few in other locations.

Figure 3.3 shows the concentration of green schools in school districts as of 2014. For most districts, only a few schools in each district are green. However, in parts of California, Texas, New York and a few other states, school districts have chosen to green substantial numbers of their school buildings.

Considering the general characteristics of U.S. and California-specific green schools in Table 3.1, California green schools have much more students than green schools do nationwide on average. In addition, the fraction of green schools per district has increased over time for both California and U.S. green districts, matching the results seen in Figure 3.2. The Energy-Star-labeled green schools are older buildings with mean years of construction in 1960 and 1929 for the U.S. and California, respectively, with 2010 as the mean year of labeling. California green schools also tend to be somewhat smaller than green schools nationwide, in terms of student count and square footage.

3.3.2 Nationwide Data Set

Data on school characteristics were obtained from the Common Core of Data available from the National Center for Education Statistics (NCES).[8] Data collected included baseline data on enrollment, demographics, and school finance. Districts were included in the study only if: (1) they were identified as an elementary, secondary or unified school district by NCES; (2) the district was open continuously between 1990 and 2012 with no substantial boundary changes.

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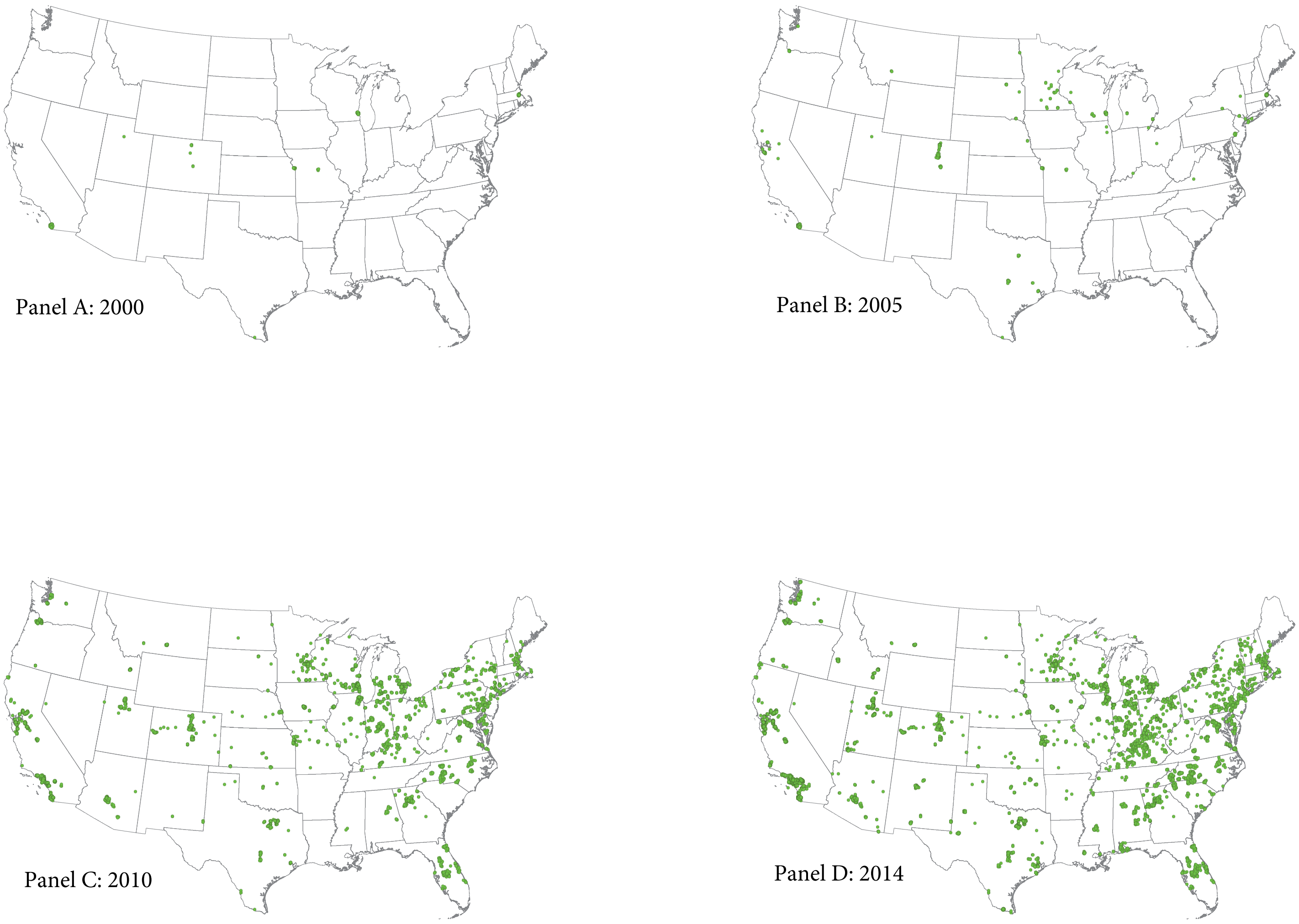
[8] Common Core of Data: http://nces.ed.gov/ccd/ccddata.asp

Figure 3.2: Location of Green Schools Throughout the United States



Panel A: 2000

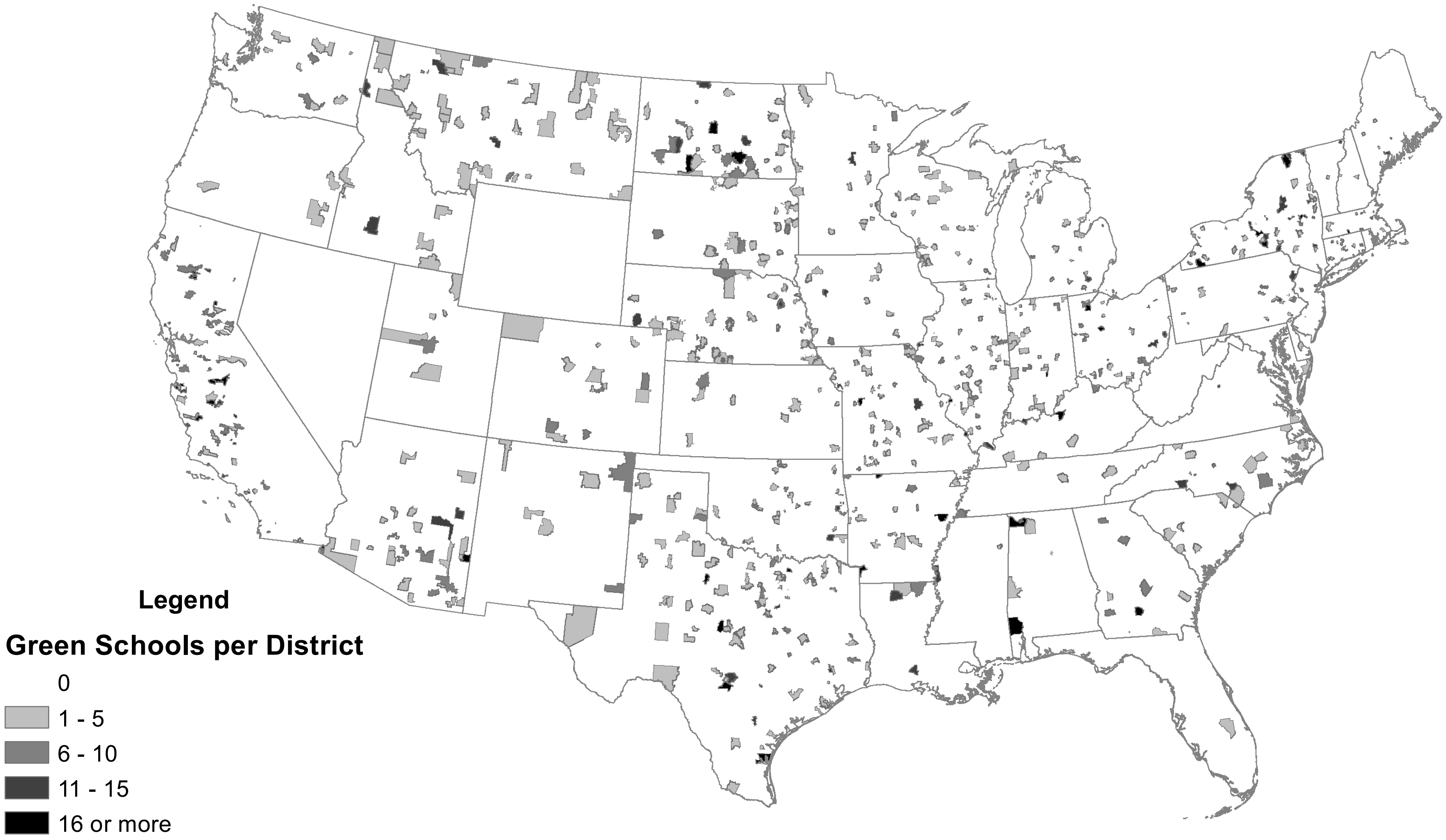
Panel B: 2005

Panel C: 2010

Panel D: 2014

This figure shows how green schools have spread throughout the United States from 2000 to 2014.

Figure 3.3: Number of Green Schools in U.S. School Districts, 2014



Data on private school characteristics were obtained from the Private School Survey (PSS).[9] Only schools that existed in both the 1990 and 2012 PSS data sets were retained. Geographic Information System software was used to assign the private schools to their corresponding public school district based on latitude and longitude data.

Data on school district boundaries were obtained from the National Historical Geographic Information System (NHGIS). Data on background demographic characteristics, such as population counts by race, school district educational attainment, median income and median housing value, were obtained from the 1990 U.S. Census at the census tract level and converted to school district data.[10]

Various types of data were collected in an attempt to proxy for attitudes toward green buildings and environmentalism in general. The percent of Republican votes for various presidential elections[11] were tabulated for counties, as well as the Green Party share of the vote in 2000, from the Congressional Quarterly (CQ) Press Voting and Elections database.[12]

Energy prices for coal, distillate fuel oil, residual fuel oil, and natural gas were obtained from the Energy Information Administration for the year 1990.[13] Climate characteristics, such as heating and cooling degree days[14], January temperature, humidity, and percent of sunshine received, were obtained from the National Climatic Data Center (NCDC) for weather stations throughout the country, then mapped to school districts using GIS software and an interpolation calculation.[15] Information on solar radiation received by a district (to proxy for the potential for deployment of solar panels) was obtained from the National Renewable Energy Laboratory (NREL).[16]

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[9] https://nces.ed.gov/surveys/pss/

[10] Census data downloaded from NHGIS. The details of the census tract to school district data conversion process are available in the data appendix.

[11] Nixon in 1968 and 1972, Reagan in 1980 and 1984, and Bush in 1988

[12] http://library.cqpress.com/elections/

[13] State Energy Data System: 1960-2012 obtained from http://www.eia.gov/state/seds/seds-data-complete.cfm?sid=US

[14] Heating (and cooling) degree days were developed by building engineers as a way to proxy for energy usage in buildings. Heating degree days are computed by taking the average daily high and low temperature, and subtracting 65 from it, if the average is lower than 65 degrees. Cooling degree days are defined similarly. http://www.erh.noaa.gov/cle/climate/info/degreedays.html

[15] NCDC Master Record of Weather Stations: ftp://ftp.ncdc.noaa.gov/pub/data/inventories/MASTER-STN-HIST.
NCDC CCD Data - Annuals, Normals: ftp://ftp.ncdc.noaa.gov/pub/data/ccd-data.

[16] NREL Solar Radiation: http://www.nrel.gov/gis/data_solar.html. Solar radiation was measured through Global Horizontal Irradiance (GHI), the sum of direct and diffuse radiation; direct radiation comes in a direct line from the sun while diffuse radiation is scattered from the direct beam by molecules and other objects. The National Renewable Energy Laboratory (NREL) uses images from weather satellites, daily snow cover, and monthly averages of atmospheric water vapor, trace gases, and the amount of aerosols in the atmosphere to calculate the total sun radiation on a surface. The direct beam radiation is then calculated using the atmospheric water vapor, trace gases, and aerosols. See https://developer.nrel.gov/docs/solar/solar-resource-v1/. GHI 10km grid data was used. GIS software was applied to create the average level of GHI per district.

Finally, as possible predictors for having a green school district, the distance from school district centroids to fault lines were calculated.[17] Schools closer to fault lines may be more likely to require renovations anyway, due to seismic activity. This calculation was repeated for distance to the nearest Sierra Club chapter.[18] Districts closer to a Sierra Club chapter may experience higher levels of advocacy for environmental initiatives, increasing their likelihood to receive a green school.

Table 3.2 present key information on the covariates in this project. Districts with green schools tend to have more students, and thus teachers, per school. They also have a tendency to have more private schools, due to their tendency to be in areas with higher income and wealth, and higher proportion of graduate degree holders. Surprisingly, the per-pupil expenditure and property tax received per student is about the same for green versus non-green school districts. These findings are consistent with the results found by numerous papers (Cidell (2009); Kontokosta (2011); Lee and Koski (2012); Lubell et al. (2009)). The outcomes are similar for the California districts considered. Per-pupil expenditure and property taxes received in CA were significantly lower, and surprisingly, green districts had lower levels of per-pupil expenditure in 1990. California's school districts also tend to be much more racially diverse. Other location-based characteristics of green schools nationwide are discussed in Appendix C.

3.3.3 California Data Set

The school-level California Data Set aims to measure the effect of green schools on academic achievement, and is used to obtain the causal estimates presented in this paper. Data is obtained from the California Department of Education.[19]

The primary dependent variable in the analysis is the California Academic Performance Index (API). The API was created by the California Department of Education in 1999 as a measure of public school academic achievement and improvement. Scores range from a low of 200 to a high of 1000 based on a school's overall student performance on statewide standardized assessment testing across multiple subjects. As they are a cross-sectional measure of student achievement, they do not track individual student progress but rather school results year-to-year. Because they are standardized across types of schools (elementary, middle and high), they are an ideal way to measure the effects of green schools on student achievement. API scores are also provided by race and ethnicity (black, Asian, hispanic, American Indian and Pacific Islander) and for socioeconomically disadvantaged students. The data also includes information on enrollment, the racial composition of students, the credentialing of teachers in the school, the percent of students

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[17] Quaternary Fault and Fold Database of the United States - US EPA: http://earthquake.usgs.gov/hazards/qfaults/

[18] Founded in 1892, the Sierra Club is one of the nation's largest environmental organizations with 64 chapters nationwide and over 2.4 million members and supporters. Sierra Club Chapters: http://www.sierraclub.org/chapters.

[19] http://www.cde.ca.gov/ds/dd/

Table 3.2: Summary Statistics: Districts with Green Schools

	Nationwide Sample				California Sample			
	Green Districts		Non-Green Districts		Green Districts		Non-Green Districts	
Variable	Mean	SD	Mean	SD	Mean	SD	Mean	SD
District characteristics								
Students Per School	542	221	377	226	669	45	481	33
Teachers Per School	31.5	12.5	23.1	12.8	22.29	9.29	17.2	11.1
Ratio of Private schools to Public Schools	0.159	0.245	0.103	0.245	0.18	0.17	0.11	0.2
Per-Pupil Expenditure (Mean)	5,216	1,845	5,233	2,585	4,662	657	5,015	1645
Property Taxes Received Per Student	1,998	1,822	1,983	2,176	1,269	859	1,281	1,205
Median Housing Value (1990)	89,356	59,518	72,558	61,571	202,557	95,525	200,029	96,576
Median Household Income	33,208	11,606	28,310	11,192	36,781	14,388	38,321	12,644
Median Per-Capita Income	14,459	4,954	12,597	5,057	16,639	6,489	16,206	7,290
College Graduates (Prop.)	0.126	0.072	0.099	0.058	0.154	0.076	0.142	0.074
Graduate School or Above (Prop.)	0.07	0.052	0.051	0.044	0.093	0.073	0.073	0.06
Baseline Demographics (1990)								
Prop. Black	6.5	12.0	6.7	15.9	9.61	11.13	5.99	9.22
Prop. Hispanic	4.4	11.1	4.9	13.2	26.6	20.8	29.2	25.5
Prop. Asian	1.8	3.2	1.1	2.8	13.3	12.4	10.6	13.1
Prop. White	86.8	17.6	85.6	21.9	49.9	23.5	53.2	28.9
Prop. Children in Poverty	13.2	9.6	17.3	11.7	18.0	14.0	16.0	12.0
Prop. Free Lunch eligible	17.4	14.1	23.2	17.7	34.4	26.3	30.1	24.0
Locale (percent)								
Urban	16.9		4.51		65.99		34.62	
Suburban	41.97		22.35		31.07		50.2	
Town/Rural	41.14		73.14		2.95		15.19	
Number of Schools	4901		51,277		574		2,617	
N (Districts)	722		8,097		38		417	

Note: SD: Standard Deviation. Green districts are the set of districts comprised of at least one green school as of the end of 2014. Non-green districts are schools that do not have any green schools as of 2014.

eligible for free or reduced lunch, parental education and a variety of other factors.

A primary component of the API is standardized test scores from the Standardized Testing and Reporting (STAR) program. Beginning in 1998, students in grades 2-11 completed exams in English Language Arts, Mathematics, and other subjects. In this paper, scores on the English and Math exams, averaged over grades within schools, are considered.[20] For high schools, additional data is available in the form of number of graduates who are eligible to attend University of California (UC) or California State Universities (CSU). High school graduate eligibility for the UC/CSU systems is determined by completion, with a "C" grade or better, of courses required for admission. Student completion rates are available for these schools as well, which were used to calculate dropout rates.

Data was also collected on the student racial/ethnic composition of schools (1999-2011), the percent of students eligible for free or reduced lunch, and rates of full teacher certification. Turning to Table 3.3, it can be seen that due to California's schools are likely to be on average 5 miles from a fault line. Given seismic activity levels, this may result in increased building maintenance needs for these schools relative to the country as a whole. The same is seen for distance to Sierra Club chapters. T-tests on the climate factors studied were significant, suggesting that climate and energy factors are a primary factor driving placement of green schools in the state. Green districts tended to be located in areas with fewer heating degree days, more cooling degree days, a higher average January temperature, lower July humidity, and more daylight as measured by possible sunshine or solar radiation.

As for academic outcomes, differences in API scores and dropout rates did not vary much by having or not having a green shool. API scores did, however, increase over time among all groups. Table 3.4 shows scores for 1999 and 2011. Trends for other academic achievement variables considered in this paper are similar.

3.3.4 Estimation

Identification in this study is based on exploiting the differential in timing of the renovation and subsequent opening of green schools using fixed effects regression. The primary specification used is:

$$Y_{it} = \alpha + \beta(G = 1) + \kappa \boldsymbol{X} + \gamma_i + \tau_t + \epsilon_{it} \tag{3.1}$$

where β identifies the (log) change in the achievement measure Y_{it}, γ_i is a school (or district) fixed effect and τ_t is a year fixed effect. In the specifications that follow, controls that may be included in the vector of $\boldsymbol{X}$ include controls for socioeconomic

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[20] In 2002, the State Board of Education replaced the previously used Stanford Achievement Test, ninth edition (Stanford 9) with the California Achievement Tests, Sixth Edition Survey (CAT/6) published by CTB/McGraw-Hill as the national norm-referenced test for the STAR Program. Since the two tests are published by different companies, no direct comparisons can be made between the 2002 and the 2003 STAR test scores. However, scaled scores are still able to tell us about the difference in overall achievement between the schools after the inclusion of year fixed effects.

Table 3.3: Environmental Attributes and Green Schools in California

	Green		Non-Green	
	Mean	SD	Mean	SD
Environmental Attitudes				
Vote for Nader in 2000 (Green Party)	4.55	2.99	4.39	2.74
Distance to Fault Line (miles)	4.45	8.7	5.93	9.19
Distance to Sierra Club Chapter	17.95	17.61	29.27	31.47
Climate				
Heating Degree Days	136	53	170	43
Cooling Degree Days	34	15	27.7	10.7
Mean January Temp	40	10	32.7	8.57
July Humidity	44	13.5	51	9.7
Percent Possible Sunshine Received	64.34	14.39	55.9	10.5
Solar Radiation	4549.32	696.39	4200.4	628.29
N (total sample schools)	441		2022	
N (district count)	38		417	

SD: Standard deviation. Values for California schools and school districts only. Distance variables computed from schools in sample to respective locations using ArcGIS software.

trends, community income as measured through property values, per-pupil expenditure, information on teacher certification, and other factors. Additionally, school-specific time trends are included where allowed by the data, and standard errors are clustered at the school district level.

As a check on the values given by equation 3.1, I also use an event-study methodology. After normalizing the data to the time of renovation, I run the following event-time specification:

$$Y_{it} = \alpha + \gamma_i + \tau_t + \sum_{k=-4}^{4} \beta_{k,it} + \epsilon_{it} \tag{3.2}$$

where I incorporate a series of dummy variables indicating time relative to the year of certification. The time-since-certification dummies are capped at $k = -4$ and $k = 4$. The omitted category is the last year prior to the school being renovated. Robust standard errors are estimated.[21]

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[21] This is due to issues with clustering on a small number of categories in this case.

Table 3.4: API Scores by Subgroup, 1999 and 2011

	Green				Non-Green			
	1999		2011		1999		2011	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Mean API Score								
Total	658	139.6	815	90.6	640	123.1	800	72.1
Black	511	85.6	741	81.7	506	75.1	738	80.1
Hispanic	540	86.7	774	69.0	523	79.2	761	62.7
Asian	760	150.7	892	84.1	761	112.0	892	66.3
White	751	107.0	856	80.4	724	87.4	841	67.3
Socioeconomically Disadvantaged	546	90.6	770	64.5	533	85.8	757	57.5
Dropout Rates								
Total	1.48	1.44	1.41	1.36	1.46	1.87	1.48	1.48
Black	2.15	3.10	2.23	3.22	2.46	6.84	2.15	3.78
Hispanic	2.05	1.85	1.86	3.22	1.89	2.18	1.71	1.64
Asian	0.69	0.97	1.57	2.58	0.84	1.93	1.55	6.13
White	1.39	1.75	1.46	1.78	1.22	2.10	1.58	2.69

Table 3.5: Fixed Effects Regressions: National Enrollment

Dependent Variable: Log Number of Students Enrolled in District				
VARIABLES	(1)	(2)	(3)	(4)
Green District	0.0635***	0.0260***		
	(0.0114)	(0.00439)		
Number of Green Schools			0.0409**	0.0129**
			(0.0160)	(0.00650)
Log Total Number of Schools		0.129***		0.129***
		(0.00497)		(0.00497)
Log Number of Teachers in District		0.580***		0.580***
		(0.0124)		(0.0124)
Log District Total Expenditure		0.163***		0.163***
		(0.00511)		(0.00511)
Log Percent of Children in Poverty		0.00825***		0.00835***
		(0.00174)		(0.00174)
Constant	6.642***	1.778***	6.642***	1.777***
	(0.00250)	(0.0631)	(0.00250)	(0.0631)
District FE	Y	Y	Y	Y
Year FE	Y	Y	Y	Y
Observations	419,121	225,444	419,121	225,444
R-squared	0.980	0.994	0.980	0.994

Cluster robust standard errors in parentheses, clustered at the school district level.
*** p<0.01, ** p<0.05, * p<0.1

3.4 Results

3.4.1 National Sample

First, I consider whether green schools have caused changes in student enrollment and secondary graduation rates. Panel regression methods with district and year fixed effects are used to obtain estimates. Additional covariates include the total number of schools, the number of teachers in the district, and the total expenditure in each district, all in logs. Data is available from 1987 to 2012. Table 3.5 indicates that, before controlling for covariates, green districts increased their enrollment by 6.4 percent over comparable, non-green districts. After controls are included, enrollment increases by 2.6 percent. Specification (4) shows that each additional green school, after including all controls, increases enrollment in the district by 1.3 percent. As a robustness check, I removed districts with more than 20 green schools from the sample, and the results are similar and remain significant.

Turning to dropout rates, I employ a similar strategy. In this case, data is available from 1991 to 2011. However, given that data is only available at the district level and not the school level, it is impossible to limit the sample to high schools. Nevertheless, districts

Table 3.6: Fixed Effects Regressions: National Dropout Rates

	Log District Dropout Rate			
VARIABLES	(1)	(2)	(3)	(4)
Green District	-0.0796*	-0.0655		
	(0.0411)	(0.0428)		
Number of Green Schools			-0.0448**	-0.0535**
			(0.0207)	(0.0262)
Log Total Number of Schools		0.00456		0.00466
		(0.0283)		(0.0283)
Log Number of Teachers in District		0.149***		0.149***
		(0.0320)		(0.0320)
Log District Enrollment		-0.523***		-0.524***
		(0.0481)		(0.0480)
Log District Total Expenditure		-0.0427**		-0.0426**
		(0.0193)		(0.0193)
Log Percent of Children in Poverty		-0.0154		-0.0155
		(0.0138)		(0.0138)
Constant	1.280***	5.096***	1.279***	5.097***
	(0.0154)	(0.373)	(0.0154)	(0.373)
District FE	Y	Y	Y	Y
Year FE	Y	Y	Y	Y
Observations	117,380	80,205	117,380	80,205
R-squared	0.682	0.656	0.682	0.656

Cluster robust standard errors in parentheses, clustered at the school district level.
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

with improved building stock may experience higher graduation rates if it improves the quality of education. Table 3.6 presents the results. Each additional school that is greened in a district appears to be associated with a roughly 5 percent decrease in dropout rates, which is statistically significant at the five percent level. However, simply being a "green" district does not result in a significant effect after all controls are included.

In Appendix C, I present (weak) evidence that green schools may also potentially serve a signaling function. The labeling of a school building serves to signal that the educational quality of the green public school is comparable to that of a private school.

3.4.2 California Sample

For the California sample, panel regressions were estimated at the school level, exploiting variance in timing between 1999 and 2011. During this period, schools were greened and API scores were available. In specification (1) of Table 3.7, I control only for school fixed effects. (2) adds year fixed effects. (3) adds CSA and district fixed effects, as well as controls for race, socioeconomic disadvantage, participation in the free and reduced

Table 3.7: Fixed Effects Regression: Effect of Green Schools on API Scores

	Dependent Variable: API Scores			
VARIABLES	(1)	(2)	(3)	(4)
Green School	0.0998***	-0.0198***	-0.00510	-0.000423
	(0.00438)	(0.00434)	(0.00561)	(0.00525)
Log Percent Black			-0.0151***	-0.0129***
			(0.00181)	(0.00146)
Log Percent Asian			-0.00837***	-0.000640
			(0.00206)	(0.00188)
Log Percent Certified Teachers			0.161***	0.100***
			(0.0106)	(0.00936)
Log Percent College Graduates			0.00202	0.00662***
			(0.00149)	(0.00138)
Log Percent Hispanics			-0.0418***	-0.0275***
			(0.00458)	(0.00388)
Log Percent Free and Reduced Lunch			-0.00768***	-0.00824***
			(0.00279)	(0.00228)
Log Percent Socioeconomically Disadvantaged			-0.0112***	-0.00855***
			(0.00252)	(0.00198)
Constant	6.585***	6.534***	5.975***	6.102***
	(0.000230)	(0.000824)	(0.0506)	(0.0619)
Observations	30,955	30,955	19,673	19,673
R-squared	0.684	0.885	0.923	0.943

Cluster robust standard errors in parentheses, clustered at the school district level.
*** p<0.01, ** p<0.05, * p<0.1

lunch program, the percent of graduate degree holders in the community, and the percent of teachers who have full certification to teach. Final specification (4) adds district and CSA-specific trends. My preferred specification, (4), yields a precisely estimated zero effect of green schools on API scores.

Table 3.8 presents the results of these regressions for API scores estimated by race and by socioeconomic status. For virtually every subgroup considered, it appears that API scores either remained flat (or decreased slightly) as a result of the introduction of the green schools.

An alternative set of assessments (which are components of the API measure) are grades on standardized English Language Arts and Mathematics tests taken by students in Grades 2-11 annually under California's STAR program. After controlling for trends, there is a small but significant decline in test scores, on the order of one percent for English Language Arts and two percent for Mathematics. The decline appears to be most pronounced among socioeconomically disadvantaged students. This points to the troubling possibility that the physical renovations of the schools, and administrators' focus on those, may have actually hurt this vulnerable student population. These findings are summarized in Table below.

Table 3.8: FE Regressions: API Effects by Subgroup

	(1)	(2)	(3)	(4)
Panel A: African American Students				
Log API	0.163****	-0.011	-0.017*	-0.014
	(0.010)	(0.009)	(0.010)	(0.011)
N	6447	6447	3169	3169
R-Sq	0.650	0.895	0.881	0.897
Panel B: Asian Students				
Log API	0.103****	0.014*	0.029***	0.012
	(0.009)	(0.008)	(0.010)	(0.011)
N	8401	8401	4768	4768
R-Sq	0.777	0.909	0.929	0.955
Panel C: Hispanic Students				
Log API	0.150****	-0.022****	-0.009	0.007
	(0.005)	(0.005)	(0.007)	(0.007)
N	24759	24759	15212	15212
R-Sq	0.447	0.875	0.888	0.908
Panel D: Socioeconomically Disadvantaged				
Log API	0.146****	-0.023****	-0.015**	0.007
	(0.005)	(0.005)	(0.006)	(0.006)
N	26354	26354	16350	16350
R-Sq	0.435	0.862	0.880	0.908
Panel E: White Students				
Log API	0.070****	-0.013****	-0.022****	-0.009*
	(0.004)	(0.004)	(0.005)	(0.005)
N	22311	22311	15095	15095
R-Sq	0.724	0.891	0.915	0.933
School FE	Y	Y	Y	Y
Year FE	N	Y	Y	Y
CSA and District FE	N	N	Y	Y
CSA and District Trends	N	N	N	Y

Cluster robust standard errors in parentheses, clustered at the school district level.
*** p<0.01, ** p<0.05, * p<0.1

Table 3.9: FE Regressions: ELA and Math Results for STAR Exams

	Dependent Variable: STAR Exam Scores							
	English Language Arts				Mathematics			
VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Green School	-0.267***	0.0104***	-0.00140	-0.00828**	-0.223***	0.00968***	-0.00677	-0.0180***
	(0.00753)	(0.00225)	(0.00440)	(0.00383)	(0.00798)	(0.00346)	(0.00658)	(0.00624)
Log Percent Black			-0.00126	-0.00157			-0.00169	-0.00234
			(0.00135)	(0.00116)			(0.00183)	(0.00166)
Log Percent Asian			0.0169***	0.0115***			0.0189***	0.0140***
			(0.00146)	(0.00126)			(0.00199)	(0.00184)
Log Percent Certified Teachers			-0.0235***	-0.00534			-0.0620***	-0.0384***
			(0.00752)	(0.00676)			(0.0120)	(0.0108)
Log Percent College Graduates			0.00881***	0.00619***			0.0103***	0.00895***
			(0.00101)	(0.000897)			(0.00142)	(0.00134)
Log Percent Hispanics			-0.0132***	-0.0199***			-0.0322***	-0.0329***
			(0.00366)	(0.00343)			(0.00535)	(0.00521)
Log Percent Free and Reduced Lunch			-0.0113***	-0.00999***			-0.00532	-0.00954***
			(0.00242)	(0.00180)			(0.00349)	(0.00269)
Log Percent Socioeconomically Disadvantaged			-0.00206	0.000163			-0.00121	0.000483
			(0.00172)	(0.00115)			(0.00225)	(0.00159)
Constant	6.032***	6.471***	6.620***	6.151***	6.086***	5.851***	6.809***	6.381***
	(0.000463)	(0.000987)	(0.0375)	(0.0625)	(0.000514)	(0.000848)	(0.0585)	(0.125)
Observations	36,573	36,573	17,970	17,970	32,220	32,220	15,718	15,718
R-squared	0.068	0.986	0.989	0.992	0.235	0.973	0.981	0.984

Cluster robust standard errors in parentheses

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 3.10: FE Regressions: ELA and Math Results by Subgroup

	English Language Arts				Mathematics			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Panel A: African American Students								
Log Score	0.050****	0.002	-0.005	-0.007	0.072****	0.011	0.006	-0.008
	(0.003)	(0.004)	(0.005)	(0.006)	(0.007)	(0.007)	(0.008)	(0.010)
N	9068	9068	5377	5377	6170	6170	3617	3617
R-Sq	0.600	0.761	0.786	0.807	0.564	0.714	0.758	0.782
Panel B: Asian Students								
Log Score	0.048****	-0.001	0.008*	0.008	0.058****	0.000	0.008	-0.006
	(0.003)	(0.003)	(0.005)	(0.006)	(0.004)	(0.004)	(0.011)	(0.014)
N	10544	10544	6067	6067	7333	7333	4214	4214
R-Sq	0.792	0.905	0.919	0.929	0.773	0.870	0.887	0.899
Panel C: Hispanic Students								
Log API	0.054****	0.000	-0.003	0.000	0.069****	0.002	0.001	-0.008
	(0.002)	(0.002)	(0.003)	(0.003)	(0.003)	(0.004)	(0.005)	(0.007)
N	24056	24056	11484	11484	19827	19827	9249	9249
R-Sq	0.618	0.863	0.884	0.896	0.555	0.795	0.839	0.858
Panel D: Socioeconomically Disadvantaged								
Log Score	-0.123****	0.004**	-0.011**	-0.026****	-0.092****	0.003	-0.014*	-0.032****
	(0.007)	(0.002)	(0.004)	(0.005)	(0.008)	(0.004)	(0.008)	(0.010)
N	28983	28983	14798	14798	24763	24763	12577	12577
R-Sq	0.033	0.985	0.989	0.990	0.218	0.972	0.983	0.985
Panel E: White Students								
Log Score	0.041****	0.000	0.003	0.002	0.058****	0.002	0.010	0.004
	(0.002)	(0.002)	(0.005)	(0.005)	(0.003)	(0.003)	(0.010)	(0.011)
N	20473	20473	10964	10964	16286	16286	8716	8716
R-Sq	0.768	0.891	0.919	0.925	0.741	0.858	0.891	0.902
School FE	Y	Y	Y	Y	Y	Y	Y	Y
Year FE	N	Y	Y	Y	N	Y	Y	Y
CSA and District FE	N	N	Y	Y	N	N	Y	Y
CSA and District Trends	N	N	N	Y	N	N	N	Y

Cluster robust standard errors in parentheses, clustered at the school district level.
*** p<0.01, ** p<0.05, * p<0.1

Table 3.11: FE Completion Rates and High School Exam

	(1)	(2)	(3)	(4)
Panel A: Log Completion Rates				
	0.003**	0.004***	0.006***	0.005*
	(0.001)	(0.001)	(0.002)	(0.003)
N	9462	9462	3745	3745
R-Sq	0.261	0.285	0.648	0.712
Panel B: Log UC and CSU Graduation Rates				
	0.327****	0.041	-0.018	-0.030
	(0.048)	(0.054)	(0.053)	(0.046)
N	27934	27934	3589	3589
R-Sq	0.850	0.870	0.815	0.856
Panel C: Log ACT Scores				
	0.017**	-0.007	-0.015	0.001
	(0.007)	(0.007)	(0.011)	(0.010)
N	4087	4087	2604	2604
R-Sq	0.839	0.853	0.834	0.854
Panel D: Log ACT Scores				
	-0.002	-0.006	-0.003	-0.007
	(0.005)	(0.005)	(0.007)	(0.007)
N	5058	5058	3305	3305
R-Sq	0.928	0.930	0.938	0.950
School FE	Y	Y	Y	Y
Year FE	N	Y	Y	Y
CSA and District FE	N	N	Y	Y
CSA and District Trends	N	N	N	Y

Cluster robust standard errors in parentheses, clustered at the school district level.
*** p<0.01, ** p<0.05, * p<0.1

In terms of completion rates, green schools do show some promise, albeit a very small one. Panel A of Table 3.11 shows that overall, green schools increase completion rates by roughly one-half percent overall. The size of this effect is similar across subgroups. To check whether this might be an economically meaningful effect, I consider whether graduation rates of graduates who meet the standard for college admission at University of California or California State University schools are affected by the infrastructure improvement. I find a zero effect on this measure. I also consider SAT scores and find no effect on those. Hence, the evidence implies that there is no meaningful effect of green schools on academic achievement. Table 3.11 Panels B-D show the results of the analyses for the additional tests.

3.4.3 Extensions: Event Study Analysis

It now appears clear that while green schools are located in a way consistent with their ability to generate energy savings, the spillover effects from the improvements are not materializing. One potential concern is that the inclusion of fixed effects, while critical to the analysis, may have removed too much variation from the data, yielding estimated effects that are practically zero. Thus, as a check on the main results in this paper, I consider a strategy which rests on a related, but somewhat different set of assumptions, namely an event study analysis.

After normalizing all schools to the year in which they went green, I examine outcomes four years before and four years after the opening of the green school according to equation 3.2. Controls are included for the racial and socioeconomic make up of the schools (percent free lunch eligible and percent socioeconomically disadvantaged). I also control for the percentage of teachers at the school who are fully certified to teach in their subject.

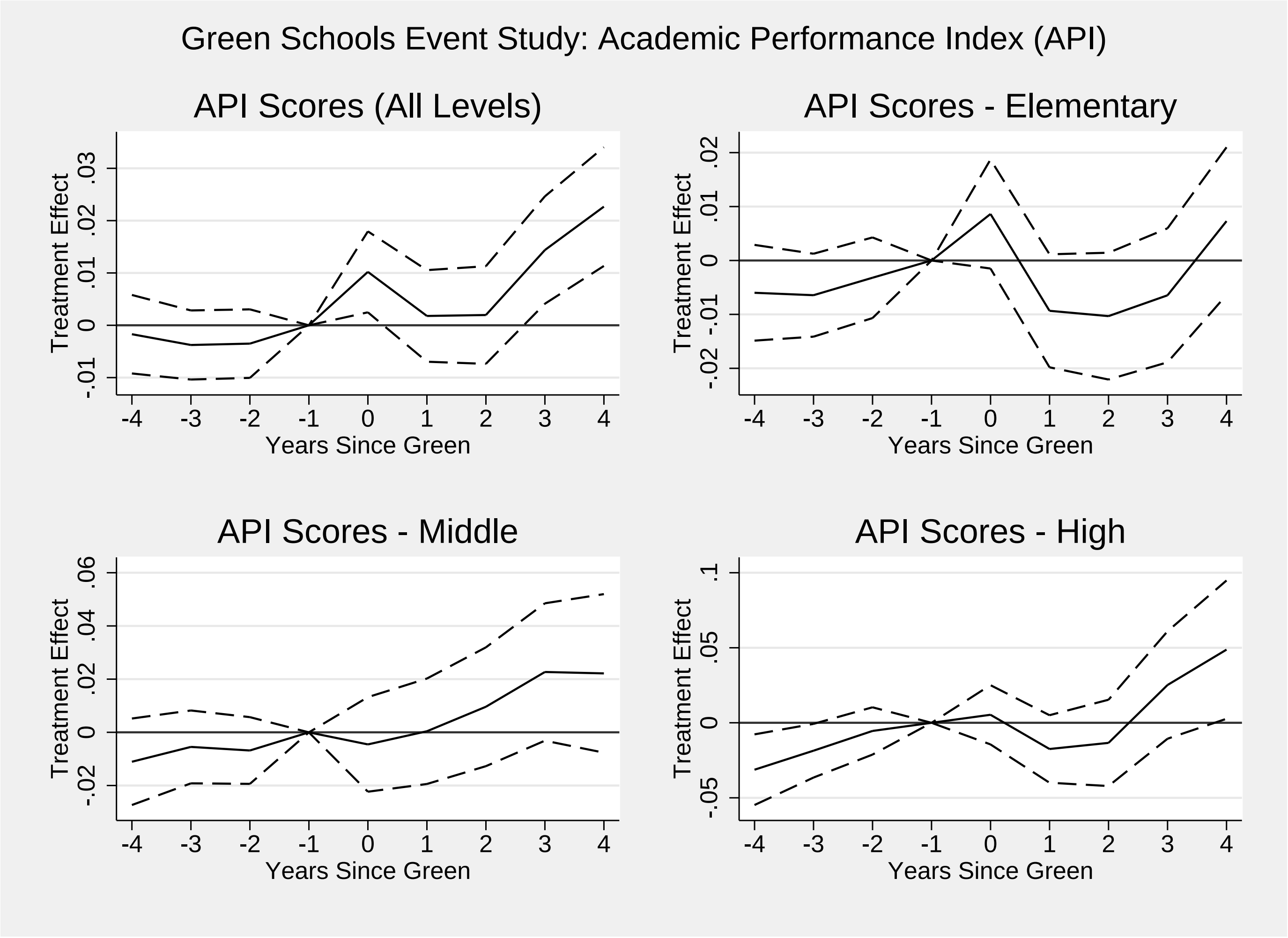
Unfortunately, in many cases, and especially in the case of the STAR exam scores, the event study estimator was unable to achieve convincing pre-treatment balance. However, for the primary dependent variable, total API, the estimator was able to achieve some balance. Figure 3.4 shows the API scores for all estimators and also by school type (Elementary, Middle, High School). Note that while there appears to be a small increase in API scores in later years, this is not found in a significant way in any of the individual school level outcomes. The results for using 3 or 5 leads and lags are similar. Outcomes were estimated for schools individually in various locales or school types. Results for the subgroup analyses were similar to those of the main analysis.

Figure 3.5also shows event study for the high school specific metrics - overall completion rate, UC graduation rate, ACT and SAT scores. The results are similar and indicate, as shown in the fixed effects analysis, no significant change in test scores. While there appears to be an increase in the high school completion rate, the pre-treatment balance is not convincing, so no conclusion can be drawn.

There is one important subgroup that had an exceptional difference in outcomes between the fixed effects analysis and the event study analysis: socioeconomically disadvantaged students. Figure 3.6 repeats the event study for socioeconomically disadvantaged students and considers API scores and STAR exam scores. In contrast to the fixed effects analysis, which estimated decreases in performance among this subpopulation, the event study indicates increases in achievement across both API and STAR test scores. Given the conflicting results between the panel estimates and the event study, no conclusions can be drawn for this subpopulation.

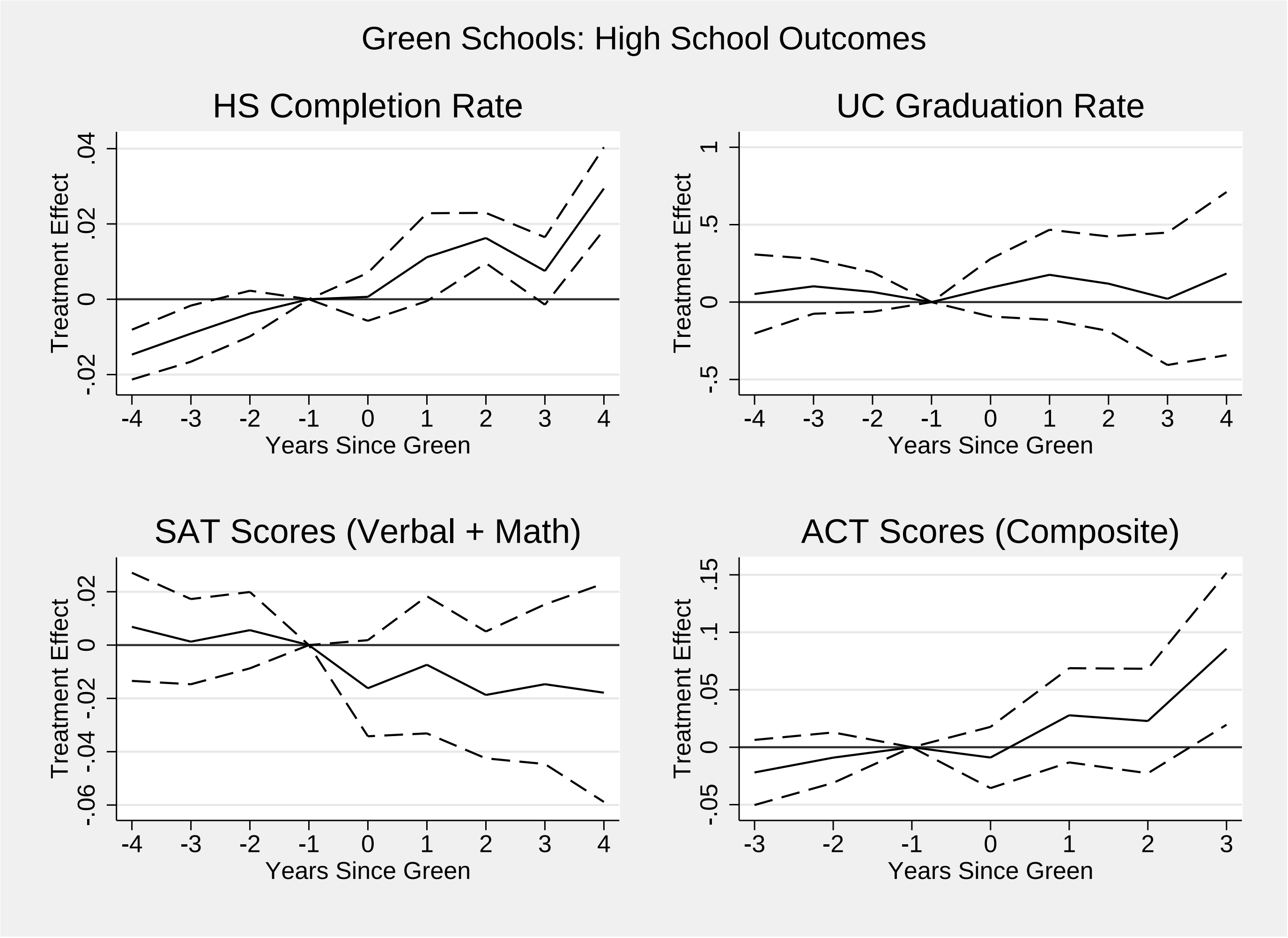
All of the event studies look similar for 3 and 5 leads and lags of their respective dependent variables.

Figure 3.4: Event Study: API Scores by Type of School



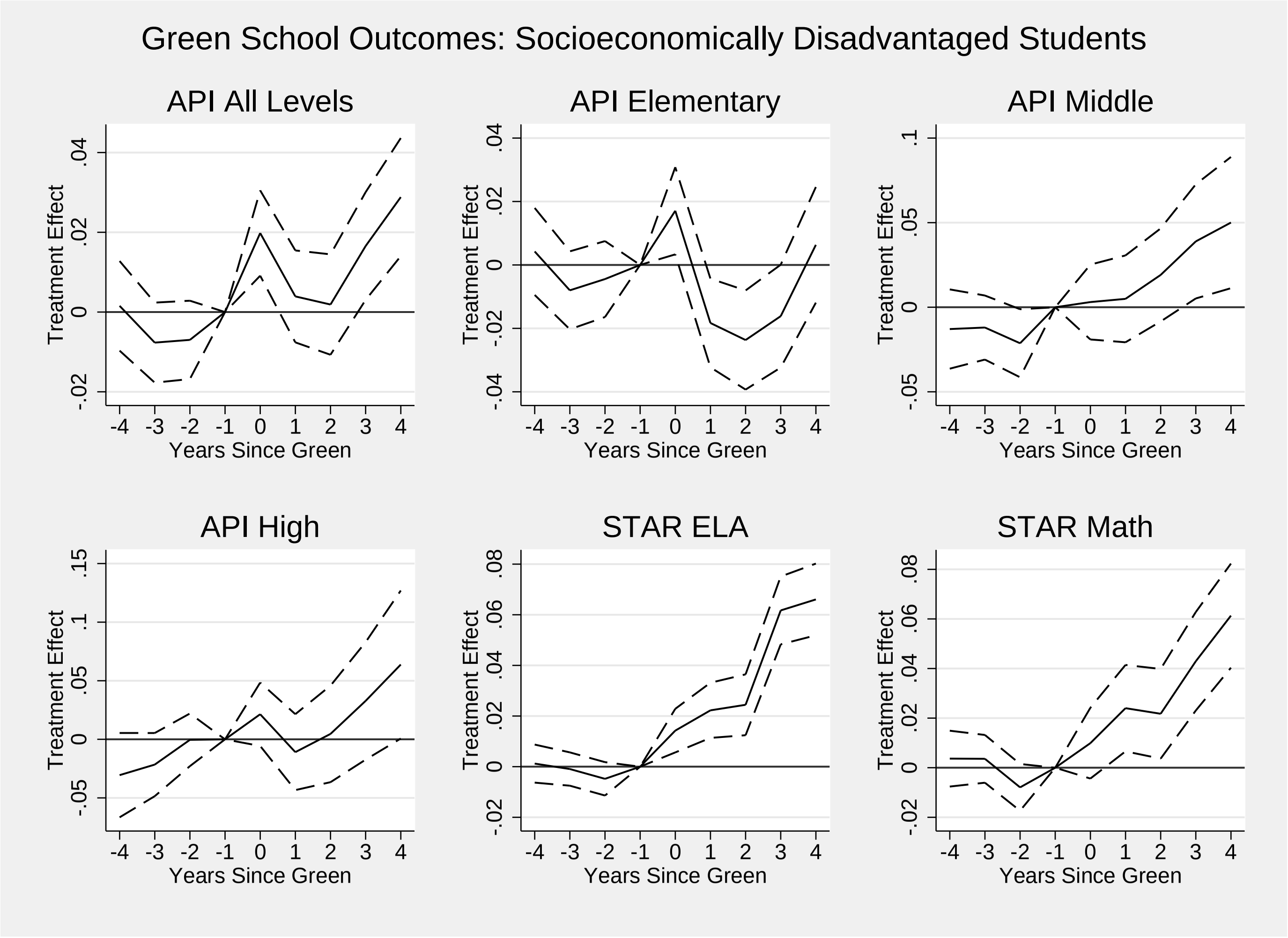
Event study estimates include controls for leads and lags, school and year fixed effects, Combined Statistical Area (CSA) fixed effects, as well as district-specific and school-specific trends. Dotted lines indicate 95 percent confidence intervals.

Figure 3.5: Event Study: High School Achievement Metrics



Event study estimates include controls for leads and lags, school and year fixed effects, Combined Statistical Area (CSA) fixed effects, as well as district-specific and school-specific trends. Dotted lines indicate 95 percent confidence intervals.

Figure 3.6: Event Study: Socioeconomically Disadvantaged Students



Event study estimates include controls for leads and lags, school and year fixed effects, Combined Statistical Area (CSA) fixed effects, as well as district-specific and school-specific trends. Dotted lines indicate 95 percent confidence intervals.

3.5 Conclusion

This paper considered the effects of an infrastructure improvement - the introduction of energy-efficient building technology - into public school buildings from 2000 to 2014. Previous research suggested these improvements would not only reduce energy prices, but also have a spillover effect on academic achievement.

First, I considered this in the nationwide context, using school districts as the primary unit of observation. I find that districts with higher numbers of energy-efficient schools have higher levels of enrollment and lower high school dropout rates, indicating some benefit to improving educational quality within the district. Turning to the case of California, I find no effect of the schools on Academic Performance Index (API) scores, state English Language Arts or Mathematics scores, SAT or ACT scores. I find that while energy efficient high schools do reduce dropout rates slightly, they have no effect on college readiness as measured by SAT, ACT, or University of California system college-ready graduation rates. This contrasts with other studies finding larger increases in standardized test scores. Because I do not observe the specific improvements made to school buildings, it is possible that the mix of improvements chosen were less evident to students and staff. However, given the high average rating of retrofitted school buildings in California, it appears that the improvements simply did not enhance educational quality.

This implies that while it is a noble goal of school districts and building managers to upgrade their facilities, the decision to do so should solely be based on the engineering business case. Adapting sustainable building techniques are no magic bullet for improving student achievement. This is not to say that students should be forced to learn in dilapidated buildings; undoubtedly students and staff benefit from a better learning environment. Yet, it is important to remember that this is only one of many things that factors into student learning. The lessons for other forms of real estate, such as commercial buildings, are less clear-cut, but suggest that corporate rent premiums are based less on productivity improvements and more on “warm glow” factors. It is important that further research be conducted on this topic to better understand the link between school building infrastructure and student learning outcomes.

Chapter 3 Bibliography

Baker, Lindsay and Harvey Bernstein, "The Impact of School Buildings on Student Health and Performance: A Call for Research.," 2012.

Choi, Eugene and Norman G. Miller, "Explaining LEED Concentration: Effects of Public Policy and Political Party," *Journal of Sustainable Real Estate*, 2011, *3* (1), 91–108.

Cidell, J., "Building green: The emerging geography of LEED-certified buildings and professionals," *The Professional Geographer*, 2009, *61* (2), 200–215.

Cidell, Julie and Miriam A. Cope, "Factors Explaining the Adoption and Impact of LEED-Based Green Building Policies at the Municipal Level," *Journal of Environmental Planning and Management*, 2014, *57* (11-12), 1763–1781.

Duran-Narucki, Valkiria, "School building condition, school attendance, and academic achievement in New York City public schools: A mediation model," *Journal of Environmental Psychology*, September 2008, *28* (3), 278–286.

Eichholtz, Piet, Nils Kok, and John M. Quigley, "Doing Well by Doing Good? Green Office Buildings," *American Economic Review*, 2010, *100* (5), 2492–2509.

_ , _ , and _ , "The Economics of Green Building," *Review of Economics and Statistics*, 2013, *95* (1), 50–63.

Fuerst, Franz and Pat McAllister, "Eco-labeling in commercial office markets: Do LEED and Energy Star offices obtain multiple premiums?," *Ecological Economics*, 2011, *70* (6), 1220–1230.

Gordon, Douglas E., *Green Schools as High Performance Learning Facilities*, National Clearinghouse for Educational Facilities, September 2010.

Hardy, Charlie L. and Mark Van Vugt, "Nice Guys Finish First: The Competitive Altruism Hypothesis," *Personality and Social Psychology Bulletin*, October 2006, *32* (10), 1402–1413.

Kahn, Matthew E. and Ryan K. Vaughn, "Green Market Geography: The Spatial Clustering of Hybrid Vehicles and LEED Registered Buildings," *B.E. Journal of Economic Analysis and Policy: Contributions to Economic Analysis and Policy*, 2009, *9* (2).

Katz, Gregory, "Greening America's Schools: Costs and Benefits | U.S. Green Building Council," 2006.

Kaza, Nikhil, T. William Lester, and Daniel A. Rodriguez, “The Spatio-temporal Clustering of Green Buildings in the United States,” *Urban Studies*, 2013, *50* (16), 3262–3282.

Kok, Nils, Marquise McGraw, and John M. Quigley, “The diffusion over time and space of energy efficiency in building,” *The Annals of Regional Science*, January 2012, *48* (2), 541–564.

Kontokosta, Constantine E., “Greening the Regulatory Landscape: The Spatial and Temporal Diffusion of Green Building Policies in U.S. Cities,” *Journal of Sustainable Real Estate*, 2011, *3* (1), 68–90.

Lee, Taedong and Chris Koski, “Building Green: Local Political Leadership Addressing Climate Change,” *Review of Policy Research*, September 2012, *29* (5), 605–624.

Lubell, Mark, Richard Feiock, and Susan Handy, “City Adoption of Environmentally Sustainable Policies in California’s Central Valley,” *Journal of the American Planning Association*, June 2009, *75* (3), 293–308.

Maxwell, Lorraine E. and Suzanne L. Schechtman, “The Role of Objective and Perceived School Building Quality in Student Academic Outcomes and Self-Perception,” *Children, Youth and Environments*, April 2012, *22* (1), 23–51.

McGraw-Hill Construction, “New and Retrofit Green Schools: The influence of a Green School on Its Occupants,” Technical Report 2012.

Simcoe, Timothy and Michael W. Toffel, “Public Procurement and the Private Supply of Green Buildings,” Working Paper 18385, National Bureau of Economic Research September 2012.

Appendix A

Airports and Local Economies

A.0.1 Census Population and Employment Data

Population data were obtained from the National Historical Geographic Information System (NHGIS) for 1900-2010. These include total population, nonwhite population and urban population. The key limitation of the County Business Patterns data is that it begins in 1946 (and my series begins in 1951), right around the time at which I claim airports are opening and aviation is coming into its own. Moreover, there appears to be some concern that the CBP data sets are not as comparable over time as one would like, likely due to changes in the way firms were selected for inclusion in this, especially early on. As a result, the primary employment data used in this analysis is derived from the Industry data of the U.S. Census, allowing for consistent series of census-derived industrial data from 1900 to 2010. Sources for each employment data point:

- Agriculture and Mining: 1900 - 1940 from IPUMS 1% Sample, 1950-1960 from CCDB (note: mining imputed from 1950 and 1970 values since missing), 1970-2010 from NHGIS

- Construction: 1900 - 1940 from IPUMS 1% Sample, 1950-1960 from CCDB, 1970-2010 from NHGIS

- Manufacturing: 1900, 1920, 1930, 1940 from NHGIS; 1910 from IPUMS (derived from 1% micro data); 1950 from City and County Data Book (CCDB) using 1949 manufacturing employee count; 1960 from CCDB using 1958 manufacturing employee count; 1970-2010 from NHGIS

- Transportation, Communication and Utilities: 1900-1930 from IPUMS 1% micro data, 1940-1960 from CCDB entries, 1970-2010 from NHGIS

- Wholesale Trade: 1900-1940 from IPUMS 1% micro data, 1950 from CCDB 1948 wholesale employment count; 1960 from CCDB 1958 wholesale employment count; 1970-2010 from NHGIS

- Retail Trade: 1900 – 1930 from IPUMS 1% micro data; 1940 from CCDB 1939 retail employment count; 1950 from CCDB 1948 retail employment count; 1960 from CCDB 1958 retail employment count; 1970-2010 from NHGIS

- Finance, Insurance, and Real Estate (FIRE): 1900 – 1940 from IPUMS 1% micro data; 1950 and 1960 from CCDB 1950/1960 FIRE employment count; 1970-2010 from NHGIS

- Services: 1900 – 1940 from IPUMS 1%, 1950-1960 linearly imputed from 1940 and 1970 values, 1970-2010 from NHGIS

- Public Administration: 1900 - 1940 from IPUMS 1%, 1950-1960 from CCDB, 1970-2010 from NHGIS

- All employment: 1900-1940 from IPUMS 1%, 1950 – 1960 from CCDB; 1970-2010 from IPUMS From these, employment shares were defined as the share of employment in the industry of interest divided by total employment (by year). Missing data was imputed by taking the geometric mean of neighboring data points (this affected 121 out of roughly 250,000 cells). Finally, cells that still were missing were imputed with values from the next ten years (this affected 10 out of roughly 250,000 cells). Finally, cells missing 1900 population or employment data were flagged, as in many cases, these counties were not officially part of the United States until 1912 or after.
- Note: “Trade” = Wholesale + Retail trade. “Financial and Other Services” = FIRE + Services
- Tradable Employment = Wholesale + Manufacturing + Agriculture + Mining
- Non-tradable employment = Retail + Finance + Services + Construction + Public Administration

Other variables derived from U.S. Census: Data on land and building prices from 1900-1950 was obtained from the NHGIS (missing post 1950). Data on median family income from 1950-2010 was obtained from NHGIS (missing prior to 1950). Data on median housing values was taken from CCDB for 1930 and 1940, and NHGIS from 1980-2010. Other years missing. Data on median rents was taken from CCDB for 1940 and 1950, and NHGIS from 1980-2010. Other years missing. Data obtained from the Bureau of Economic Analysis (BEA) include earnings, earnings per worker, personal income, and per capita personal income for 1970-2010.

A.0.2 Other data sources:

- County Characteristics 2005 – data on Census division, region, latitude, longitude, January temperature and other climate characteristics, topography measure, from ICPSR study 20660.[1]
- Planned highway mileage – courtesy of Nate Baum-Snow, aggregated to the county level using GIS software
- Railway straight-line mileage in 1887 – courtesy of Jeremy Atack, aggregated to the county level using GIS software
- Coastal Counties – U.S. Census Bureau and National Oceanic and Atmospheric Administration: https://www.census.gov/geo/landview/lv6help/coastal_cty.pdf

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[1] http://www.icpsr.umich.edu/icpsrweb/ICPSR/studies/20660

- Port Cities – NOAA: http://www.ngs.noaa.gov/RSD/coastal/projects/coastal/ports_list.html Land grant colleges - http://espnational.org/about-us/land-grant-universities.html
- County / CBSA Size: County land areas over time were derived for each 10-year interval by obtaining data on county boundaries from the Atlas of Historical Counties Project.[2] CBSAs with changes in land areas greater than three percent were dropped from the analysis.
- Geography / Human Capital: These include a dummy variable for whether a county contains a political capital city or a land grant college.[3]
- Climate and Geography: From the ICPSR's county characteristics study, I use a measure of mean January temperature. [4] Dummy variables were derived for whether a county contains a port, is located on a coast, or on a river.[5] I also control for planned highway mileage in as of 1947,[6] as well as total straight-line rail mileage in 1887.[7]
- Air Traffic Data: I use air traffic data (enplanements and operations) from the FAA's Terminal Area Forecast for 1976-2012 traffic.[8] Between 1964 and 1976, where available, I hand-collected data from annual versions of the *FAA Statistical Handbook* to obtain traffic data.

The next step is to aggregate this data to the level of the Core Based Statistical Area (CBSA). 2010 CBSA data were obtained from the National Historical Geographic Information System. The overriding goal of what follows is to create a consistent data series from 1900 to 2010 in which data are compiled for a consistent geography. This means that both the composition of counties in each CBSA and the size of each CBSA, in terms of land area, must be the same for each data point in the time series. This will allow for a consistent estimation of the effects of the airport over time. As counties form the building blocks of CBSAs, much of what follows involves operations on county level data. The steps involved are: (1) standardize county sizes, and flag counties in which counties change "too much"; (2) aggregate county-level census, employment, airport, aviation history, and county characteristics data; and (3) remove CBSAs where geography cannot be made consistent due to political changes.

County size. Counties were standardized to their 2010 land areas. County land areas over time were derived for each 10-year interval by obtaining data on county boundaries

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[2] Atlas of Historical Counties Project: http://publications.newberry.org/ahcbp/

[3] http://www.higher-ed.org/resources/land_grant_colleges.htm

[4] ICPSR County Characteristics, 2000-2007; ICPSR Study 20660.

[5] http://www.ngs.noaa.gov/RSD/coastal/projects/coastal/ports_list.html

[6] I thank Nate Baum-Snow for sharing this data.

[7] I thank Jeremy Atack for sharing this data.

[8] http://www.faa.gov/about/office_org/headquarters_offices/apl/aviation_forecasts/taf/

from the Atlas of Historical Counties Project. Next, for each county, a flag was created indicating if the county's area had changed more than three percent since 1930. CBSAs flagged in this way are dropped. To standardize county areas, a ratio of the then-year county area to the 2010 county area was derived. Dividing employment and population data through by this ratio yields the adjusted county level information used in the analysis. Aggregation subsequently yielded the CBSA information used in this study.

A.1 Event-Time Difference-in-Difference

Following **?** and **?**, I implement an "event-time" version of the differences-in-differences (DD) estimator. It differs from the standard DD approach in that instead of a simple "post-treatment" indicator, I create a series of dummy variables indicating time (in decades) relative to implementation ($k = 0$ is normalized to 1950) in order to estimate the dynamic effects of the airports on their local economic outcomes. The specification is:

$$y_{it} = \alpha + \theta_i + \gamma_t + \sum_{k=-5}^{6} \lambda_k \delta_{k,it} + \epsilon_{it} \tag{A.1}$$

where α is a constant, θ_i is a CBSA fixed effect, and γ_t is a year fixed effect. $\delta_{k,it}$ is an indicator variable equal to 1 if the CBSA is in year k of having its airport, and 0 otherwise. In the regressions, $k = 0$ is left out as the reference year. The pattern of λ_ks describes the change in trend in the outcome of interest, y_{it}, associated with having an airport. For example, λ_1 - λ_0 gives the change in the dependent variable associated with moving from $k = 0$ (1950) to $k = 1$ (1960). Importantly, it allows for a partial test of the identifying assumption that absent receiving an airport, the growth trends of treated and control CBSAs would have trended similarly. In most cases, this condition fails, as a glance at Figure A.2 shows. In practice, many places receiving airports were smaller than average in the pre-period, relative to their eventual position in 1950, and yet were growing faster than the average. As a result, in many cases the DD specification provides another point of reference on the values obtained by IV and Caliper Matching, but in no case should these be taken as more than that. Since the entire equation is normalized to 1950 ($k = 0$), growth effects are given by λ_6 in the dynamic event-time specification.

A.2 Alternative Model of Local Labor Markets and Airports

I use the local labor markets model derived in **?** to model an airport as a productive amenity. I will not derive the model in full here, but rather use its main results. I focus entirely on re-distributive effects and ignore agglomeration effects. I also do not explicitly model dynamic effects.

Suppose there are two cities (indexed by c) endowed with amenity A_c. Residents consume a traded good G that has the same price in all cities, say, 1. They also consume housing, H, with the price of housing varying across locations. Workers are identical in taste and skill, and supply one unit of labor. A worker in city c solves the problem

$$\max U(G, H, A_c) \text{ s.t. } w_c = G + p_c H,$$

where w_c is the wage in city c and p_c is the per-unit price of housing.

Firms produce X, a vector of goods that includes tradable goods and non-tradable goods. Tradable goods are produced in the agriculture, mining, manufacturing, and wholesale trade sectors. Non-tradable goods are produced in the construction, retail trade, finance, insurance and real estate, public administration, and services sector. (The transportation, communications, and utilities sector is considered separately.)

In the first case, suppose that one of the goods, x_1, is the traded good. The cost of producing x_1, $C(w_c, p_c, A_c)$ depends on the price of labor and also on the price of housing, which itself incorporates factors such as the price of factory space. In the Roback framework, wages and housing prices adjust to equalize utility across all cities. On the firm side, production costs are assumed to be identical everywhere. Production in city c is Cobb-Douglas with constant returns to scale:

$$\ln y_c = Z_c + hN_c + (1-h)K_c,$$

where Z_c is a city-specific productivity shifter whose effect is shared by all firms in city c. Similarly, the labor demand curve is:

$$\ln w_c = Z_c - (1-h)N_c + (1-h)K_c + \ln h.$$

Since capital flows instantaneously to the place where its return is highest, in equilibrium its return is the same everywhere. Also, assume the price of housing is given by

$$p_c = u + k_c N_c,$$

where k_c characterizes the elasticity of the supply of housing and is assumed to be exogenously determined by geography and local land regulations, and u is simply a shifter to ensure equality. In cities where constructing new housing is relatively easy, k_c is low. However, as constraints make it harder to construct new housing, k_c becomes larger.

Consider two cities a and b that are identical in Period 1. In Period 2, city b builds an airport and attracts service. In this case, the labor demand curve for city b is upward sloping:

$$w_b = w_a + (p_b - p_a) - (A_a - A_b) + s\frac{N_b - N_a}{N},$$

where N_c is the log of the number of workers in city c, and $N_a + N_b = N$ is the fixed labor supply. Assume that worker i's relative preference for city a over city b is given by $U[-s, s]$. The parameter s characterizes mobility resulting from idiosyncratic preferences. If s is large, workers have high preferences for location and thus labor mobility will be low; however if s is low, the converse will be true. As the shock only affects those firms that can benefit from it, $X_{b2} = X_{b1} + \Delta$, where $\Delta > 0$. As Δ characterizes a productivity increase, wages $(w_{b2} - w_{b1})$ will increase by that amount as well. Firms already located in city b might enjoy economic rents and be less inclined to move. Conversely, firms that could benefit from the airport would be much more likely to move to city b, increasing their demand for labor. To satisfy this, workers, attracted by higher wages, move from a to b so that, as shown in **?**,

$$N_{b2} - N_{b1} = \frac{N}{N(k_a + k_b) + 2s}\Delta \geq 0. \tag{A.2}$$

Equation A.2 shows that as a result, employment and population are expected to increase overall in the airport city b. Additionally, wages and land prices may also increase, the magnitude of which depends on s and k. A high s, meaning people are heavily tied to their current location, or a high k, indicating a relatively inelastic housing supply, would reduce the size of final population increase.

Table A.1: Covariates by Airport Status

	Controls ($n = 379$)		Airport CBSAs ($n = 131$)	
Variable	Mean	SD	Mean	SD
Airport Predictors				
On 1938 Air Mail Network	0.087	(0.282)	0.679	(0.469)
On 1922 Army Air Service Defense Plan	0.026	(0.160)	0.313	(0.465)
CBSA County on 1944 National Airport Plan	0.135	(0.342)	0.092	(0.290)
Had CAA Intermediate Airfield	0.314	(0.465)	0.412	(0.494)
Transport				
Planned Highway Mileage as of 1947	18.261	(24.417)	60.267	(58.424)
Located near river	0.348	(0.477)	0.534	(0.501)
Has Port	0.032	(0.175)	0.099	(0.300)
1887 Straight-Line Rail Mileage	79.749	(63.590)	170.672	(151.773)
Geography/Climate				
Has Political Capital City	0.018	(0.135)	0.168	(0.375)
NOAA Coastal County	0.251	(0.434)	0.244	(0.431)
Has Land Grant College	0.042	(0.201)	0.153	(0.361)
Mean January Temperature	32.110	(11.119)	32.838	(11.865)
CBSA and Region				
CBSA Land Area (std. to 2010)	1440.966	(2168.268)	2571.252	(2080.955)
Region 1: Northeast	0.127	(0.333)	0.122	(0.329)
Region 2: Midwest	0.380	(0.486)	0.321	(0.469)
Region 3: South	0.314	(0.465)	0.382	(0.488)
Region 4: West	0.179	(0.384)	0.176	(0.382)

Table A.2: Summary of Estimates: Long Difference in Sectoral Employment Outcomes, All Methods, 1950-2010

	All Airports				
Sector/Outcome by Analysis	OLS	DD	IV	Matching	Synth
Population (Age 15-64)	0.235***	0.248***	0.255*	0.194***	0.136**
	(0.053)	(0.060)	(0.134)	(0.068)	(0.067)
Total Employment	0.292***	0.290***	0.312**	0.265***	0.160**
	(0.056)	(0.063)	(0.130)	(0.053)	(0.073)
Tradable Sector	0.311***	0.236***	0.335**	0.355***	0.255***
	(0.065)	(0.071)	(0.137)	(0.056)	(0.086)
Non-tradable Sector	0.164***	0.143**	0.178	0.149***	0.027
	(0.047)	(0.064)	(0.123)	(0.038)	(0.067)
Agriculture and Mining	0.317***	0.142	0.478***	0.283***	0.322***
	(0.068)	(0.090)	(0.116)	(0.048)	(0.100)
Construction	0.155**	0.172***	0.076	0.237***	0.151*
	(0.062)	(0.060)	(0.134)	(0.026)	(0.091)
Manufacturing	0.307***	0.030	0.240	0.315***	0.401***
	(0.083)	(0.102)	(0.161)	(0.053)	(0.133)
Transportation/Comm/Util	0.248***	0.100	0.433***	0.567***	0.333***
	(0.068)	(0.071)	(0.152)	(0.055)	(0.106)
Trade (Wholesale and Retail)	0.253***	0.068	0.095	-	0.041
	(0.067)	(0.080)	(0.160)	-	(0.095)
Services (incl. Finance)	0.149***	0.202***	0.166	-	0.100
	(0.045)	(0.050)	(0.121)	-	(0.063)

Notes: See section 1.4.2 of the text for details regarding each estimation strategy. OLS and IV estimates include all covariates as in specification (3) of Table 1.2 and 1.4 respectively. The difference-in-difference estimates include year and CBSA fixed effects, as well as additional controls for pre-1950 values. Matching and Synthetic Control estimates include all covariates as in specification (6) of Tables 1.5 and 1.6, respectively. All standard errors are clustered at the CBSA level (except for those from Matching, which are robust Abadie-Imbens standard errors).

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table A.3: Summary of Estimates: Long Difference in Sectoral Employment Shares, All Methods, 1950-2010

	All Airports		
Sector/Outcome by Analysis	OLS	IV	Matching
Tradable Sector	-0.092**	-0.234**	-0.142***
	(0.040)	(0.101)	(0.015)
Non-tradable Sector	0.022**	0.038*	0.052***
	(0.010)	(0.022)	(0.005)
Agriculture and Mining	-0.068	-0.087	-
	(0.081)	(0.172)	-
Construction	-0.015	-0.120**	-
	(0.024)	(0.057)	-
Manufacturing	-0.227***	-0.618***	-0.235***
	(0.053)	(0.143)	(0.027)
Transportation/Comm/Util.	-0.087***	-0.090	-0.119***
	(0.033)	(0.073)	(0.017)
Trade (Wholesale and Retail)	0.023	-0.015	-
	(0.014)	(0.038)	-
Services (incl. Finance)	0.024**	0.028	-
	(0.011)	(0.026)	-

Notes: See section 1.4.2 of the text for details regarding each estimation strategy. OLS and IV estimates include all covariates as in specification (3) of Table 1.2 and 1.4 respectively. The difference-in-difference estimates include year and CBSA fixed effects, as well as additional controls for pre-1950 values. Matching and Synthetic Control estimates include all covariates as in specification (6) of Tables 1.5 and 1.6, respectively. All standard errors are clustered at the CBSA level (except for those from Matching, which are robust Abadie-Imbens standard errors).

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table A.4: IV Results: Decade-by-Decade Effect of Airports on CBSA Outcomes, Long Differences 1950-2010 (Population and Employment Measures), By Sector

	(1)	(2)	(3)	(4)	(5)	(6)
Outcome by Decade	1950-60	1960-70	1970-1980	1980-1990	1990-2000	2000-10
Panel A: Change in Log Agricultural and Mining Employment						
Airport	0.0304	0.174***	0.00714	0.192***	-0.0857	0.199***
($n = 503$)	(0.0578)	(0.0574)	(0.0527)	(0.0628)	(0.0756)	(0.0645)
First Stage F	28.67	27.25	28.27	27.86	28.17	27.55
Panel B: Change in Log Construction Industry Employment						
Airport	0.272***	-0.0612	0.0238	-0.131**	0.0313	0.0108
($n = 375$)	(0.0897)	(0.0622)	(0.0639)	(0.0663)	(0.0520)	(0.0515)
First Stage F	29.06	28.86	30.61	30.43	29.51	28.97
Panel C: Change in Log Manufacturing Employment						
Airport	0.123	-0.157**	0.136**	0.0406	-0.0669	0.0958**
($n = 456$)	(0.0830)	(0.0694)	(0.0596)	(0.0559)	(0.0425)	(0.0480)
First Stage F	28.59	27.57	26.74	26.37	25.53	24.68
Panel D: Change in Log Wholesale and Retail Trade Employment						
Airport	0.0252	-0.0531	0.105**	-0.00236	-0.0385	-0.0102
($n = 446$)	(0.0495)	(0.0642)	(0.0454)	(0.0390)	(0.0346)	(0.0363)
First Stage F	32.55	31.95	31.26	30.56	29.47	28.60
Panel E: Change in Log Finance and Service Employment						
Airport	0.0258**	-0.0151*	0.102**	0.00246	-0.0376	-0.00331
($n = 485$)	(0.0127)	(0.00886)	(0.0407)	(0.0303)	(0.0296)	(0.0268)
First Stage F	34.01	33.20	33.08	32.54	32.22	30.93
Controls:						
Pre-period Employment	Y	Y	Y	Y	Y	Y
Region	Y	Y	Y	Y	Y	Y
Geography/Transport	Y	Y	Y	Y	Y	Y

Notes: Table reports results of instrumental variables (IV) regressions of log population/employment outcomes given above on an indicator variable for whether a CBSA has an airport, with various controls as indicated. Each specification represents one decade. Cluster-robust standard errors in parentheses clustered at the CBSA level. Pre-period controls include employment controls specific to the sector being analyzed, in log levels, for 1900 up to the base year, in ten year increments. For example, specification (3) includes log employment controls, by decade, through 1970 in ten year increments. (Log population is substituted for log employment in Panel A.) Population controls include controls for pre-period 15-64 population, in log levels, for 1900-1950 in ten year increments. Region controls include dummy variables for each of the nine Census divisions and CBSA land area. Geography/transport includes controls for 1887 straight-line rail mileage, planned 1947 highway mileage, having a port, being a political capital city, mean January temperature, having a coastal location, and for close proximity to a river. Tradable sector employment is the sum of agricultural, mining, manufacturing, and wholesale trade sector employment. Non-tradable sector employment is the sum of retail trade, finance/insurance/real estate, business, professional and other services, construction, and public administration sector employment.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table A.5: Fixed Effects Regression: Air Traffic and Sectoral Employment

	Sector of Employment			
	(1)	(2)	(3)	(4)
VARIABLES	Tradable	Non-tradable	Total Emp.	Population (15-64)
Log Enplanements Per Capita	0.0352	0.0674***	0.0660**	0.0478*
	(0.0351)	(0.0254)	(0.0267)	(0.0257)
Constant	10.05***	10.84***	11.31***	11.75***
	(0.0171)	(0.0125)	(0.0136)	(0.0135)
Observations	576	576	576	576
R-squared	0.982	0.991	0.989	0.990

Note: This table gives results from a fixed effects regression of log population/employment on log enplanements (passenger boardings), 1980- 2010. Standard errors clustered at the CBSA level. CBSA and year fixed effects are included in all specifications.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table A.6: Robustness of IV Estimates to Choice of Instruments

Dependent Variable: Change in Log Employment, 1950-2010						
Specification	(1)	(2)	(3)	(4)	(5)	(6)
Airport	0.312**	0.329**	0.310**	0.328**	0.341	0.176
	(0.130)	(0.136)	(0.130)	(0.136)	(0.544)	(0.332)
Constant	2.347***	2.379***	2.342***	2.378***	2.403**	2.085***
	(0.478)	(0.476)	(0.477)	(0.475)	(1.124)	(0.790)
AAS Defense Plan 1922	Y	N	Y	N	N	Y
Air Mail 1938	Y	Y	Y	Y	N	N
CAA Intermediate Airfield	Y	Y	N	N	Y	N
Observations	506	506	506	506	506	506
R-squared	0.486	0.479	0.482	0.474	0.396	0.406
F-statistic	31.61	32.29	32.14	32.09	19.93	21.45
Overid Test p-value	0.906	0.981	0.660	-	-	-

Note: Table reports the first stage regressions of CBSA airport status on whether the CBSA was on the 1922 Army Air Service Proposed Airways Systems of the United States, the 1938 Air Mail network, or on a CAA intermediate airfield, conditional on all controls but different combinations of instruments as given above. Cluster-robust standard errors given in parentheses, clustered on the CBSA level.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table A.7: Placebo Test: Estimated Effects on Non-Commercial Airports (Long Differences, 1950-2010)

Sector/Outcome by Analysis	OLS	DD	IV	Matching	Synth
Population	0.060	-0.007	0.165	-0.169***	-0.124
	(0.100)	(0.168)	(1.150)	(0.052)	(0.173)
Total Employment	0.085	-0.010	0.243	0.014	-0.154
	(0.122)	(0.184)	(1.165)	(0.053)	(0.176)
Tradable Sector	0.228	0.056	-0.146	-0.106	0.419
	(0.160)	(0.166)	(1.154)	(0.124)	(0.234)
Non-tradable Sector	0.010	-0.064	0.134	-0.109	0.017
	(0.115)	(0.180)	(1.165)	(0.081)	(0.213)
Transportation/Comm/Util	-0.086	-0.127	-0.191	-0.047*	0.208
	(0.149)	(0.195)	(1.446)	(0.025)	(0.172)

Notes: This table gives the results from a placebo test (where it is assumed that a non-commercial general airport CBSA is an airport CBSA) and the associated results for each outcome of interest. See section 1.4.2 of the text for details regarding each estimation strategy. OLS and IV estimates include all covariates as in specification (3) of Table 1.2 and 1.4 respectively. The difference-in-difference estimates include year and CBSA fixed effects, as well as additional controls for pre-1950 values. Matching and Synthetic Control estimates include all covariates as in specification (6) of Tables 1.5 and 1.6, respectively. All standard errors are clustered at the CBSA level (except for those from Matching, which are robust Abadie-Imbens standard errors).

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table A.8: Placebo Test: Estimated Effects on Neighboring CBSAs (Long Differences, 1950-2010)

	Combined Sample			
Sector/Outcome by Analysis	OLS	DD	IV	Matching
Population	-0.098*	-0.081	-0.157	0.027
	(0.055)	(0.071)	(0.513)	(0.029)
Total Employment	-0.036	-0.047	-0.331	0.008
	(0.063)	(0.073)	(0.567)	(0.041)
Tradable Sector	-0.003	-0.054	-0.225	0.041
	(0.067)	(0.076)	(0.474)	(0.040)
Non-tradable Sector	-0.060	-0.049	-0.228	0.008
	(0.053)	(0.068)	(0.594)	(0.025)

Notes: This table gives the results from a placebo test (where it is assumed that a neighboring airport CBSA is an airport CBSA) and the associated results for each outcome of interest. See section 1.4.2 of the text for details regarding each estimation strategy. OLS and IV estimates include all covariates as in specification (3) of Table 1.2 and 1.4 respectively. Matching and Synthetic Control estimates include all covariates as in specification (6) of Tables 1.5 and 1.6, respectively. All standard errors are clustered at the CBSA level (except for those from Matching, which are robust Abadie-Imbens standard errors).

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table A.9: OLS Results: Decade-by-Decade Effect of Airports on CBSA Outcomes, Long Differences (Population and Employment Measures)

	(1)	(2)	(3)	(4)	(5)	(6)
Outcome by Decade	1950-60	1960-70	1970-80	1980-90	1990-2000	2000-10
Panel A: Change in Population (All Persons, Ages 15 - 64)						
Airport	0.0719***	0.0232	0.0459***	0.0103	0.000868	-0.00393
($n = 506$)	(0.0250)	(0.0142)	(0.0135)	(0.0108)	(0.00736)	(0.00777)
R^2	0.424	0.267	0.504	0.653	0.659	0.677
Panel B: Change in Total Employment						
Airport	0.0892***	0.0168	0.0558***	0.0167	-0.00212	0.000721
($n = 506$)	(0.0268)	(0.0137)	(0.0130)	(0.0121)	(0.00901)	(0.00918)
R^2	0.407	0.267	0.626	0.582	0.613	0.610
Panel C: Change in Tradable Sector Employment						
Airport	0.110***	0.0217	0.0694***	0.0229	-0.00930	0.0245
($n = 504$)	(0.0287)	(0.0184)	(0.0205)	(0.0201)	(0.0139)	(0.0211)
R^2	0.347	0.254	0.492	0.386	0.326	0.342
Panel D: Change in Non-Tradable Sector Employment						
Airport	0.0271*	0.0138	0.0472***	0.00526	-0.00339	0.00182
($n = 494$)	(0.0140)	(0.0106)	(0.0153)	(0.0109)	(0.00961)	(0.00907)
R^2	0.542	0.362	0.534	0.546	0.561	0.525
Panel E: Change in Transportation Sector Employment						
Airport	0.0877***	0.0660**	0.0397	0.0351	-0.0398*	-6.88e-05
($n = 419$)	(0.0221)	(0.0308)	(0.0243)	(0.0232)	(0.0232)	(0.0220)
R^2	0.305	0.328	0.324	0.354	0.227	0.102
Controls:						
Pre-period Employment	Y	Y	Y	Y	Y	Y
Region	Y	Y	Y	Y	Y	Y
Geography/Transport	Y	Y	Y	Y	Y	Y

Notes: Table reports results of OLS regressions of log population/employment outcomes given above on an indicator variable for whether a CBSA has an airport, with various controls as indicated. Each specification represents one decade. Cluster-robust standard errors in parentheses clustered at the CBSA level. Pre-period controls include employment controls specific to the sector being analyzed, in log levels, for 1900 up to the base year, in ten year increments. For example, specification (3) includes log employment controls, by decade, through 1970 in ten year increments. (Log population is substituted for log employment in Panel A.) Region controls include dummy variables for each of the nine Census divisions and CBSA land area. Geography/transport includes controls for 1887 straight-line rail mileage, planned 1947 highway mileage, having a port, being a political capital city, mean January temperature, having a coastal location, and for close proximity to a river. Tradable sector employment is the sum of agricultural, mining, manufacturing, and wholesale trade sector employment. Non-tradable sector employment is the sum of retail trade, finance/insurance/real estate, business, professional and other services, construction, and public administration sector employment.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table A.10: OLS Results: Decade-by-Decade Effect of Airports on CBSA Outcomes, Long Differences 1950-2010 (Income and Housing Measures)

	(1)	(2)	(3)	(4)	(5)	(6)
	1950-60	1960-70	1970-80	1980-90	1990-00	2000-10
Panel A: Total Payroll (County Business Patterns Measure)						
Airport	0.105*	0.0476**	0.0686***	0.0266	0.0156	0.0128
	(0.0579)	(0.0202)	(0.0264)	(0.0253)	(0.0174)	(0.0210)
R^2	0.240	0.216	0.370	0.341	0.333	0.351
Panel B: Per-Worker Payroll (County Business Patterns)						
Airport	0.0191	0.0207**	0.005	-0.005	-0.002	-0.004
	(0.0260)	(0.008)	(0.010)	(0.001)	(0.009)	(0.01)
R^2	0.199	0.422	0.170	0.179	0.162	0.241
Panel C: Total Earnings (Bureau of Economic Analysis)						
Airport	-	-	0.0770***	0.0147	0.0123	0.00177
			(0.0222)	(0.0191)	(0.0137)	(0.0184)
R^2			0.389	0.391	0.435	0.389
Panel D: Earnings Per Worker (Bureau of Economic Analysis)						
Airport	-	-	0.0130	-0.0159*	0.00412	0.00233
			(0.00901)	(0.00960)	(0.00730)	(0.0107)
R^2			0.293	0.310	0.196	0.289
Panel E: Median Rent (Census)						
Airport	-	-	-	-0.0246	0.00555	-0.00474
				(0.0170)	(0.00934)	(0.00922)
R^2				0.470	0.399	0.292
Observations	506	506	506	506	506	506
Pre-period Population	Y	Y	Y	Y	Y	Y
Region	Y	Y	Y	Y	Y	Y
Geography/Transport	Y	Y	Y	Y	Y	Y

Notes: Table reports results of OLS regressions of log population/employment outcomes given above on an indicator variable for whether a CBSA has an airport, with various controls as indicated. Each specification represents one decade. Cluster-robust standard errors in parentheses clustered at the CBSA level. Pre-period controls include employment controls specific to the sector being analyzed, in log levels, for 1900 up to the base year, in ten year increments. For example, specification (3) includes log employment controls, by decade, through 1970 in ten year increments. (Log population is substituted for log employment in Panel A.) Region controls include dummy variables for each of the nine Census divisions and CBSA land area. Geography/transport includes controls for 1887 straight-line rail mileage, planned 1947 highway mileage, having a port, being a political capital city, mean January temperature, having a coastal location, and for close proximity to a river. Tradable sector employment is the sum of agricultural, mining, manufacturing, and wholesale trade sector employment. Non-tradable sector employment is the sum of retail trade, finance/insurance/real estate, business, professional and other services, construction, and public administration sector employment.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table A.11: Results: OLS Estimates of Airport Long Difference Effects By 1950 Population Quartile

	(1)	(2)	(3)	(4)
Quartile	First	Second	Third	Fourth
Panel A: Population (All Persons, Age 15 - 64)				
Airport	0.178*	0.303***	0.247***	0.248**
	(0.0914)	(0.0806)	(0.0847)	(0.117)
R^2	0.551	0.523	0.525	0.541
n	408	408	408	407
Panel B: Total Employment				
Airport	0.266***	0.359***	0.286***	0.270**
	(0.0941)	(0.0823)	(0.0869)	(0.121)
R^2	0.500	0.471	0.473	0.490
n	408	408	408	407
Panel C: Tradable Sector Employment				
Airport	0.283**	0.374***	0.381***	0.338**
	(0.116)	(0.0882)	(0.101)	(0.133)
R^2	0.432	0.405	0.399	0.427
n	406	406	406	405
Panel D: Non-Tradable Sector Employment				
Airport	0.117	0.247***	0.186**	0.195*
	(0.0764)	(0.0746)	(0.0782)	(0.105)
R^2	0.558	0.535	0.539	0.553
n	396	398	398	397
Panel E: Transportation Sector Employment				
Airport	0.183	0.203**	0.351***	0.372***
	(0.123)	(0.102)	(0.0983)	(0.132)
R^2	0.483	0.468	0.480	0.506
n	323	330	331	329
Controls:				
Pre-period Employment	Y	Y	Y	Y
Region	Y	Y	Y	Y
Geography/Transport	Y	Y	Y	Y

Notes: Table reports results of OLS regressions of log population/employment outcomes given above on an indicator variable for whether a CBSA has an airport, with various controls as indicated. Each specification represents one decade. Cluster-robust standard errors in parentheses clustered at the CBSA level. Pre-period controls include employment controls specific to the sector being analyzed, in log levels, for 1900 up to the base year, in ten year increments. For example, specification (3) includes log employment controls, by decade, through 1970 in ten year increments. (Log population is substituted for log employment in Panel A.) Region controls include dummy variables for each of the nine Census divisions and CBSA land area. Geography/transport includes controls for 1887 straight-line rail mileage, planned 1947 highway mileage, having a port, being a political capital city, mean January temperature, having a coastal location, and for close proximity to a river. Tradable sector employment is the sum of agricultural, mining, manufacturing, and wholesale trade sector employment. Non-tradable sector employment is the sum of retail trade, finance/insurance/real estate, business, professional and other services, construction, and public administration sector employment.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table A.12: Results: OLS Estimates of Airport Long Difference Effects By Census Region

	(1)	(2)	(3)	(4)
Census Region	Northeast	Midwest	South	West
Panel A: Population (All Persons, Age 15 - 64)				
Airport	0.125	0.281***	0.302***	0.147
	(0.102)	(0.0631)	(0.0871)	(0.134)
R^2	0.527	0.517	0.535	0.562
n	391	417	425	398
Panel B: Total Employment				
Airport	0.142	0.320***	0.377***	0.230*
	(0.105)	(0.0672)	(0.0955)	(0.134)
R^2	0.469	0.463	0.482	0.521
n	391	417	425	398
Panel C: Tradable Sector Employment				
Airport	0.0296	0.219**	0.496***	0.418***
	(0.126)	(0.0907)	(0.103)	(0.147)
R^2	0.404	0.387	0.413	0.471
n	389	415	423	396
Panel D: Non-Tradable Sector Employment				
Airport	0.110	0.288***	0.188**	0.0515
	(0.0998)	(0.0683)	(0.0805)	(0.107)
R^2	0.543	0.529	0.546	0.571
n	381	407	414	387
Panel E: Transportation Sector Employment				
Airport	0.0381	0.395***	0.177	0.402**
	(0.130)	(0.0849)	(0.118)	(0.179)
R^2	0.483	0.471	0.484	0.500
n	314	338	343	318
Controls:				
Pre-period Employment	Y	Y	Y	Y
Region	Y	Y	Y	Y
Geography/Transport	Y	Y	Y	Y

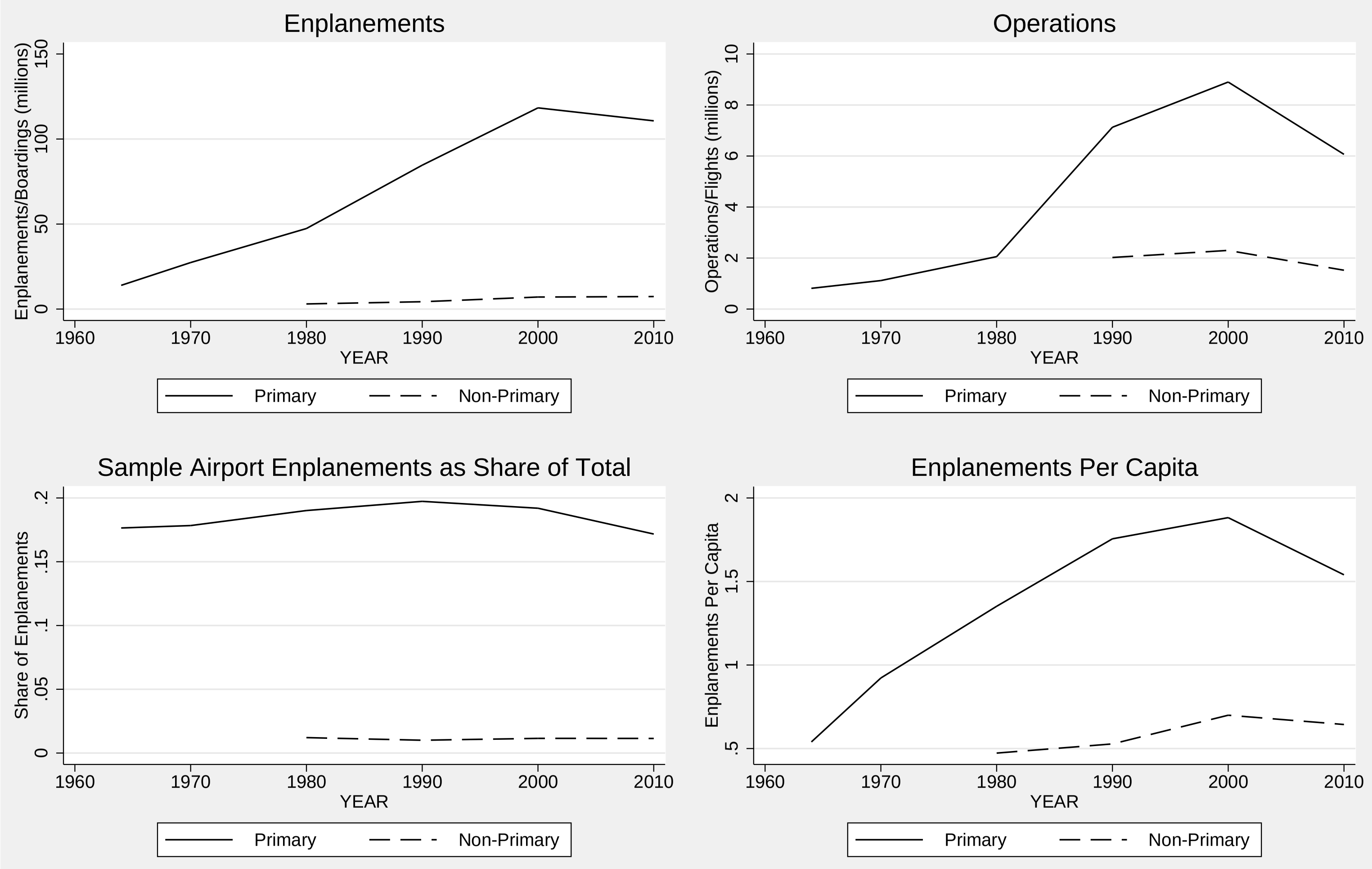
Notes: Table reports results of OLS regressions of log population/employment outcomes given above on an indicator variable for whether a CBSA has an airport, with various controls as indicated. Each specification represents one decade. Cluster-robust standard errors in parentheses clustered at the CBSA level. Pre-period controls include employment controls specific to the sector being analyzed, in log levels, for 1900 up to the base year, in ten year increments. For example, specification (3) includes log employment controls, by decade, through 1970 in ten year increments. (Log population is substituted for log employment in Panel A.) Region controls include dummy variables for each of the nine Census divisions and CBSA land area. Geography/transport includes controls for 1887 straight-line rail mileage, planned 1947 highway mileage, having a port, being a political capital city, mean January temperature, having a coastal location, and for close proximity to a river. Tradable sector employment is the sum of agricultural, mining, manufacturing, and wholesale trade sector employment. Non-tradable sector employment is the sum of retail trade, finance/insurance/real estate, business, professional and other services, construction, and public administration sector employment.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table A.13: Mean Airport Treatment Effects by Region and City Size (Synthetic Control)

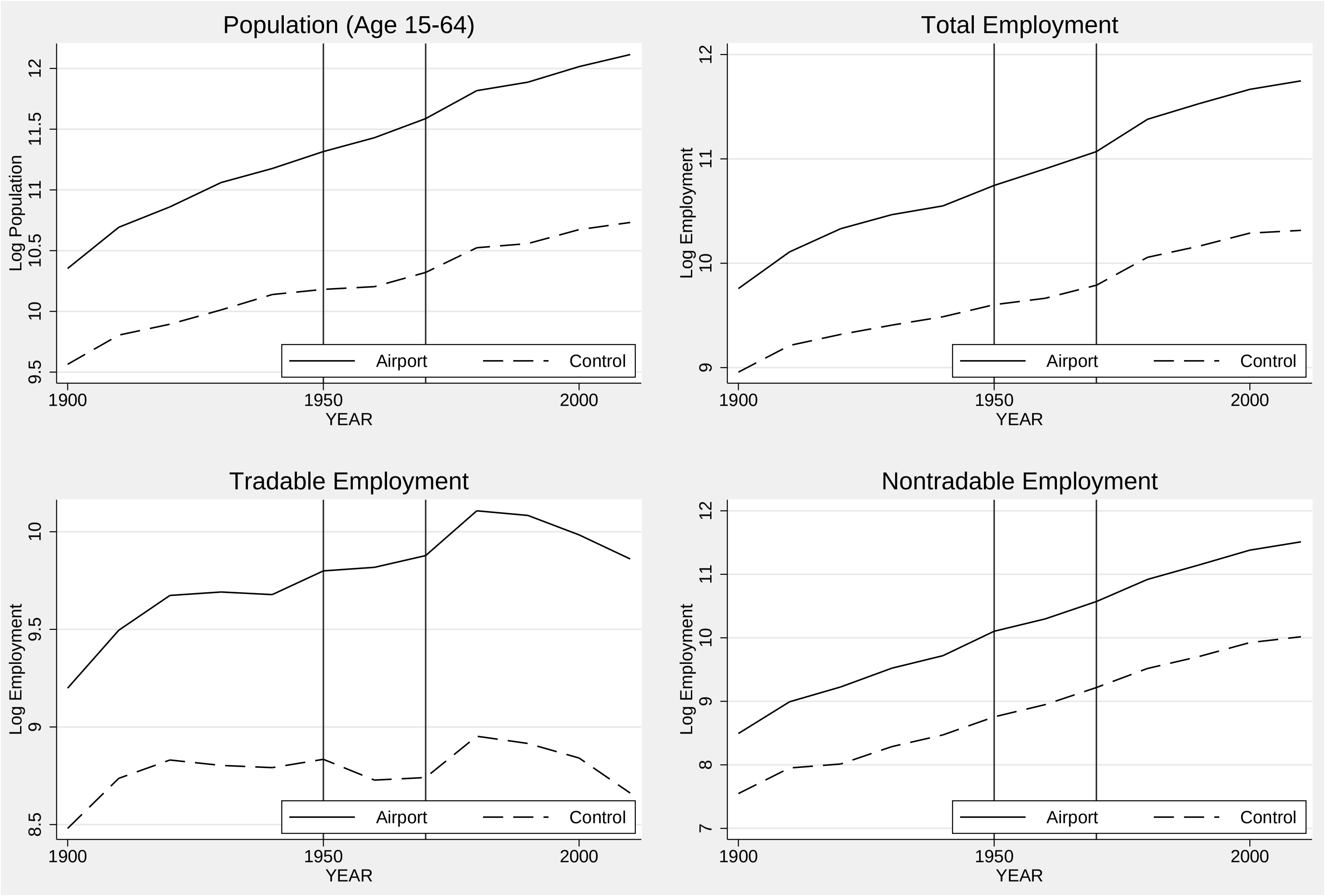
Region/Population Quartile in 1950	1	2	3	4	All Quartiles
Northeast		0.235	0.227	-0.110	0.117
Midwest	0.601	0.435	0.130	0.152	0.329
South	-0.240	0.099	0.046	0.266	0.043
West	-0.361		0.195	0.379	0.071
All Regions	0.000	0.256	0.150	0.172	0.147

Figure A.1: Enplanements and Operations at Sample Airports



Notes: Primary airports are airports for which a full series of traffic data is available since 1964. Non-primary airports are secondary commercial airports, mostly in smaller cities, for which traffic data was not available until 1980. One enplanement is equivalent to one passenger boarding one flight at an airport. One operation is equivalent to one flight taking off from or landing at an airport. Enplanements as a share of total is simply the quotient of enplanements in the 131 airports in the sample to total enplanements at all airports. Enplanements per capita is given by enplanements in a CBSA divided by total CBSA population.

Figure A.2: 1900-2010 Population and Employment, by CBSA Airport Status



Population (Age 15-64)

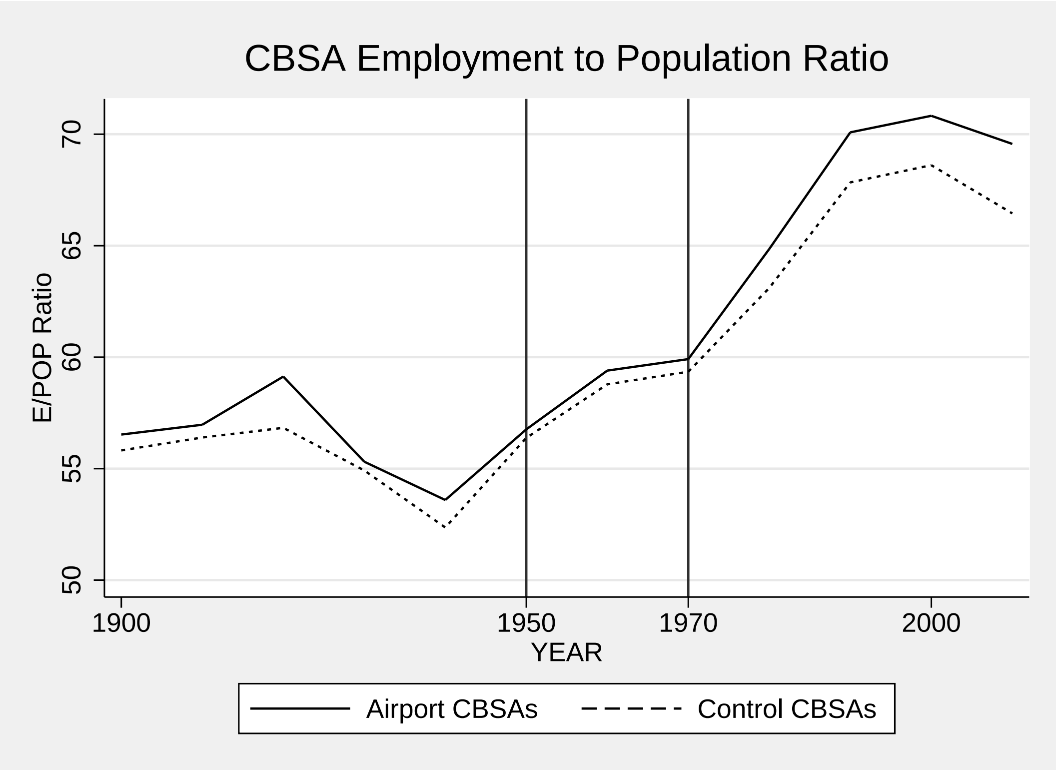
Total Employment

Tradable Employment

Nontradable Employment

Notes: Vertical bars at 1950 and 1970. Each series compares mean outcomes in CBSAs with airports to those without in the sample.

Figure A.3: Ratio of Employment to Population, Airport Versus Non-Airport CBSAs



Notes: Population is defined as all persons in CBSA, ages 15-64, as derived from Census files.

Figure A.4: Synthetic Control Estimated Treatment Effects: Population

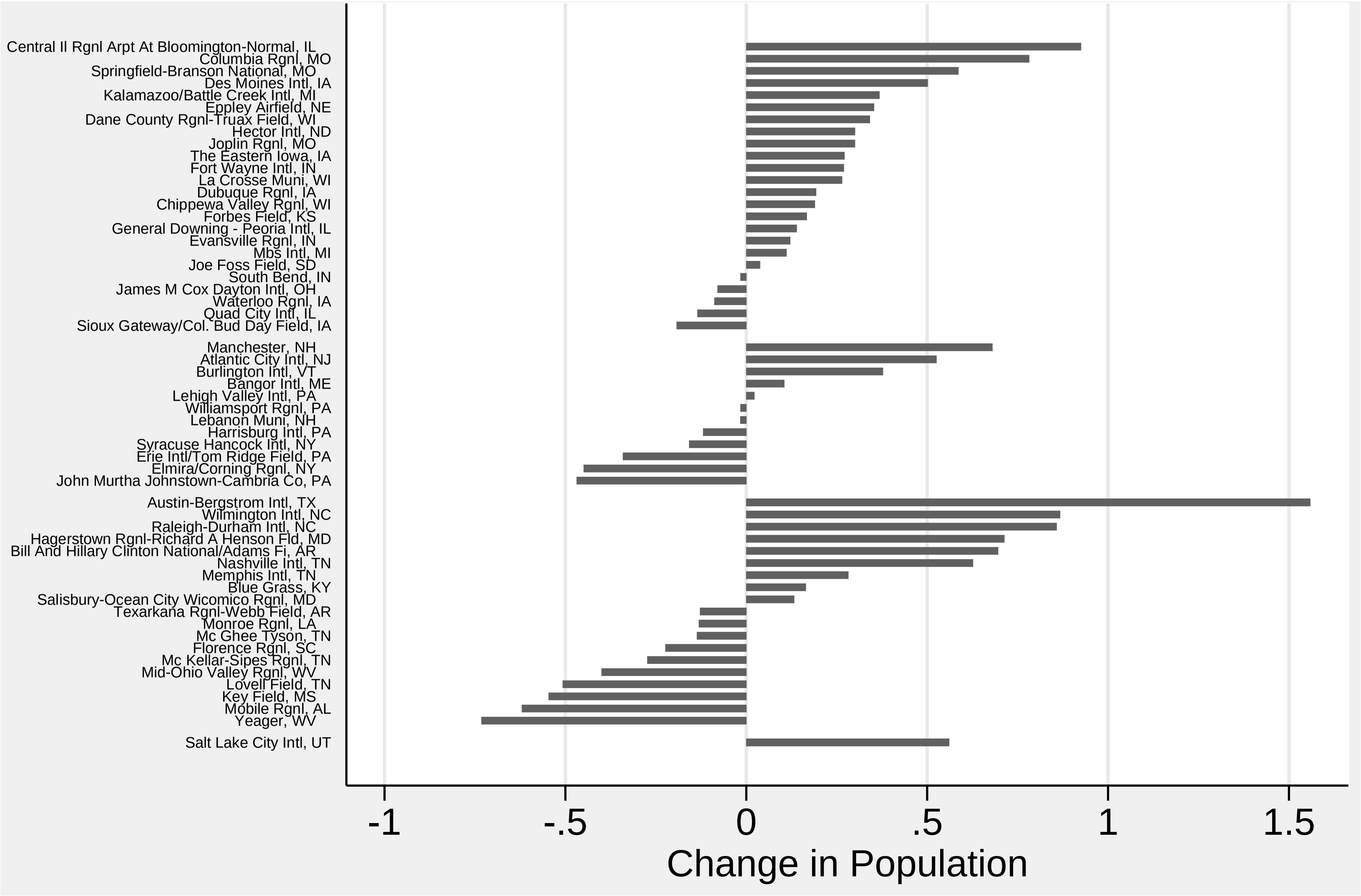
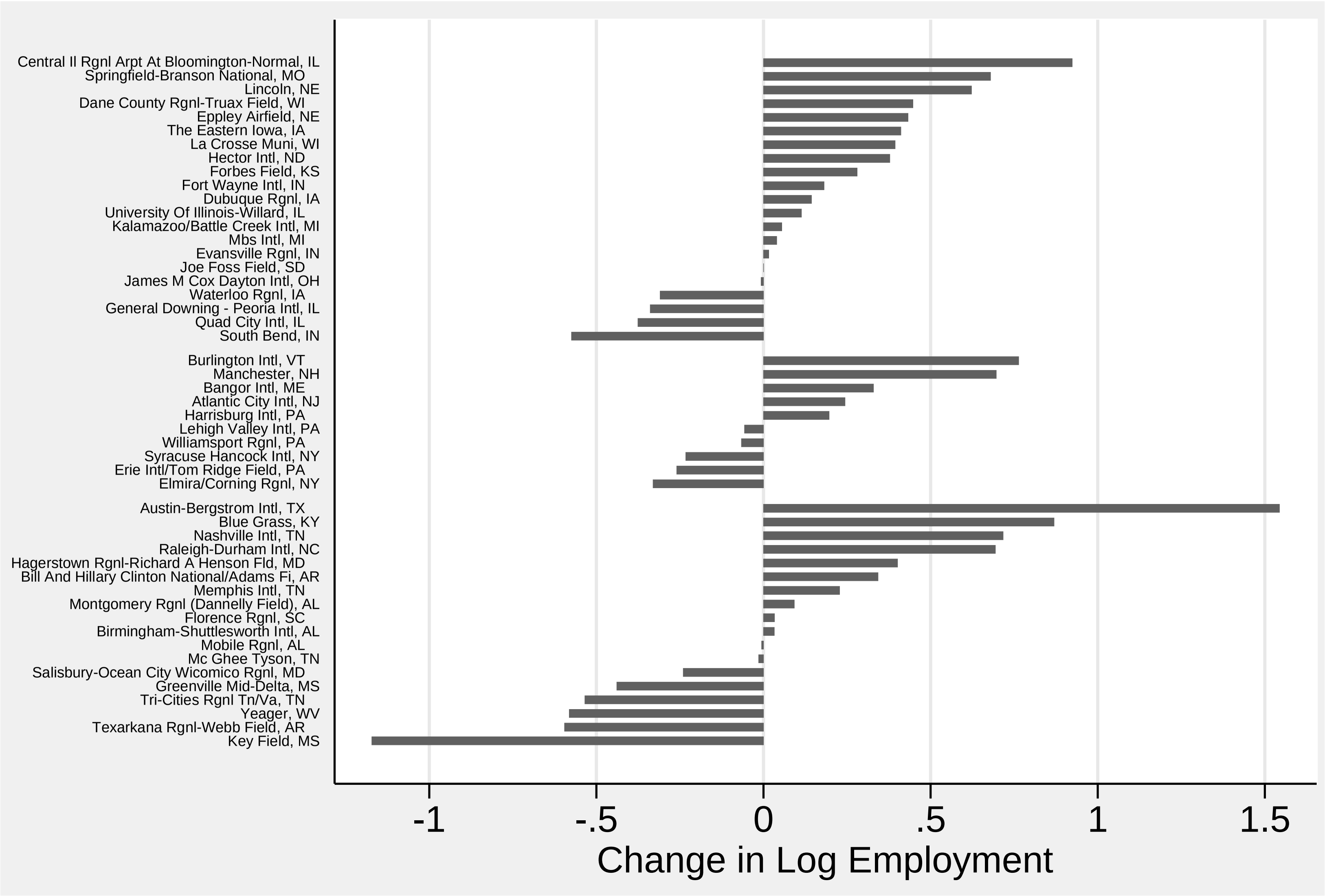


Figure A.5: Synthetic Control Estimated Treatment Effects: Employment



Appendix B

Additional Info - Air Hubs and Urban Development

This Appendix presents additional information on the hubs used in the study, as well as the historical activities (mergers, acquisitions, bankruptcies) that led to the hub openings and closings reference in the paper.

Below, I present the outcomes of a model estimated only with hubs affected by merger and/or acquisitions. I present both a panel model and event studies. Please see the main text for more details.

Table B.1: Study Hub Airport Characteristics

ID	Name	City	State	NDestNS	Enpl	Avg Tkt	Open	Closed
ATL	Hartsfield - Jackson Atlanta Intl	Atlanta	GA	190	24	163	1978	
BNA	Nashville Intl	Nashville	TN	129	3	153	1987	1995
CLE	Cleveland-Hopkins Intl	Cleveland	OH	123	3	163	1978	
CLT	Charlotte/Douglas Intl	Charlotte	NC	116	7	189	1979	
CMH	Port Columbus Intl	Columbus	OH	105	2	148	1991	2003
CVG	Cincinnati/Northern Kentucky Intl	Covington	KY	112	3	201	1986	
DAY	James M Cox Dayton Intl	Dayton	OH	82	1	171	1982	1992
DEN	Denver Intl	Denver	CO	143	14	163	1979	
DTW	Detroit Metropolitan Wayne County	Detroit	MI	130	9	155	1984	
GSO	Piedmont Triad Intl	Greensboro	NC	60	1	171	1993	1995
LAS	Mc Carran Intl	Las Vegas	NV	77	11	106	1986	2008
MCI	Kansas City Intl	Kansas City	MO	66	4	128	1983	1989
MEM	Memphis Intl	Memphis	TN	64	3	198	1985	
MKE	General Mitchell Intl	Milwaukee	WI	52	2	163	1985	
MSP	Minneapolis-St Paul Intl/Wold-Chamberlain	Minneapolis	MN	60	9	189	1978	
OMA	Eppley Airfield	Omaha	NE	36	1	151	1994	2009
PDX	Portland Intl	Portland	OR	38	4	131	1980	
PHL	Philadelphia Intl	Philadelphia	PA	46	7	182	1985	
PHX	Phoenix Sky Harbor Intl	Phoenix	AZ	39	11	116	1983	
PIT	Pittsburgh Intl	Pittsburgh	PA	39	6	182	1979	2003
RDU	Raleigh-Durham Intl	Raleigh/Durham	NC	27	3	185	1987	2003
RNO	Reno/Tahoe Intl	Reno	NV	18	2	99	1992	1999
SAN	San Diego Intl	San Diego	CA	22	5	103	1978	1988
SEA	Seattle-Tacoma Intl	Seattle	WA	22	8	140	1980	
SJC	Norman Y. Mineta San Jose Intl	San Jose	CA	11	3	112	1988	1999
SLC	Salt Lake City Intl	Salt Lake City	UT	13	5	155	1982	
STL	Lambert-St Louis Intl	St Louis	MO	12	8	143	1980	2009
SYR	Syracuse Hancock Intl	Syracuse	NY	6	1	163	1983	1991

Notes: ID = Airport location ID. NDestNS = Number of destinations that can be reached with a non-stop flight from the airport. Enpl = Enplanements (passenger boardings) in millions. Avg Tkt = (inflation-unadjusted) average one-way fare. Open = Year hub opened. Closed = Year Hub Closed. Dates of closures during or after year 2012 are not included.

Table B.2: Study Hub Potential (Control) Airport Characteristics

ID	Name	City	State	NDestNS	Enpl	Avg Tkt
ABQ	Albuquerque Intl Sunport	Albuquerque	NM	119	2	133
ALB	Albany Intl	Albany	NY	97	1	173
AUS	Austin-Bergstrom Intl	Austin	TX	113	2	139
BDL	Bradley Intl	Windsor Locks	CT	114	2	173
BHM	Birmingham-Shuttlesworth Intl	Birmingham	AL	99	1	160
BUF	Buffalo Niagara Intl	Buffalo	NY	95	2	137
DSM	Des Moines Intl	Des Moines	IA	69	1	177
ELP	El Paso Intl	El Paso	TX	70	1	138
GEG	Spokane Intl	Spokane	WA	60	1	134
ICT	Wichita Mid-Continent	Wichita	KS	50	0	179
IND	Indianapolis Intl	Indianapolis	IN	75	2	146
JAX	Jacksonville Intl	Jacksonville	FL	60	2	156
LIT	Bill And Hillary Clinton National/Adams Fi	Little Rock	AR	46	1	156
MSY	Louis Armstrong New Orleans Intl	New Orleans	LA	46	3	158
OKC	Will Rogers World	Oklahoma City	OK	37	1	160
PVD	Theodore Francis Green State	Providence	RI	23	1	174
ROC	Greater Rochester Intl	Rochester	NY	18	1	193
SAT	San Antonio Intl	San Antonio	TX	19	2	165
SDF	Louisville Intl-Standiford Field	Louisville	KY	16	1	154
SMF	Sacramento Intl	Sacramento	CA	9	3	125
TUL	Tulsa Intl	Tulsa	OK	3	1	189
TUS	Tucson Intl	Tucson	AZ	2	1	248

Notes: ID = Airport location ID. NDestNS = Number of destinations that can be reached with a non-stop flight from the airport. Enpl = Enplanements (passenger boardings) in millions. Avg Tkt = (inflation-unadjusted) average one-way fare. Open = Year hub opened. Closed = Year Hub Closed.

Table B.3: Results: Panel Regressions - Air Access Factors

	(1)	(2)	(3)	(4)
Panel A				
Log Boardings	0.337	0.369	0.389	0.299****
	(0.276)	(0.229)	(0.242)	(0.076)
N	918	918	918	918
R-Sq	0.812	0.857	0.869	0.952
Panel B				
Log Flights	0.374	0.345	0.353	0.281***
	(0.253)	(0.222)	(0.233)	(0.077)
N	918	918	918	918
R-Sq	0.795	0.823	0.835	0.927
Panel C				
Log Non-Stop Destinations	0.295***	0.135*	0.106	0.031
	(0.080)	(0.069)	(0.083)	(0.087)
N	908	908	908	908
R-Sq	0.943	0.958	0.971	0.965
Panel D				
Log One-Stop Destinations	0.132**	0.061	0.072	0.012
	(0.050)	(0.049)	(0.051)	(0.027)
N	918	918	918	918
R-Sq	0.987	0.992	0.993	0.995
Panel E				
Log Average One-Way Ticket Price	-0.146***	0.014	-0.004	-0.010
	(0.042)	(0.071)	(0.077)	(0.096)
N	918	918	918	918
R-Sq	0.470	0.746	0.805	0.786
City (Airport) FE	Y	Y	Y	Y
Time Trend (Linear and Quadratic)	N	Y	N	Y
Year FE	N	N	Y	N
City-Specific Trends	N	N	N	Y

Cluster robust standard errors in parentheses, clustered at the city (airport) level.
*** p<0.01, ** p<0.05, * p<0.1

Table B.4: Panel Regression Results: Population, Output and Wage Measures

	(1)	(2)	(3)	(4)
Panel A				
Log Population	-0.076	0.041	0.043	-0.012
	(0.063)	(0.048)	(0.051)	(0.015)
N	918	918	918	918
R-Sq	0.926	0.970	0.970	0.998
Panel B				
Log Personal Income	-0.477**	0.085	0.076	0.037**
	(0.194)	(0.057)	(0.057)	(0.015)
N	918	918	918	918
R-Sq	0.487	0.984	0.985	0.997
Panel C				
Log Per-Capita Personal Income	-0.401***	0.044***	0.033****	0.049**
	(0.141)	(0.014)	(0.009)	(0.018)
N	918	918	918	918
R-Sq	0.086	0.990	0.993	0.992
Panel D				
Log Earnings Per Worker	-0.354**	0.028	0.023	0.034****
	(0.129)	(0.024)	(0.024)	(0.009)
N	918	918	918	918
R-Sq	0.066	0.989	0.991	0.993
Panel E				
Log Payroll	-0.471**	0.039	0.041	0.008
	(0.212)	(0.086)	(0.092)	(0.022)
N	918	918	918	918
R-Sq	0.524	0.969	0.970	0.994
Panel F				
Log Payroll Per Worker	-0.335***	0.023	0.010	0.027*
	(0.117)	(0.030)	(0.029)	(0.013)
N	918	918	918	918
R-Sq	0.088	0.981	0.985	0.990
City (Airport) FE	Y	Y	Y	Y
Time Trend (Linear and Quadratic)	N	Y	N	Y
Year FE	N	N	Y	N
City-Specific Trends	N	N	N	Y

Cluster robust standard errors in parentheses, clustered at the city (airport) level.
*** p<0.01, ** p<0.05, * p<0.1

Table B.5: Panel Results: Sectoral Employment (1)

	(1)	(2)	(3)	(4)
Panel A				
Air Travel Employment	0.232	0.553****	0.608****	0.327**
	(0.170)	(0.092)	(0.085)	(0.137)
N	918	918	918	918
R-Sq	0.610	0.815	0.826	0.882
Panel B				
Wholesale Trade Employment	-0.091	-0.048	-0.037	-0.011
	(0.133)	(0.102)	(0.109)	(0.013)
N	918	918	918	918
R-Sq	0.901	0.925	0.928	0.981
Panel C				
Eating and Drinking Places	-0.223**	0.032	0.030	-0.007
	(0.085)	(0.038)	(0.038)	(0.023)
N	918	918	918	918
R-Sq	0.793	0.976	0.977	0.992
Panel D				
Hotels and Lodging	-0.063	0.078	0.079	0.087*
	(0.157)	(0.113)	(0.116)	(0.049)
N	918	918	918	918
R-Sq	0.907	0.948	0.949	0.973
Panel E				
Amusements and Recreation	-0.606****	-0.100	-0.059	-0.115**
	(0.135)	(0.068)	(0.079)	(0.044)
N	918	918	918	918
R-Sq	0.541	0.910	0.925	0.961
Panel F				
Museums, Zoos, Parks	-0.498	0.042	0.071	-0.156
	(0.406)	(0.227)	(0.234)	(0.241)
N	917	917	917	917
R-Sq	0.664	0.865	0.871	0.913
City (Airport) FE	Y	Y	Y	Y
Time Trend (Linear and Quadratic)	N	Y	N	Y
Year FE	N	N	Y	N
City-Specific Trends	N	N	N	Y

Cluster robust standard errors in parentheses, clustered at the city (airport) level.
*** p<0.01, ** p<0.05, * p<0.1

Table B.6: Panel Results: Sectoral Employment (2)

	(1)	(2)	(3)	(4)
Panel A				
Total Employment	-0.136	0.016	0.031	-0.019
	(0.099)	(0.057)	(0.064)	(0.016)
N	918	918	918	918
R-Sq	0.863	0.960	0.963	0.992
Panel B				
Tradables	0.000	-0.061	-0.001	-0.106
	(0.089)	(0.087)	(0.083)	(0.062)
N	918	918	918	918
R-Sq	0.812	0.820	0.940	0.863
Panel C				
Nontradables	-0.209*	0.011	0.022	-0.020
	(0.109)	(0.047)	(0.052)	(0.016)
N	918	918	918	918
R-Sq	0.791	0.974	0.976	0.993
Panel D				
Services	-0.298*	-0.004	0.013	-0.037****
	(0.146)	(0.050)	(0.057)	(0.004)
N	918	918	918	918
R-Sq	0.674	0.971	0.973	0.994
Panel E				
Finance, Insurance, Real Estate	-0.109	0.050	0.048	-0.018
	(0.085)	(0.067)	(0.064)	(0.046)
N	918	918	918	918
R-Sq	0.899	0.967	0.970	0.987
Panel F				
Retail Trade	-0.126	0.026	0.028	-0.012
	(0.074)	(0.042)	(0.043)	(0.023)
N	918	918	918	918
R-Sq	0.879	0.972	0.974	0.992
City (Airport) FE	Y	Y	Y	Y
Time Trend (Linear and Quadratic)	N	Y	N	Y
Year FE	N	N	Y	N
City-Specific Trends	N	N	N	Y

Cluster robust standard errors in parentheses, clustered at the city (airport) level.
*** p<0.01, ** p<0.05, * p<0.1

Table B.7: Panel Results: Sectoral Establishment Counts (1)

	(1)	(2)	(3)	(4)
Panel A				
Air Travel Establishments	-0.184	0.086*	0.075	0.083
	(0.140)	(0.046)	(0.050)	(0.066)
N	918	918	918	918
R-Sq	0.602	0.903	0.908	0.946
Panel B				
Wholesale Trade	0.014	-0.008	-0.005	-0.006
	(0.141)	(0.108)	(0.112)	(0.027)
N	918	918	918	918
R-Sq	0.915	0.949	0.954	0.991
Panel C				
Eating and Drinking Places	-0.140	0.059	0.043	0.019
	(0.103)	(0.057)	(0.054)	(0.015)
N	918	918	918	918
R-Sq	0.836	0.975	0.979	0.993
Panel D				
Hotels and Lodging	-0.071	0.094**	0.086**	0.050**
	(0.051)	(0.041)	(0.041)	(0.022)
N	918	918	918	918
R-Sq	0.838	0.937	0.940	0.980
Panel E				
Amusements and Recreation	-0.233	0.069	0.068	0.045***
	(0.151)	(0.065)	(0.069)	(0.015)
N	918	918	918	918
R-Sq	0.699	0.965	0.967	0.991
Panel F				
Museums, Zoos, Parks	-0.472***	0.030	0.045	-0.065
	(0.169)	(0.083)	(0.086)	(0.094)
N	901	901	901	901
R-Sq	0.583	0.902	0.909	0.937
City (Airport) FE	Y	Y	Y	Y
Time Trend (Linear and Quadratic)	N	Y	N	Y
Year FE	N	N	Y	N
City-Specific Trends	N	N	N	Y

Cluster robust standard errors in parentheses, clustered at the city (airport) level.
*** p<0.01, ** p<0.05, * p<0.1

Table B.8: Panel Results: Sectoral Establishment Counts (2)

	(1)	(2)	(3)	(4)
Panel A				
Total Establishments	-0.085	0.048	0.033	0.027
	(0.088)	(0.050)	(0.048)	(0.018)
N	918	918	918	918
R-Sq	0.887	0.976	0.979	0.994
Panel B				
Tradables	-0.019	-0.027	-0.012	-0.032
	(0.124)	(0.092)	(0.091)	(0.044)
N	918	918	918	918
R-Sq	0.910	0.936	0.963	0.967
Panel C				
Nontradables	-0.121	0.048	0.040	0.021
	(0.095)	(0.046)	(0.046)	(0.012)
N	918	918	918	918
R-Sq	0.854	0.979	0.980	0.996
Panel D				
Services	-0.177	0.044	0.033	0.020*
	(0.116)	(0.047)	(0.045)	(0.012)
N	918	918	918	918
R-Sq	0.784	0.980	0.982	0.997
Panel E				
Finance, Insurance, Real Estate	-0.203**	0.057**	0.062**	0.009
	(0.094)	(0.022)	(0.030)	(0.030)
N	918	918	918	918
R-Sq	0.762	0.970	0.976	0.988
Panel F				
Retail Trade	-0.023	0.039	0.024	0.014
	(0.069)	(0.051)	(0.046)	(0.020)
N	918	918	918	918
R-Sq	0.952	0.978	0.982	0.994
City (Airport) FE	Y	Y	Y	Y
Time Trend (Linear and Quadratic)	N	Y	N	Y
Year FE	N	N	Y	N
City-Specific Trends	N	N	N	Y

Cluster robust standard errors in parentheses, clustered at the city (airport) level.
*** p<0.01, ** p<0.05, * p<0.1

Figure B.1: Hub Closing Event Study - M&A Airports: CBSA - Air Travel Indicators

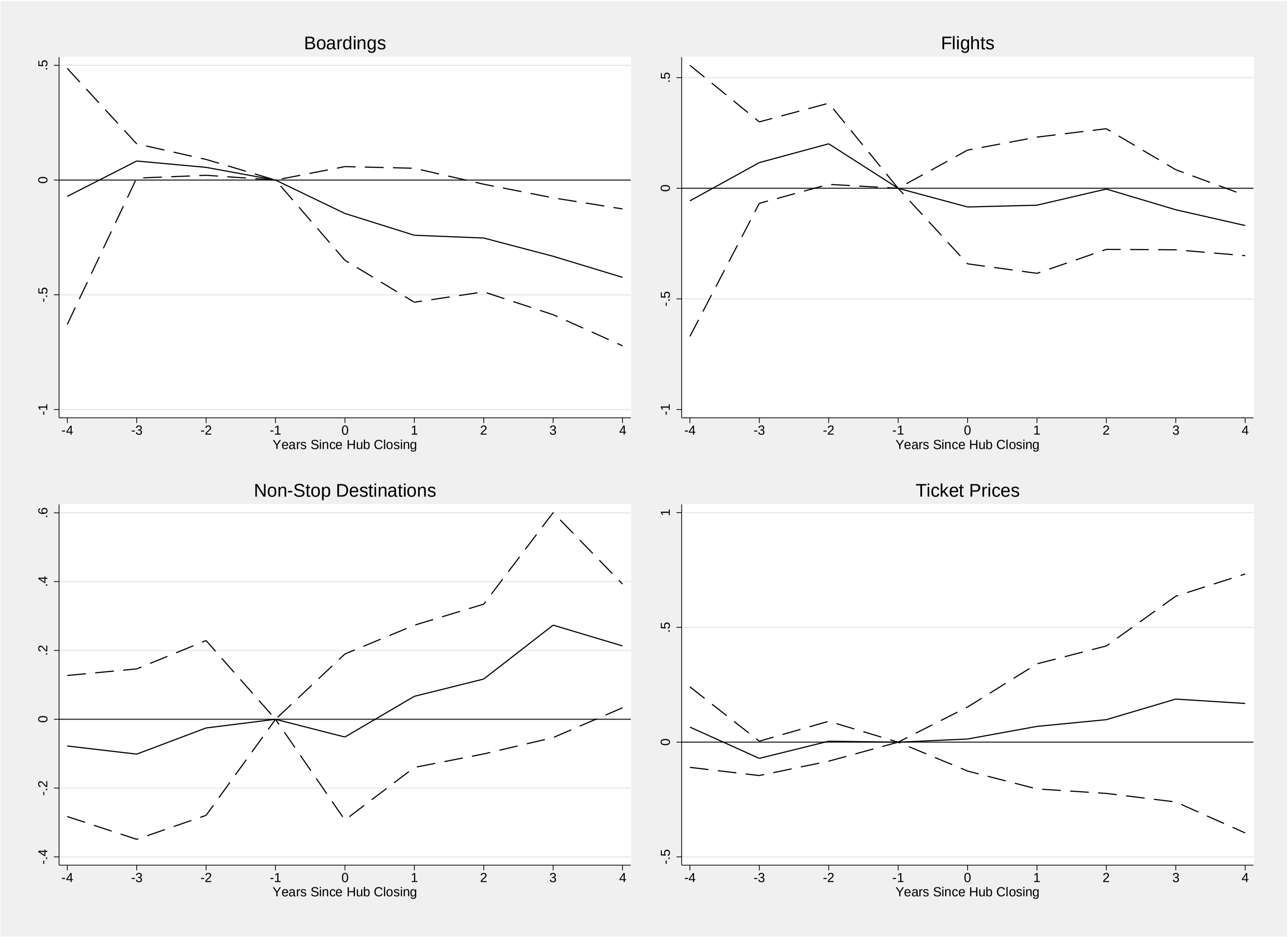


Figure shows event study outcomes on the quantities indicated above. Event studies include airport (city) and year fixed effects, as well as city specific trends. Standard errors are clustered at the city level. Dotted lines indicate 95 percent confidence intervals.

Figure B.2: Hub Closing Event Study - M&A Airports: CBSA - Local Economy Indicators

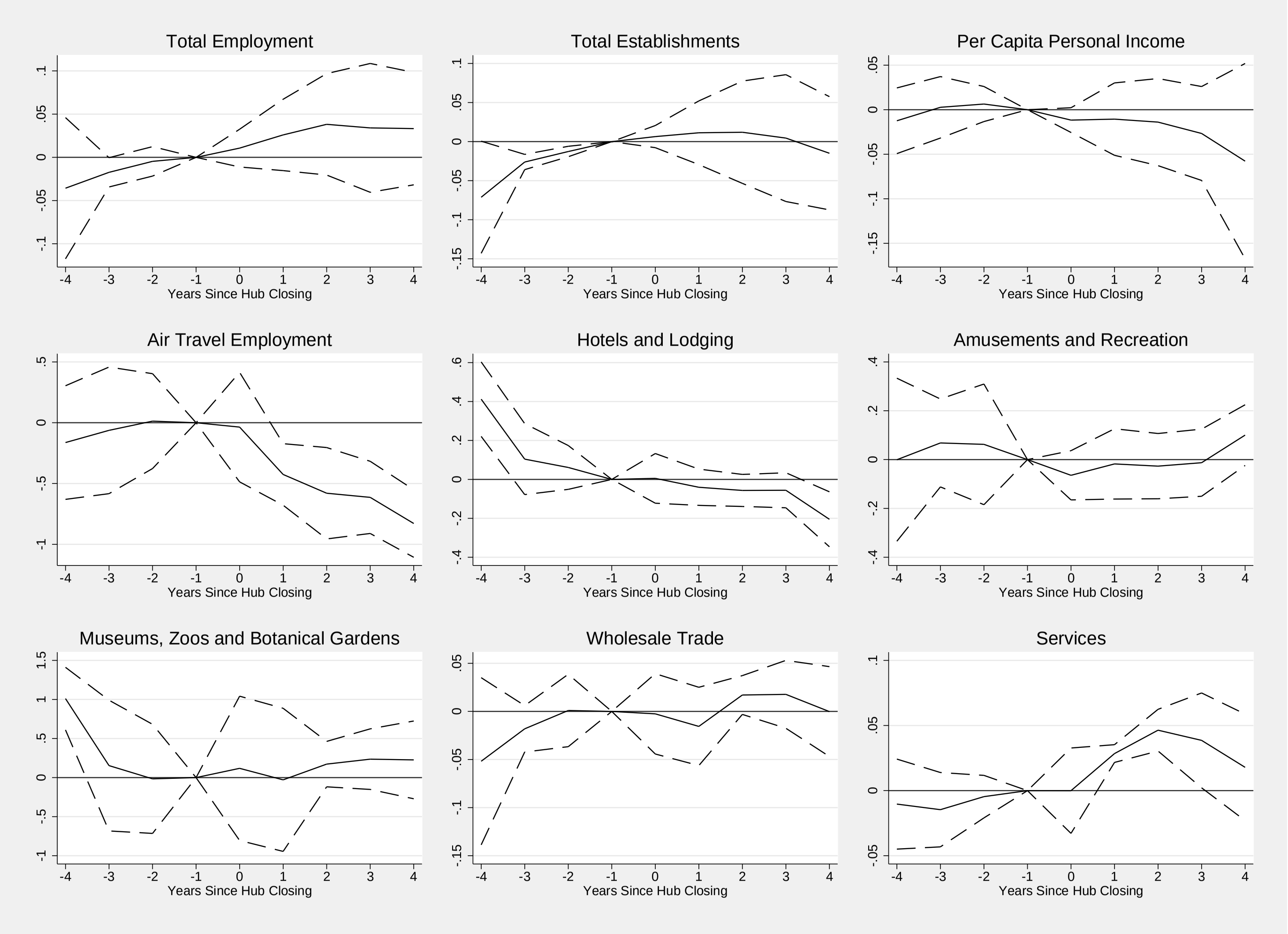


Figure shows event study outcomes on the quantities indicated above. Event studies include airport (city) and year fixed effects, as well as city specific trends. Standard errors are clustered at the city level. Dotted lines indicate 95 percent confidence intervals.

Appendix C

Additional Analysis - Green Schools

C.0.1 Nationwide Sample: Additional Location Characteristics

It is evident from Chapter 3, Figure 3.3 that some districts have only a few schools, while others have many more. Table C.1 shows that schools are highly concentrated in urban and suburban neighborhoods as opposed to non-green districts that are for the most part located in town or rural areas. Green districts did tend to be significantly closer to Sierra Club Chapters than non-green districts.[1] Thus, the presence of a Sierra Club chapter in the area could influence the presence of green policy or other environmental practices. Turning to other environmental influences, there was little difference in terms of voting for Nader in the 2000 U.S. Presidential election for the Green Party. Additionally, there was no difference seen in terms of voting for Democratic or Republican parties in the Presidential election. Green schools are also significantly closer to fault lines than non-green schools, possibly due to seismic activity increasing the necessity of building repairs and renovations.

Table C.1 shows that green school districts were also located in areas that had significantly more sunshine and solar radiation. Of the other climate variables examined, only cooling degree days seemed to be important. With respect to daylight, Energy Star supports increased natural lighting as a way to save energy and cites enhanced learning as a positive benefit. In addition, solar panels allegedly reduce energy expenditures by making use of solar radiation.[2] While electricity prices did not vary between green and non-green school districts, the fuel oil prices for both distillate and residual fuel did with higher prices present in green districts. This is important for districts in colder climates, many of which rely on older fuel-oil-based boilers to heat their buildings.

The location of green schools is dictated by a number of factors. In an effort to determine which factors are most important, I use a probit model, the results of which are shown in Appendix Table C.2. The dependent variable is the number of green schools. All models include district, locale, and census division fixed effects. In specification (1), I include only environmentalism - related factors. Green schools are significantly associated with proximity to a Sierra Club chapter, as well as the Green Party vote in 2000. However, upon the inclusion of controls for climate, such as heating and cooling degree days, solar radiation received, and the percent of sunny days in the district, only relative humidity remains significant. Proximity to the Sierra Club remains significant. In specification (3), I control for energy prices. Electricity, natural gas and fuel oil prices are significantly associated with the placement of green schools. Adding Census background

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[1] Founded in 1892, the Sierra Club is one of the nation's largest environmental organizations with 64 chapters nationwide and over 2.4 million members and supporters.

[2] Solar radiation was measured through Global Horizontal Irradiance (GHI), the sum of direct and diffuse radiation; direct radiation comes in a direct line from the sun while diffuse radiation is scattered from the direct beam by molecules and other objects. The National Renewable Energy Laboratory (NREL) uses images from weather satellites, daily snow cover, and monthly averages of atmospheric water vapor, trace gases, and the amount of aerosols in the atmosphere to calculate the total sun radiation on a surface. The direct beam radiation is then calculated using the atmospheric water vapor, trace gases, and aerosols. See https://developer.nrel.gov/docs/solar/solar-resource-v1/.

Table C.1: District-Level Climate and Energy Covariates

	Green Districts		Non-Green Districts	
	Mean	SD	Mean	SD
Environmental Attitudes				
Vote for Nader in 2000 (Green Party)	2.7	1.9	2.6	2
Distance to Fault Line (miles)	319	289	373	303
Distance to Sierra Club Chapter	70.7	55.7	90.1	58.4
Climate				
Heating Degree Days	167.8	71.2	172.5	69.1
Cooling Degree Days	43.6	28.3	40.7	26.4
Mean January Temp	32.4	11.7	31.7	11.2
July Humidity	53	13.6	55.2	12.2
Percent Possible Sunshine Received	61.43	8.63	59.58	7.77
Solar Radiation	4283	571	4182	507
Energy Prices (Dollars per million BTU)				
Electricity	19.4	4	19.4	3.96
Fuel Oil				
-Distillate	6.46	0.212	6.43	0.233
-Residual	2.62	0.339	2.52	0.322
N (district count)	722		8097	

Note: SD: Standard Deviation.

characteristics in in specification (4) does not change much. In specification (5), my preferred specification, proximity to the Sierra Club, cooling degree days, electricity price, fuel oil price, number of children in poverty, and the number of white students remain as the most important characteristics. Green schools are less likely in districts with larger numbers of black students, however. It is puzzling that in all five specifications, having a green school is negatively associated with electricity prices. However, districts do respond to heating oil prices as expected. Many schools, especially older ones, use fuel oil based heating systems to generate heat, explaining the importance of fuel oil prices in its association with the diffusion of green schools.

The presence of private schools in the district appears to have some effect on this. In Table C.3, I regress the number of green schools as of 2014 on the number of private schools as of 1990. This accounts for the conditions in place before the Energy Star program began. Specification (2) of Panel (B) shows that a one percent increase in the number of private schools leads to a 0.73 percent drop in the number of schools converted to green schools. This may be seen as a signaling tactic regarding education quality. In other words, districts appear to signal to parents that their green public school is just as good as a private school. This may serve as a preemptive tactic to preclude the possibility of additional private school capacity being created within the confines of the district. However, this evidence is admittedly weak at best.

C.0.2 California Sample - Location Factors

Repeating the probit exercise presented in Table C.2, I find that green schools in California are significantly more likely to be located near a fault line (suggesting that, perhaps greening a school is also related to other renovations a school building may need). Just as in the national sample, environmental advocacy organizations seem to be important – distance to the Sierra Club remains significant. Being located in a democratic Congressional district is also a strong predictor of where schools are located, at least in the first two specifications. This suggests that politics may drive some of the decisions on attitudes toward and placement of green schools.

California green schools tend to be located in parts of the state with higher January temperatures and lower humidity. They are more likely in places with higher percentages of children in poverty, and lower solar radiation receipt. That said, higher property values and incomes are associated with the presence of a green school. This discrepancy may speak to the level of inequality in these communities. Districts with higher shares of white students also appear more likely to receive the schools. This can be seen from the Table shown in Appendix Table C.4.

Table C.2: Results: Probit Model - Green Schools - Nationwide Sample

	(1)	(2)	(3)	(4)	(5)
VARIABLES	Dependent Variable: District Has Green School				
Log Distance to Fault Line	-0.0176	0.0316	0.0131	0.00366	-0.0303
	(0.0146)	(0.0259)	(0.0253)	(0.0264)	(0.0403)
Log Distance to Sierra Club Chapter	-0.167***	-0.169***	-0.168***	-0.121***	-0.145***
	(0.0370)	(0.0371)	(0.0373)	(0.0392)	(0.0545)
"Blue" Congressional District 1990	0.0321	0.0327	0.0603	0.0853	0.0106
	(0.0639)	(0.0648)	(0.0662)	(0.0683)	(0.102)
Vote for Green Party 2000	0.142**	0.0740	0.0931	0.0470	-0.0202
	(0.0609)	(0.0601)	(0.0578)	(0.0621)	(0.106)
Log Solar Radiation		-0.342	-0.457	-0.851	-0.311
		(1.014)	(1.043)	(1.105)	(1.723)
Log Cooling Degree Days		0.173	0.173	0.180	0.309*
		(0.120)	(0.120)	(0.128)	(0.169)
Log Heating Degree Days		0.108	0.0641	0.0538	-0.00719
		(0.198)	(0.204)	(0.207)	(0.308)
Log January High Temperature		0.323	0.230	0.156	-0.208
		(0.314)	(0.321)	(0.328)	(0.477)
Log Percent Sunshine		-1.106	-0.240	-0.0617	-0.680
		(0.721)	(0.762)	(0.806)	(1.235)
Log Relative Humidity		-1.127***	-0.762***	-0.846***	-0.580
		(0.231)	(0.258)	(0.265)	(0.379)
Log Electricity Price			-1.852***	-1.812***	-1.940***
			(0.306)	(0.319)	(0.537)
Log Natural Gas Price			1.129***	1.254***	0.723
			(0.417)	(0.437)	(0.677)
Log Residual Fuel Oil Price			0.794*	0.695	1.452**
			(0.463)	(0.472)	(0.693)
Log Bachelors Degree (1990)				0.0634	0.221
				(0.131)	(0.231)
Log Graduate Degree (1990)				0.146	-0.0554
				(0.0967)	(0.166)
Log Children in Poverty (1990)				0.0783	-0.226*
				(0.0994)	(0.123)
Log Median Housing Value (1990)				-0.220	-0.0610
				(0.136)	(0.248)
Log Median Household Income (1990)				0.461**	0.0991
				(0.197)	(0.371)
Log Number Public Schools (1990)					-0.186
					(0.185)
Log Number Private Schools (1990)					0.105
					(0.0755)
District FE	Y	Y	Y	Y	Y
Locale FE	Y	Y	Y	Y	Y
Census Division FE	Y	Y	Y	Y	Y
Observations	4,607	4,607	4,607	4,604	1,445
R-squared	0.0933	0.105	0.121	0.159	0.130

Cluster-robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table C.3: OLS, IV Regressions of Green School Intensity

Dependent Variable: Log Number Green Schools		
VARIABLES	(1)	(2)
Panel A: OLS		
Log Number of Private Schools	0.342***	-0.148
	(0.0769)	(0.112)
Observations	446	228
R-squared	0.275	0.512
Panel B: IV		
Log Number of Private Schools	-0.167	-0.730**
	(0.222)	(0.338)
Observations	429	223
R-squared	0.165	0.417
Panel C: First Stage		
Log Number of Catholics in County, 1950	0.136***	0.121***
	(0.0195)	(0.0259)
Log Total Number of Churches in County, 1950	0.0340	-0.00867
	(0.0412)	(0.0580)
Log Total Religious Adherents in County, 1950	-0.0851**	-0.110*
	(0.0417)	(0.0582)
Observations	2,701	1,398
R-squared	0.284	0.532
F-statistic	40.73	27.96
Controls	N	All
District, Division and Locale FE	Y	Y

Cluster robust standard errors in parentheses, clustered at the district level
*** p<0.01, ** p<0.05, * p<0.1

Table C.4: Probit - California Sample

PROBIT: Dependent Variable: Green vs Non-Green School			
VARIABLES	(1)	(2)	(3)
Log Distance to Fault	-0.135***	-0.0866***	0.0691
	(0.0223)	(0.0235)	(0.0585)
Log Distance to Sierra Club	-0.281***	-0.388***	-0.192
	(0.0473)	(0.0510)	(0.135)
Democratic District (1990)	0.822***	0.432***	0.265
	(0.0845)	(0.106)	(0.227)
Log Vote for Nader (2000)	-0.303*	-0.229	0.518
	(0.161)	(0.162)	(0.319)
Log Cooling Degree Days		0.678**	0.533
		(0.314)	(0.492)
Log Heating Degree Days		0.974*	2.074***
		(0.516)	(0.750)
Log January High Temperature		5.640***	11.43***
		(1.538)	(2.915)
Log Percent Possible Sunshine		1.137	-0.965
		(0.816)	(1.863)
Log Relative Humidity		-2.723**	-1.586
		(1.183)	(2.599)
Log Solar Radiation (GHI)		-4.442***	-3.743**
		(1.099)	(1.606)
Log Private Enrollment			-0.0305
			(0.0499)
Log Public Enrollment			-0.0788
			(0.129)
Log Children in Poverty			-0.151***
			(0.0553)
Log Median Housing Value			0.756**
			(0.315)
Log Median Household Income			-1.586***
			(0.611)
Constant	0.676***	14.91	-8.370
	(0.254)	(11.79)	(19.45)
Observations	2,463	2,463	863
R-squared	0.224	0.311	0.220

Cluster robust standard errors in parentheses, clustered at the district level
*** p<0.01, ** p<0.05, * p<0.1