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Does public infrastructure affect economic activity? Evidence from the rural interstate highway system

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Abstract

We examine the relationship between large infrastructure spending, of the type implied by interstate highway construction, and the level of economic activity. By collecting historical data on interstate highway construction and economic activity in the United States at the county level we find that highways have a differential impact across industries: certain industries grow as a result of reduced transportation costs, whereas others shrink as economic activity relocates. Additionally, we find that highways affect the spatial allocation of economic activity. They raise the level of economic activity in the counties that they pass directly through, but draw activity away from adjacent counties.

Keywords: Public infrastructure; Interstate highways and spatial analysis

JEL classification: H5; R4; O4

1. Introduction

On June 9th 1998, President Clinton signed into law the Transportation Equity Act; a $203 billion bill designed to improve the nation's highway infrastructure. Of this amount, $167 billion is allocated for highway construction. The justifica-

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tion for spending of this type comes from the theoretical belief that large-scale investments in public infrastructure, such as interstate highways, contribute to economic growth[1]. Unfortunately, empirical support for this hypothesis is extremely controversial, and consists of studies that are divided on both the magnitude and direction of the net effect of infrastructure spending on economic growth[2]. In addition, the impact of public infrastructure on economic activity in non-metropolitan areas remains unclear given that any economic impact may be prone to leak outside of small economic areas (Munnell, 1992; Rephann and Isserman, 1994). Such ''leakages'' are particularly likely for certain types of public investments, such as investments in transportation infrastructure. This is because investments in transportation infrastructure in non-metropolitan areas may cause some economic activity to shift from these areas to nearby metropolitan areas, as a result of lower transportation costs. Therefore, the net impact of such investments on aggregate output and earnings remains an empirical question. This theoretical possibility, along with the fact that interstate highways can cost almost twenty million dollars per mile in construction costs, challenges the strategy of making highway infrastructure investments in non-metropolitan areas as a means to stimulate growth[3].

The contribution of this paper is to offer an empirical assessment of whether large infrastructure spending, of the type implied by interstate highway construc-

[1]President Eisenhower commissioned the basic 42,500 miles of the Dwight D. Eisenhower System of Interstate and Defense Highways on June 29th 1956. Its estimated cost in 1996 dollars was over 329 billion. By 1960, 10 000 miles were opened, by 1970, 30 000 miles were open, and by 1980 over 80 000 miles were completed (United States Department of Transportation, 1976). Other countries have also undertaken enormous highway construction initiatives with the purpose of stimulating economic growth: the American system was inspired by the German Autobahn construction of the 1930s, and Canada's completion of the MacDonald-Cartier Freeway in the 1950s.

[2]Aschauer (1989), Munnell (1992), and Nadiri and Mamuneas (1994), argue that increases in public capital raise output growth. Empirically, this has been confirmed by Duffy-Deno and Eberts (1991), Garcia-Mila and McGuire (1992), Carlino and Voith (1992), and Morrison and Schwartz (1996). However, in a series of recent papers that criticize the econometric assumptions behind many of these studies Evans and Karras (1994), Holtz-Eakin (1994), Holtz-Eakin and Schwartz (1995a,b), and Holtz-Eakin and Lovely (1996) find little evidence of spillover effects from public sector investments, including state highways. Most recently, Dalenberg and Partridge (1997) study the relationship between public infrastructure and wages, and note that highways raise wages in manufacturing but cause declines in the size of the overall private sector.

[3]This emphasis on the economic development impacts of highways is to be contrasted to the practice of evaluating highway investments on the basis of national economic efficiency. Federal Highway Administration guidelines correctly evaluate projects based on benefit–cost comparisons using national road user benefits such as the value of time savings and accident reduction (United States Department of Transportation, 1995). However, despite the advantages of evaluating highway project impacts on national economic efficiency, it is evident that local economic development impacts are a motivation for highway investment. For example, Rephann and Isserman (1994) note that regional development goals were a primary motivation for highway investments undertaken by the Appalachian Regional Commission.

tion, has an impact on economic growth. Our choice of highways is not accidental: Highways are seen as being the quintessential public sector investment in much of the theoretical literature on economic growth; see, for example, Barro and Sala-i-Martin (1995). This paper is undertaken in the light of the new highway spending bill, the surrounding allegations of highway investments as ''pork,'' and the growing attention given to ''infrastructure'' debates in the popular and academic presses. To answer this question we use improved historical data on interstate highway construction and economic activity in the United States from 1969 to 1993. Unlike previous studies that have pursued their analysis at the level of a specific state, we conduct our examination at the county level using data from the entire continental United States. In our analysis we study the assumption that the incidence of a new highway is an exogenous event, unrelated to past economic growth. Furthermore, we study the hypothesis that highways have a differential impact across industries as certain industries will grow as a result of reduced transportation costs, whereas others will shrink as economic activity now relocates to other areas. Additionally, we analyze the conjecture that highways affect the level of economic activity in the counties that they pass through, but draw activity away from adjacent counties, thereby having an ambiguous effect on the level of net regional economic activity.

Our focus will be on non-metropolitan counties and regions. This geographical focus is important in its own right for those interested in non-metropolitan economic development. In addition, our focus is important because of the greater potential for endogeneity-induced bias in metropolitan counties receiving new highways. Non-metropolitan counties often receive an interstate because they happen to fall in the route between cities that have been selected to receive a new highway. But, metropolitan areas can be specifically chosen to receive a new highway due to their size, their rate of growth, or to alleviate congestion on existing highways. Thus, an empirical assessment of the relationship between highway construction and growth, that ignores the endogeneity issue, may be prone to incorrectly characterize the relationship between new highways and economic growth. And, to the extent that regions receive new highways due to more rapid growth, an empirical assessment could incorrectly conclude that the opening of a new highway affects growth positively. Our paper exploits the quasi-experimental nature of highway construction by demonstrating that highways are exogenous to the non-metropolitan counties that they run through.

Our empirical results may be summarized as follows: We find evidence that it is correct to treat new interstate highway construction as an exogenous public-infrastructure shock to non-metropolitan counties. New interstate highways raise earnings in counties that benefit directly from the new construction, relative to counties that did not receive such infrastructure. For total earnings, this cumulative growth premium ranges 6–8% 24 years after the initial opening. For such counties, earnings grew by 5–8% in the services and retail industries over the same period. However, in counties that are adjacent to highway counties, total earnings fell by

1–3%, while earnings in retail fell by 8–11%. Using estimates derived from a seemingly unrelated fixed-effects model, the net effect of a new interstate on regional growth is found to be essentially zero.

The next section of this paper provides a theoretical model of how a new highway affects earnings growth. The model provides an explanation for why the impact of a new highway will differ across industries, and on whether the highway runs through a county or is adjacent to it. In Section 3, we provide an extensive discussion of the data used in this analysis. We develop the econometric model and its extensions and discuss econometric complications that may arise in its application to the problem under study. Regression results and extensions are examined in the fourth section, and the fifth section offers concluding comments.

2. Theory

Several studies examining the contribution of public capital stock to state or metropolitan output have specifically examined the impact of transportation investment. Keeler and Ying (1988) provide a thorough introduction to this literature, and document the positive effect of interstate highways on productivity growth in the trucking industry. Their analysis however, is restricted to regions and to the trucking industry and therefore precludes the identification of the spatial general-equilibrium effects that we seek to discover. Garcia-Mila and McGuire (1992) find that greater expenditures on highways increased the output of state economies. Carlino and Mills (1987) find that greater interstate highway density was associated with higher levels of manufacturing employment and total employment in counties overall. Carlino and Voith (1992) note that more highway miles increased productivity in state economies. These findings support the contention that highway stock, and therefore, new highway investment, increases output in state economies. Recently, however, Holtz-Eakin (1994) has criticized the empirical content of these papers, and has argued that previous findings of a positive impact of public capital stock may have arisen due to a failure to account for the endogeneity of public capital stock. After all, more productive states could easily be spending more on public capital. By controlling for unobserved, state-specific characteristics Holtz-Eakin effectively demonstrates that there is no relationship between *aggregate* public-sector capital and private sector productivity. A careful study by Evans and Karras (1994) using similar methods also arrives at similar conclusions.

Recent studies focused on the impact of highway improvements on county economies have found limited evidence that highway investments increase the size of local economies. Given that data on output are not generally available for rural counties, these studies have focused on changes in income or employment. Stephanades (1990) and Stephanades and Eagle (1986) find that highway spending increases economic growth in urban counties. However, both these studies relied on inferences made from a limited group of industries in the state of Minnesota, and as discussed below, ignore the possible endogeneity of highway spending. Thompson et al. (1992) did not find that job growth or per capita income in Florida counties was a function of highway spending. Using a quasi-experimental approach instead of regression analysis, Rephann and Isserman (1994) find that new interstate highways have a significant impact on earnings in services, retail trade, manufacturing, and in transportation and public utilities (TCPU) in counties near an urban area. In counties that had medium-sized towns (population above 25 000) but were not near an urban area, a significant and positive impact was identified for retail trade industries and government. However, for counties far from cities and without a medium-sized town, a new highway had a significant impact only on retail trade earnings, and the impact was smaller in percentage terms than the retail trade impact in the other highway counties. Rephann and Isserman (1994) also looked at counties that are adjacent to counties with a new interstate highway. A highway opening did not have a positive and significant impact on earnings in these adjacent counties. Looking at existing rather than new highways, Goode and Hastings (1989) find results similar to Rephann and Isserman. The authors find that proximity to a limited access highway had a positive impact on manufacturing plant location in small metropolitan counties, but not in non-metropolitan counties.

Despite the results from Holtz-Eakin, and Evans and Karras which demonstrate no relationship between infrastructure investments and *aggregate* performance, we have reason to expect that a highway investment can help *specific* industries in the region gain a competitive advantage over other regions of the country. We therefore separate our analysis by industry, to test this conjecture. As demonstrated below, through a spatial competition model based on Hotelling (1929), Kraft et al. (1971) and Rephann (1993), the magnitude and direction of this effect will depend on the extent to which a given industry's output is traded nationally or regionally. Additionally, as was found by Rephann and Isserman (1994), a new highway may also reorganize activity within the region by concentrating growth in retail and service industries in counties that the new interstate highway passes through.

2.1. Regionally traded goods

Assume that a firm i competes for customers for its regionally traded goods along two highways, one headed north and south (Route 1), and the other headed east and west (Route 2), as pictured in Fig. 1. Competitors and customers are located along the two routes. Along Route 2, focus on firm i's interaction with one of its competitors for regionally traded goods or services, firm j, which is located to the east. The distance between firms i and j is defined by the Euclidean metric D_{ij}. The on-site cost of purchase from firm i is C_i, while the cost from firm j is C_j. The travel costs along Route 2 are T_2 per mile. There will exist an individual customer p^1 located between firm i and firm j that would be indifferent between

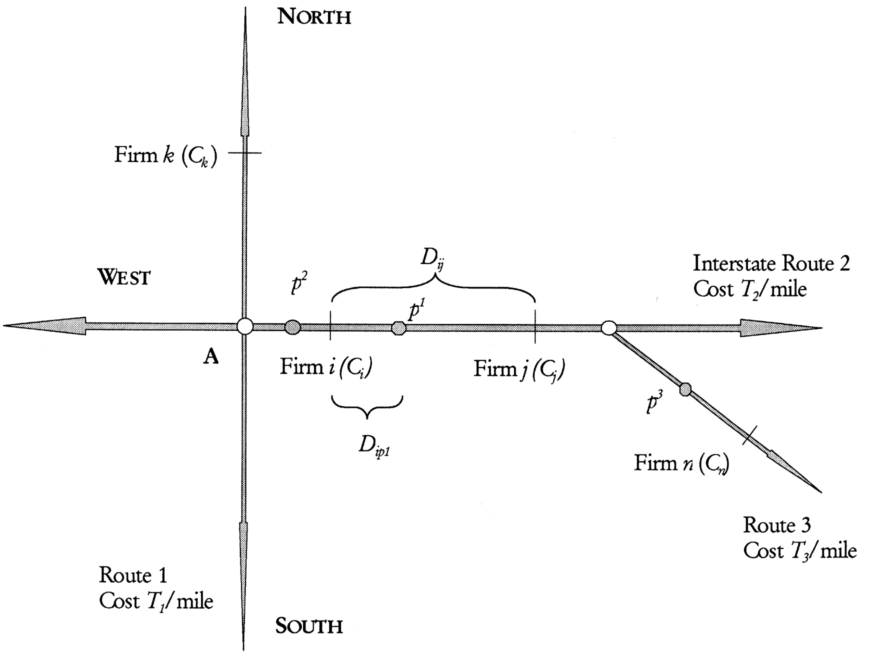

Fig. 1. Relationship between new highways and economic growth.

purchasing from the two firms. Mathematically, customer p^1 would be located at a distance D_{ip1} from firm i and a distance $D_{ij} - D_{ip1}$ from firm j such that:

$$C_i + T_2 D_{ip1} = C_j + T_2(D_{ij} - D_{ip1}) \tag{1}$$

Given C_i and C_j, the total cost of traveling to firm i and purchasing the good or service is the same as the total cost of traveling to firm j and purchasing the good or service. Similarly, the cost for the two firms upon delivery to customer p^1 would be the same. Firm i will capture all customers indexed by p such that $D_{ip} < D_{ip1}$, that is, where the customers are closer to firm i than the indifferent customer. Similarly, firm j will capture all customers where $D_{ip1} < D_{ip}$.

The location of the market boundary at the indifferent customer, D_{ip1}, is determined by the difference in the cost of purchase at firms i and j, and the travel cost T_2. To see this, rearrange the terms in Eq. (1), such that:

$$C_i - C_j = T_2(D_{ij} - 2D_{ip1}) \tag{2}$$

If firm i has lower on-site purchase costs so that the left hand side of Eq. (2) is negative, then for the right hand side to be negative it must be true that

$D_{ip1} > D_{ij}/2$. In other words, it must be true that firm *i* captures customers along more than one-half of the section of Route 2 between firm *i* and firm *j*. This is a restatement of the standard result that the lower cost producers have a wider market area.

Now consider the impact on the location of the market boundary (i.e. the change in the position of the marginal consumer) should there be an improvement in Route 2, so that T_2 falls. Using Eq. (2) and invoking the implicit function theorem yields the following relationship:

$$\mathrm{d}D_{ip1}/\mathrm{d}T_2 = (D_{ij} - 2D_{ip1})/2T_2 \tag{3}$$

We model the construction of a new highway as a fall in transportation costs. The impact of falling transportation costs on the movement of the market boundary depends on the initial value of D_{ip1}. If $D_{ip1} > D_{ij}/2$, as is the case when firm *i* has a lower on-site purchase cost, that is, when $C_i < C_j$, then the value of D_{ip1} rises as transportation costs fall. The market area of the lower cost firm increases as transportation costs fall, implying that high transportation costs protect the market of the high cost firm. The fortunes of a firm located along an improved highway with regards to regionally traded goods and services will depend on whether that firm has lower production costs.

The situation for regionally traded goods and services is somewhat different for regional firms located some distance away from the improved highway (for example, located in counties that are adjacent to the highway county). In particular, such firms would be even more likely to lose customers due to the highway improvement. An example of such a firm, firm *k*, is also labeled in Fig. 1. The indifferent customer between firms *i* and *k* is p^2. If p^2 is located along Route 2, then firm *i* will gain customers from firm *k* when Route 2 is improved as long as $C_k + T_1 D_{kA}, < C_i$, where $T_1\ D_{kA}$ is the travel cost from firm *k* to the crossroads at Point *A*. Firm *k* will need to have a lower cost of purchase delivered to point *A* if it is to gain customers due to the improvement to Route 2. Thus, even if p^2 lies on the improved highway Route 2, firm *k* will need to have much lower production costs in order gain customers to firm *i*. This suggests that in many cases firms like firm *k* that are located some distance away from the improved highway will lose customers for regionally traded goods and services to competitors located on the improved highway. To further bolster this point, it should be pointed out that if p^2 is located along Route 1, then firm *k* will certainly lose customers. This is evident in the following discussion for the case of nationally traded goods and services.

2.2. Nationally traded goods

For nationally traded goods and services, the implications of the model are quite different than with regionally traded goods and services. The term ‘nationally traded goods and services’ refers to goods and services that are traded between regions, and perhaps nationally, rather than just within the highway region. In this case, firm i would face a competitor, firm n, that does not use the improved highway when travelling to customers, or at least, when travelling to most customers around the nation. Examining customers in a different region far to the southeast of firm i's region, there would be a customer p^3 who would be indifferent between purchasing from firm i or firm n, given C_i and C_n. This situation is also illustrated in Fig. 1.

Mathematically, customer p^3 would be located at a distance D_{ip3} from firm i and a distance $D_{in} - D_{ip3}$ from firm n such that:

$$C_i + T_{2*}D_{ip3} = C_n + T_3(D_{in} - D_{ip3}) \tag{4}$$

D_{in} is the distance between firm i and firm n. The cost per mile T_{2*} indicates that the travel cost to reach customer p^3 is a weighted average of travel costs on Routes 2 and 3[4]. Firm i will capture all customers where $D_{ip} < D_{ip3}$, that is, where the customers are closer to firm i than the indifferent customer. Similarly, firm n will capture all customers where $D_{ip3} < D_{ip}$. Note that the two firms have different average travel costs. To consider the impact of an improvement in Route 2 on the location of the market boundary between firm i and firm n, rearrange the terms in Eq. (4) such that:

$$C_i - C_n = T_3(D_{in} - D_{ip3}) - T_{2*}D_{ip3} \tag{5}$$

Invoking the implicit function theorem yields the following relationship:

$$\mathrm{d}D_{ip3}/\mathrm{d}T_{2*} = -D_{ip3}/(T_{2*} + T_3) \tag{6}$$

Eq. (6) indicates that a decline in transportation costs along Route 2 would cause the market area to increase for the nationally traded goods and services of firm i[5]. The market area also would increase for the nationally traded goods and services of firms such as firm k which are located some distance from Route 2, but would utilize Route 2 to reach many of their national customers. Thus, businesses in a region receiving a highway improvement or a new interstate highway should expect to see an increase in market area for nationally traded goods.

Overall, our model predicts that the growth of a firm within a region receiving a highway improvement will depend on whether that firm: (1) is a low cost producer, (2) is located near the improved highway, and (3) specializes in

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[4]This weight will change whenever travel costs change along Route 2 since such a change in travel costs will also move the market boundary p^3. However, it is unambiguous that a decrease in T_2 will lead to a decrease in T_{2*}, even with the changing weight. As is seen in Eq. (6), a decrease in T_2 would cause p^3 to move further from firm i, which would tend to offset the drop in T_{2*} in cases where travel costs are higher on Route 3 than Route 2. However, the offset could not cause T_{2*} to actually increase since overall delivered costs past p^3 must fall in order to capture customers from firm n.

[5]More precisely, this is always the case for all competitive situations similar to that picture in Fig. 1. That is, in all cases where the indifferent customer p^3 is not located along Route 2.

regionally or nationally traded goods and services. A firm that specializes in a nationally traded goods or services, such as manufacturing goods will expand if there is a highway improvement in the region in which it is located. A firm that specializes in regionally traded goods and is located along the improved highway will expand if it is a low cost producer and contract if it is a high cost producer. A firm that specializes in regionally traded goods and is located adjacent to the improved highway would tend to contract unless it is a very low cost producer. For non-metropolitan counties in regions receiving a new interstate highway, this suggests that the county's manufacturing firms would expand, but the relationship to growth in its regionally oriented retail and service firms is ambiguous. We predict that retail and service firms located in counties adjacent to an improved interstate would be particularly likely to contract.

3. Data and econometric model

3.1. Data

To empirically assess the relationship between new highways and economic growth we use data on the set of non-metropolitan counties in United States that received an interstate highway after 1969, the set of non-metropolitan counties adjacent to these counties receiving a highway, and the set of non-metropolitan counties that never had an interstate and are not adjacent to a county receiving an interstate as of January 1, 1994[6]. Depending on the specification, the first two sets of counties constitute the treatment group for our regression analysis, and the set of counties that were neither highway nor adjacent counties and that had not received an interstate highway were used as the control group in the regressions. Non-metropolitan counties that received an interstate highway before 1969 were not included in the dataset, as they add no informational content to our estimation.

County, state, and national earnings by 1-digit SIC group industry were available for the years 1969 through 1993 from the U.S. Department of Commerce's Regional Economic Information System (United States Department of Commerce, 1995). Even at the county level, this data contains few suppressed

[6]The share of total personal income produced by non-metropolitan areas has remained surprisingly stable over time (approximately 17%), while their share of total employment has fallen by a little over 1 percentage-point over the 1969–1993 time period to 18.7% in 1993. Metropolitan areas produce more than 80% of TPI but there is substantial variation in these numbers across states. Some states in our sample that received interstate highways have non-metropolitan areas that produce almost 50% of state personal income (in Kentucky, Louisiana, Montana, South Dakota, and West Virginia). In others, (Colorado, Florida, Illinois, Georgia, Missouri) the share is less than 30%. We included only those observations that comprised non-MSA counties in the continental United States. Therefore, we excluded any data on highway construction in Alaska, Hawaii, Samoa, Guam, North Mariannas, Puerto Rico, and the Virgin Islands.

values for 1-digit SIC code industries. For most industries, the occasional suppressed value was not expected to be a source of bias in the fixed-effects model. However, suppressed values were very common in the mining, wholesale trade, and agriculture, forestry, and fisheries industries. As a result, we do not conduct a regression analysis for these three industries.

Counties that had received a highway in a given year were identified using PR-511 data (United States Department of Transportation, 1996) from the U.S. Department of Transportation[7]. Opening dates were verified using annual Rand-McNally maps from the study period[8]. These efforts, while greatly time-intensive, significantly improved the accuracy of the opening dates. Because mismeasured data tend to bias least-squares coefficients towards zero, our analysis resulted in parameter estimates that were significantly superior to those obtained using unverified PR-511 data. In total, 185 non-metropolitan counties were identified which received one highway after 1969 but did not have a highway before that date. Seventeen percent of our sample received the highway ''treatment'' in 1969, and 80% of our sample received a new highway prior to 1977. Because the bulk of new highway construction associated with the basic 42 500 miles of the Eisenhower System was completed in the 1960s, the observed distribution of opening dates is consistent with the historical record. Corresponding to these 185 highway counties, our sample also yielded a set of 391 adjacent counties[9]. Pooled counties are comprised of the combined sample of highway and adjacent counties.

[7]The PR-511 data contain the universe of interstate highway construction operations for the United States. They provide three potential measures of a highway's opening date in a given county. The data-fields of interest were: the date record proceeded from construction to open status; the date record proceeded from adequate for traffic, additional work still necessary, to open to traffic; and the date record proceeded from construction to open to traffic, additional work necessary. In principle, the data should logically contain an entry for each field listed above for a given highway segment. Unfortunately, this is often not the case; several records are observed in only one of the above statuses. We therefore selected the open date for a given highway segment to be the earliest date of the above three fields. To determine when the highway opened in a given county (as opposed to a given segment), we picked the earliest opening date out of all segments in a given county. We also experimented with alternative ways to determine opening dates, by examining other methods such as last opening date of all segments, or the median opening date of all segments. Our empirical results are insensitive to these modifications.

[8]For 30 counties in the PR-511 data set we were unable to identify any open dates based on these criteria. To circumvent this problem, we consulted historical atlases from the Rand-McNally Corporation. From the PR-511 tape we knew the county and route, and we searched the Rand-McNally maps for when the given route appeared in a county. To adjust for publication lags we set the open date to the year prior to the published printing year of the relevant Rand-McNally map. In addition, on the PR-511 tape, we found 25 counties that in actuality did not have the putative highway pass through it. This determination was made after verifying that each county on the PR-511 tape actually had the reported highway pass through it. The verification process used the Rand-McNally atlases.

[9]Adjacent counties include only those adjacent counties that were non-metropolitan, and were not highway counties themselves. This restriction ensures us that we isolate a pure ''treatment'' effect as a result of the new highway.

Table 1
Summary statistics for highway, adjacent, pooled and control counties[a]

	Highway counties	Adjacent counties	Pooled counties	Control counties
I. mean 1969 values (in 000s of dollars)				
Population (in 000s)	16.60	12.40	13.2	12.3
Total earnings	117 942.70	84 463.59	94 098.24	89 599.84
Manufacturing earnings	19 021.24	11 701.74	13 296.36	13 615.29
Services earnings	13 942.08	9439.75	10 315.84	10 666.23
Retail earnings	14 304.32	10 008.69	10 937.93	11 418.26
Sample size (number of counties)	185	392	577	1204
II. Combined 1969–1993 values				
Population (in 000s)	17.5	13.0	14.1	13.5
Total earnings	141 161.5	95 366.62	107 499.64	104 761.12
Manufacturing earnings	24 479.16	14 327.89	17 698.39	16 613.25
Services earnings	16 958.08	10 926.59	12 755.64	12 961.25
Retail earnings	16 097.96	9849.96	11 433.32	11 813.25
Sample size (county–year observations)	4 625	9 800	14 375	30 111

[a] Notes: Authors tabulations from the United States Department of Transportation *PR-511 Master File* merged with data from the United States Department of Commerce *Regional Economic Information System*. Sample is non-metropolitan counties in the continental United States and all dollar values are in 1993 dollars. Highway counties refer to those counties through which a highway directly passes; adjacent counties are non-highway counties that are adjacent to highway counties; pooled counties refer to highway counties and adjacent counties combined. Control counties refer to the counterfactual case, which are neither highway, adjacent nor pooled counties.

Our control group consisted of over 1204 non-metropolitan counties that had no highway as of the end of the study period in 1993. Table 1 shows the average earnings in 1969 (reported in 1993 dollars) of highway counties, adjacent counties, pooled counties and our control counties[10].

[10]The PR-511 data distinguishes between 'counties' and 'independent cities' in the Commonwealth of Virginia. Because the historical economic data that we were using in our analysis were derived from the Regional Economic Information System (REIS) database, we had to make the PR-511 and REIS data compatible for merging. To facilitate this step of our analysis we chose to aggregate the PR-511 data up to the 'Virginia-900' series that the REIS uses. The 'Virginia-900' series, combines numbers from the independent cities in Virginia with the counties in which they reside, producing county-level data that is identical to the more conventional definition of counties used by other states. The '900' refers to the new FIPS code that is assigned to this aggregated county.

3.2. Econometric model

In this section we use the preceding theoretical discussion to derive an empirical model and justify the use of additional explanatory variables. As our model has made clear, highways may have differential effects on different industries. Therefore, we use county-level earnings, by industry, as our outcome variable of interest. By estimating separate industry equations we can formally test the differential impact hypotheses.

We utilize earnings rather than output as the dependent variable because output is not widely available at the county level. However, worker earnings is a major component of value-added output in most industries. Industries with expanding firms would be expected to have an increasing wage bill. Industries in counties containing contracting firms would have a declining wage bill.

Previous infrastructure studies at the state level by Garcia-Mila and McGuire (1992) and Holtz-Eakin (1994), and others have modeled output using a production function approach with the inputs including public infrastructure, private sector capital and labor. Due to the data limitations discussed above, our modeling approach does not utilize a production function approach to estimate how new highways affect output. Rather, our approach is to estimate how new highways affect earnings, after adjusting for other national, regional, and local factors that influence the level of local economic activity. National factors influencing industry earnings include trends in consumer and industrial demand for an industry's products, changes in labor productivity in an industry, and the phase of the national business cycle. To control for these factors, we include a variable that measures industry specific levels in national economic activity. To control for state-level trends we include the corresponding level of state economic activity. Many factors such as land availability, weather, natural beauty, and location near larger cities are fixed factors, that is, characteristics of counties, which do not change over time. A time-invariant (county) fixed-effect is used to capture the effect of these factors. Additionally, a series of age of highway indicator variables also is included to capture the impact of a new highway on county earnings.

The fixed-effects equation for county earnings in each industry is illustrated in Eq. (7) below. Separate equations were estimated for each industry based on 1-digit Standard Industrial Classification (SIC) codes:

$$y_{it} = \alpha + X\beta + \eta STATE_t + \gamma US_t + u_{it} \tag{7}$$

Here, for a given industry in county i, the dependent variable is the natural log of real earnings (in 1993 dollars) for a given industry in year t. α is the estimated constant term for the industry (α is constrained to be the same across all counties). $STATE_t$ is the state-level total non-metropolitan earnings in time t for the given industry. The state-level total for an industry is measured as the natural log of industry earnings totaled across all non-metropolitan counties in a state for the relevant industry in year t minus the county i's contribution in year t. The US_t variable is the natural log of total earnings nationally for an industry in year t[11]. The ***X*** matrix is a series of age of highway variables, and is used to isolate the treatment effect of receiving a new interstate highway[12]. The age of highway variable refers to the number of years since the highway opened in county i. Each coefficient measures the earnings impact of having a new highway of a given age on a county's log of earnings in the industry. The advantage of including separate dummies to capture age effects is that it is completely non-parametric in nature; we impose no parametric restrictions on the relationship between the age of a highway and economic growth. This would not be the case if we had included a quartic or even a quintic polynomial in age. While this approach requires us to estimate 25 separate parameters at the cost of computational time, possible loss of parameter efficiency, and a loss of degrees of freedom, we believe that our sample sizes can accommodate these criticisms. To capture ''run-up'' effects in highway construction on economic activity, or the reallocation of new economic activity into the highway county *before* the highway actually opened, we allow the age of highway variable to take on values for up to 5 years before the highway opened. The inclusion of these ''run-up'' effects reflects the fact that the treatment effect of receiving a new highway occurs before the highway actually opens, it occurs as soon as construction for the new interstate begins in a given county. As the results section of this paper notes, we find significant empirical evidence for our hypothesis of ''run-up'' effects, especially in the construction industry.

Following Holtz-Eakin's (1994) and Evans and Karras (1994) suggestion that infrastructure–productivity regressions adopt a fixed-effects specification, the error term in (7) is comprised of a time-invariant county fixed-effect μ_i and a remainder disturbance v_{it}:

$$u_{it} = \mu_i + v_{it} \quad (8)$$

[11] The inclusion of both *STATE* and *US* may appear to be redundant, or highly collinear. *STATE* refers to the state's non-metropolitan earnings in an industry, while the *US* variable is total earnings for the industry. This variable primarily captures movements in the earnings levels of metropolitan counties, and is therefore not necessarily collinear with *STATE*. To the extent that they are collinear, it is important to note that least-squares estimates of both variables will still be asymptotically efficient and unbiased. Also note that the *US* variable is perfectly collinear with period (year) effects. That is, it is impossible to simultaneously identify the effects of the national business cycle and a time trend.

[12] More formally, the identification of our model is as follows: the interstate highway or public infrastructure investment is an exogenous treatment effect ($T=1$) whose effect is allowed to vary with time (X). Therefore, for the treatment group of counties:

$E(y_{it}|T=1) = \alpha + X\beta + \eta STATE_t + \gamma US_t$ whereas for the control group of counties,

$E(y_{it}|T=0) = \alpha + \eta STATE_t + \gamma US_t$. The difference in the two groups

$E(y_{it}|T=1) - E(y_{it}|T=0) = X\beta$ isolates the pure treatment effect.

For each industry, we can formally test for the presence of autocorrelation (or that $|\rho|<1$) in the context of panel data by using the generalization of the Durbin-Watson statistic to panel data that is proposed by Bhargava et al. (1982) (BFN)[13]. Furthermore, following the results of Arellano (1987) and the treatment in Baltagi (1995) we can also extend the application of the standard Huber-White variance–covariance matrix to panel data.

Estimation of Eq. (7) for total earnings and industry earnings can be undertaken to estimate the impact of new highways on the level of earnings in counties. The magnitudes of the coefficients on the age of highway variables measure the highway's impact on earnings growth. These estimates correspond to the structural parameters if there are not unobservables that are correlated with receiving a new highway. To address the possibility of the potential endogeneity of new highway construction we estimate random-effects logistic regressions to test whether the incidence of a new highway in county i in year t can be explained as a function of its prior growth rates (HIGHWAY$=1$ for county i if construction on a new highway began in year t). The regressions are of the following form:

$$\Pr(HIGHWAY_{it}=1)=\Lambda\left(\sum_{t=1}^{4}\psi^{i}\Delta EARN_{(t)-(t-1)}\right) \tag{9}$$

The sample for the above regression described in (9) includes the set of all county–year observations for counties receiving a new highway (included until the year that construction actually commenced), and the set of all county–year observations which never received a highway. We estimated Eq. (9) separately for highway counties, their adjacent counties, and the pooled group of counties. Through these exclusion restrictions we are able to explicitly isolate a test of the hypotheses that prior growth rates do not affect the incidence of a new highway. Because we have repeated observations for the same county, the observations are

[13] For each industry we test whether the disturbance term follows an AR(1) process: $vit=\rho v_{it-1}+\omega_{it}$, by using the test statistic proposed by BFN:

$$d_p=\left(\sum_{i=1}^{N}\sum_{t=2}^{T}(v_{it}-v_{it-1})^2\right)\Big/\sum_{i=1}^{N}\sum_{t=1}^{T}v_{it}^2$$

In the above equation, the v_{it} are the residuals obtained from the estimation of (7). N indexes panels (here, counties), and T indexes time. The resulting test statistic can be shown to be a locally most powerful invariant test in the neighborhood of $\rho=0$. We also use a modified version of the Berenblut-Webb statistic to test the null hypothesis that $\rho=0$. This is the locally most powerful invariant test in the neighborhood of $\rho=1$. This statistic is given by:

$$g_p=\sum_{i=1}^{N}\sum_{t=2}^{T}\Delta u_{it}^2\Big/\sum_{i=1}^{N}\sum_{t=1}^{T}v_{it}^2$$

where Δu_{it}^2 denotes the squared OLS residuals from a first-differenced version of (7). Bhargava et al. (1982) have shown that the g_p and d_p statistics are asymptotically equivalent as N increases, and we confirm this finding empirically.

not i.i.d implying in turn that we need to adjust our estimates of the naïve covariance matrix[14].

4. Results and extensions

Tables 2–4 contain regression results for three sets of counties from our basic fixed-effects specification defined in Eq. (7). These tables are organized as follows: results for the pooled group of counties are reported in Table 2; those for highway counties in Table 3, and those for adjacent counties alone are reported in Table 4. The pooled group of counties demonstrates the net effect of a highway investment on the regional economy, whereas Tables 3 and 4 report the effect on the constituent highway and adjacent counties. In each table, we report the transformed regression coefficients on the Highway-Age dummies (using Peter Kennedy's recommendation for semi-log equations with a binary explanatory variable)[15]. In addition to reporting these transformed coefficients, we also graph these results for selected industries in Fig. 2. In Fig. 2, the smoothed line represents the imposition of a third order polynomial on the transformed coefficients. The panels in Fig. 2 separate the analysis by industry, and pictorially demonstrate the relationship between earnings growth in highway counties and adjacent counties. The pictures and regression coefficients demonstrate the reorganization of economic activity from adjacent counties towards highway counties. These effects are especially prominent in the results for total earnings, retail earnings and services earnings.

By separating the effects of a new highway on highway and adjacent counties, we can also test the predictions of our theoretical model. As predicted by our spatial competition model, opening an interstate highway in a non-metropolitan region acts to increase earnings in industries that typically produce nationally traded goods, such as the manufacturing industry. For industries primarily producing regionally traded goods, such as retail and services, a new highway

[14]To adjust for the fact that the observations in our sample are not i.i.d (we have repeated observations on the same county therefore observations are independent across clusters, but not within them), we correct the reported naïve standard errors using the method outlined in Rodgers (1993) who in turn follows Huber (1967).

[15]In our paper the dependent variable is the natural logarithm of a county earnings in a given industry. The explanatory variables may therefore be loosely interpreted as representing the percentage increase in the dependent variable for a given highway-age. However, as Kennedy (1981) notes, this approximation is not entirely correct when there are dummy explanatory variables (as is the case in our model where the highway age variables are all indicator variables). To make the stated inference, the estimated coefficients should be transformed to exp[0.5 (var (Estimated Coefficient))] − 1, where VAR refers to variance. After this transformation, we can read off the transformed coefficient on a highway age of *t* years to measure the percentage increase in industry earnings *t* years after the interstate opens. Following the logic of footnote (12) the transformed coefficients reflect the increase in industry earnings relative to the control group of counties that did not receive an interstate highway.

Table 2
Fixed effects estimates of the impact of a new interstate highway on earnings by industry: highway and adjacent counties combined[a]

Age of highway	Earnings	Farming	TrPubU	Manuf.	Const.	Retail	Services	Govt.	FIRE
−5	0.029*	−0.052	0.033	−0.011	0.033	0.024	0.041*	−0.002	0.063*
−4	0.033*	−0.065	0.033	0.013	0.068*	0.034*	0.030	−0.003	0.059*
−3	0.008	−0.072*	0.032*	0.021	0.032	0.018	0.032	−0.009*	0.054*
−2	0.022	−0.044	0.037*	0.032	0.074*	0.014	0.028	−0.021*	0.060*
−1	0.022	−0.081*	0.043*	0.036	0.084*	0.015*	0.041*	−0.013*	0.068*
0	0.008	−0.107*	0.031*	0.011	0.046	0.000	0.035*	−0.030*	0.039*
1	0.011	−0.061	0.025	0.015	0.039	−0.004	0.033*	−0.031*	0.046*
2	0.017	−0.066*	0.041*	0.026	0.018	−0.008	0.042*	−0.032*	0.060*
3	0.016	−0.066*	0.050*	0.021	0.008	−0.008	0.046**	−0.032*	0.067*
4	0.012	−0.131*	0.040*	0.048*	0.008	−0.007	0.046*	−0.030*	0.061*
5	0.007	−0.089*	0.030*	0.064*	0.004	−0.014	0.045*	−0.031*	0.067*
6	−0.003	−0.092*	0.011	0.035	0.016	−0.018*	0.046*	−0.030*	0.056*
7	−0.011	−0.075*	0.014	0.043*	−0.007	−0.020*	0.051*	−0.033*	0.065*
8	−0.010	−0.068*	0.008	0.041	−0.019	−0.025*	0.050*	−0.035*	0.064*
9	−0.010	−0.091*	0.008	0.038	−0.024	−0.020*	0.049*	−0.037*	0.066*
10	−0.016*	−0.079*	0.005	0.028	−0.036*	−0.029*	0.042*	−0.038*	0.064*
11	−0.009	−0.048*	−0.001	0.022	−0.064*	−0.033*	0.045*	−0.035*	0.070*
12	−0.003	−0.162*	−0.001	0.027	−0.080*	−0.028*	0.038*	−0.030*	0.067*
13	−0.004	−0.127*	0.007	0.021	−0.087*	−0.029*	0.042*	−0.024*	0.063*
14	−0.007	−0.226*	0.024	0.025	−0.075*	−0.029*	0.046*	−0.023*	0.069*
15	0.003	−0.236*	0.028	0.045*	−0.064*	−0.025*	0.046*	−0.020*	0.069*
16	0.009	−0.264*	0.012	0.055*	−0.081*	−0.024*	0.049*	−0.021*	0.056*
17	0.011	−0.274*	0.020	0.059*	−0.074*	−0.033*	0.043*	−0.021*	0.059*
18	0.026*	−0.274*	0.029	0.086*	−0.088*	−0.025*	0.049*	−0.019*	0.060*
19	0.024	−0.281*	0.018	0.069*	−0.065*	−0.018*	0.058*	−0.013*	0.079*
20	0.018	−0.256*	0.023	0.079*	−0.092*	−0.033*	0.047*	−0.017*	0.063*
21	0.020	−0.223*	0.013	0.069*	−0.098*	−0.044*	0.037*	−0.020*	0.063*
22	0.002	−0.169*	0.010	0.070*	−0.085*	−0.053*	0.035*	−0.020*	0.070*
23	0.010	−0.205*	0.033*	0.055*	−0.087*	−0.042*	0.051*	−0.028*	0.050*
24	0.046*	−0.203*	0.047*	0.136*	−0.036	0.000	0.094*	0.010	0.084*

Ln State Level)	1.089*	0.557*	0.720*	0.648*	0.852*	1.032*	0.860*	0.890*	0.966*
Ln (US Level)	−0.225*	0.476*	0.052*	0.371*	−0.013	−0.364*	−0.103*	0.083*	−0.124*
F-test for Significance of Fixed Effects (significant at a *P*-value of 1% or less?)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
F-test for joint significance of Highway-Age Dummies (significant at a *P*-value of 0.10 or less?)	Yes	Yes	No	No	Yes	Yes	No	Yes	No
Number of County Year Obs.	44 434	40 643	42 043	41 584	43 222	44 278	42 968	44 435	42 811
Panel Durbin-Watson	1.944	1.966	1.958	1.962	1.979	1.977	1.973	0.139	1.985
R^2 Within	0.29	0.36	0.12	0.12	0.21	0.30	0.41	0.54	0.26

[a] Dependent variable is the natural log of industry earnings (in 1993 dollars). The reported coefficients have been transformed into percentage growth rates using the appropriate transformation for semi-log equations: $\beta = \exp[0.5\ (\mathrm{var}\ (\text{Estimated Coefficient}))] - 1$. Asterisk indicates statistical significance at a 10% significance level. See text for details.

Table 3
Fixed effects estimates of the impact of a new interstate highway on earnings by industry: highway counties[a]

Age of highway	Earnings	Farming	TrPubU	Manuf.	Const.	Retail	Services	Govt.	FIRE
−5	0.008	−0.075	−0.004	−0.010	0.013	0.038*	0.008	0.004	0.036
−4	0.020	−0.011	0.006	−0.002	0.069	0.048*	0.004	0.005	0.055*
−3	0.012	−0.029	0.040	−0.017	0.088*	0.026	0.010	0.000	0.039
−2	0.009	−0.091	0.042	−0.044	0.152*	0.020	0.017	−0.013	0.041*
−1	0.014	−0.106*	0.054*	−0.024	0.148*	0.030*	0.030	−0.009	0.049*
0	0.001	−0.122*	0.054*	−0.051	0.049	0.012	0.036*	−0.018	0.025
1	0.008	−0.103*	0.043	−0.008	0.022	0.012	0.031	−0.016	0.035
2	0.027	−0.073	0.068*	0.014	0.023	0.017	0.052*	−0.017	0.046*
3	0.019	−0.112*	0.079*	−0.005	0.015	0.022	0.041*	−0.018	0.040*
4	0.027	−0.131*	0.073*	0.024	0.003	0.029*	0.044*	−0.017	0.033
5	0.027	−0.136*	0.052*	0.030	0.012	0.030*	0.050*	−0.016	0.041*
6	0.016	−0.124*	0.052*	0.018	0.020	0.048*	0.052*	−0.008	0.047*
7	0.018	−0.141*	0.063*	0.029	−0.016	0.052*	0.070*	−0.006	0.063*
8	0.019	−0.163*	0.057*	0.033	−0.029	0.052*	0.070*	−0.006	0.069*
9	0.016	−0.178*	0.053*	0.025	−0.017	0.065*	0.071*	−0.004	0.084*
10	0.024	−0.140*	0.060*	0.036	−0.014	0.062*	0.062*	−0.003	0.093*
11	0.025	−0.082	0.063*	0.039	−0.054	0.051*	0.071*	0.004	0.102*
12	0.033*	−0.239*	0.072*	0.036	−0.077*	0.060*	0.081*	0.008	0.111*
13	0.040*	−0.230*	0.069*	0.027	−0.083*	0.072*	0.086*	0.007	0.114*
14	0.038 *	−0.221*	0.085*	0.019	−0.079*	0.071*	0.095*	0.008	0.127*
15	0.043*	−0.270*	0.085*	0.038	−0.083*	0.078*	0.104*	0.014	0.132*
16	0.060*	−0.291*	0.070*	0.053	−0.106*	0.088*	0.111*	0.020	0.149*
17	0.069*	−0.306*	0.075*	0.058	−0.084*	0.079*	0.114*	0.021	0.117*
18	0.091 *	−0.323*	0.101*	0.070	−0.058	0.105*	0.126*	0.026*	0.124*
19	0.084*	−0.322*	0.095*	0.061	−0.037	0.111*	0.138*	0.032*	0.144*
20	0.095*	−0.337*	0.120*	0.085*	−0.101*	0.102*	0.130*	0.037*	0.139*
21	0.112*	−0.293*	0.107*	0.084	−0.080*	0.124*	0.134*	0.027	0.166*
22	0.089*	−0.184*	0.141*	0.051	−0.091*	0.116*	0.120*	0.031*	0.180*
23	0.087*	−0.230*	0.102*	−0.050	−0.096*	0.124*	0.129*	0.016	0.134*
24	0.127*	−0.282*	0.162*	0.069	−0.013	0.186*	0.147*	0.073*	0.193*

Ln (State Level)	1.103*	0.573*	0.751*	0.685*	0.864*	1.051*	0.901*	0.878*	0.966*
Ln (US Level)	−0.243*	0.480*	0.048*	0.338*	−0.050*	−0.391*	−0.129*	0.089*	−0.127*
F-test for Significance of Fixed Effects (significant at a *P*-value of 1% or less?)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
F-test for joint significance of Highway-Age Dummies (significant at a *P*-value of 0.10 or less)	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes
Number of County Year Obs.	34 685	31 767	32 973	32 493	33 810	34 570	33 619	34 685	33 489
Panel Durbin-Watson	1.975	1.961	1.957	1.982	1.996	1.983	1.955	0.140	1.959
R^2 Within	0.30	0.37	0.12	0.12	0.21	0.31	0.43	0.54	0.27

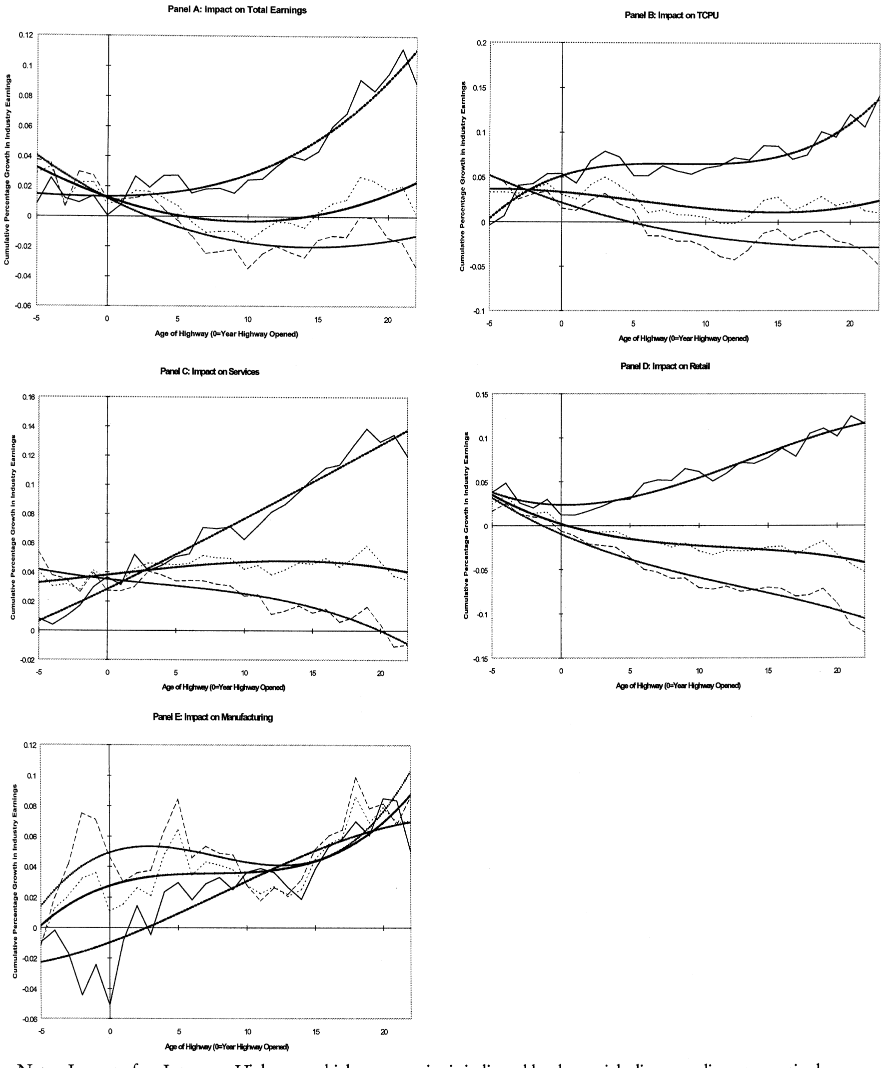
[a] Dependent variable is the natural log of industry earnings (in 1993 dollars). The reported coefficients have been transformed into percentage growth rates using the appropriate transformation for semi-log equations: $\beta = \exp[0.5\ (\text{var (Estimated Coefficient)})] - 1$. Asterisk indicates statistical significance at a 10% significance level. See text for details.

Table 4
Fixed effects estimates of the impact of a new interstate highway on earnings by industry: adjacent counties[a]

Age of highway	Earnings	Farming	TrPubU	Manuf.	Const.	Retail	Services	Govt.	FIRE
−5	0.038*	−0.041	0.052*	−0.012	0.041	0.016	0.054*	−0.005	0.076*
−4	0.035*	−0.090*	0.044*	0.020	0.069*	0.025	0.038	−0.006	0.062*
−3	0.007	−0.095*	0.025	0.041	0.008	0.013	0.035	−0.014*	0.062*
−2	0.030	−0.022	0.031*	0.075*	0.040	0.010	0.026	−0.025*	0.069*
−1	0.027	−0.072	0.034*	0.071*	0.054	0.007	0.039*	−0.016*	0.078*
0	0.011	−0.105*	0.015	0.046	0.045	−0.006	0.027	−0.037*	0.045*
1	0.011	−0.044	0.013	0.030	0.048	−0.012	0.027	−0.038*	0.050*
2	0.012	−0.057	0.024	0.036	0.015	−0.021*	0.030	−0.039*	0.067*
3	0.015	−0.046	0.032	0.038	0.004	−0.023*	0.040*	−0.039*	0.080*
4	0.005	−0.128*	0.020	0.064*	0.010	−0.025*	0.038*	−0.036*	0.075*
5	−0.003	−0.067	0.014	0.084*	0.000	−0.036*	0.034*	−0.038*	0.079*
6	−0.013	−0.079	−0.015	0.046	0.013	−0.050*	0.034	−0.041*	0.059*
7	−0.025*	−0.038	−0.016	0.053	−0.004	−0.053*	0.034	−0.045*	0.064*
8	−0.023*	−0.016	−0.021	0.049	−0.014	−0.060*	0.032	−0.049*	0.059*
9	−0.022*	−0.049	−0.021	0.048	−0.026	−0.059*	0.031	−0.051*	0.055*
10	−0.035*	−0.047	−0.029	0.028	−0.045*	−0.070*	0.024	−0.054*	0.049*
11	−0.025*	−0.030	−0.039	0.018	−0.068*	−0.072*	0.024	−0.053*	0.052*
12	−0.020*	−0.121*	−0.043*	0.026	−0.081*	−0.069*	0.011	−0.047*	0.043
13	−0.024*	−0.072*	−0.030	0.022	−0.087*	−0.075*	0.013	−0.039*	0.036
14	−0.027*	−0.229*	−0.012	0.032	−0.069*	−0.073*	0.017	−0.038*	0.039
15	−0.015	−0.224*	−0.007	0.051*	−0.050*	−0.070*	0.012	−0.036*	0.037
16	−0.013	−0.248*	−0.021	0.060*	−0.064*	−0.072*	0.015	−0.039*	0.013
17	−0.013	−0.260*	−0.013	0.064*	−0.063*	−0.080*	0.006	−0.039*	0.032
18	0.000	−0.249*	−0.009	0.099*	−0.095*	−0.079*	0.009	−0.038*	0.030
19	−0.001	−0.261*	−0.021	0.078*	−0.071*	−0.071*	0.016	−0.034*	0.048*
20	−0.014	−0.216*	−0.025	0.082*	−0.081*	−0.088*	0.004	−0.042*	0.027
21	−0.017	−0.188*	−0.033	0.068*	−0.102*	−0.112*	−0.011	−0.041*	0.017
22	−0.033*	−0.163*	−0.049	0.086*	−0.079*	−0.122*	−0.010	−0.043*	0.021
23	−0.022	−0.194*	−0.001	0.114*	−0.079*	−0.108*	0.009	−0.048*	0.010
24	0.013	−0.164*	−0.005	0.175*	−0.043	−0.073*	0.062*	−0.017	0.038

Ln (State Industry Level)	1.092*	0.579*	0.735*	0.631*	0.854*	1.030*	0.860*	0.870*	0.959*
Ln (US Industry Level)	−0.231*	0.455*	0.070*	0.381*	−0.034*	−0.372*	−0.103*	0.103*	−0.122*
F-test for Significance of Fixed Effects (significant at a *P*-value of 1% or less?)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
F-test for joint significance of Highway-Age Dummies (significant at a *P*-value of 0.01 or less?)	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes
Number of County Year Obs.	39 859	36 504	37 743	37 130	38 688	39 703	38 587	39 860	38 302
Durbin-Watson	2.015	1.964	1.953	1.985	1.979	1.943	1.929	0.143	1.966
R^2 Within	0.28	0.36	0.11	0.12	0.21	0.30	0.40	0.54	0.26

[a] Dependent variable is the natural log of industry earnings (in 1993 dollars). The reported coefficients have been transformed into percentage growth rates using the appropriate transformation for semi-log equations: $\beta = \exp[0.5\ (\text{var (Estimated Coefficient)})] - 1$. Asterisk indicates statistical significance at a 10% significance level. See text for details.



Notes: Impact of an Interstate Highway on highway counties is indicated by the straight line; on adjacent counties by a dashed line; on the pooled (region) counties by a dotted line. The smoothed line is a third-order polynomial that has been fitted to the estimated coefficients.

Fig. 2. Fixed-effects estimates of the impact of a new interstate highway on earnings.

tends to spur earnings in direct highway counties. In adjacent counties, highway investments are predicted to reduce earnings in retail industries. As for total earnings, the location of a new interstate highway acts to increase total earnings in non-metropolitan counties that the highway directly runs through, but may cause a decline in total earnings in adjacent counties. The net effect on regional economic activity is therefore ambiguous. Together, the results described in this section are consistent with the earlier literature on the relationship between public-infrastructure and economic activity.

The reported tables also include tests for serial-correlation. Our test, as defined BFN (1982), does not reject the hypothesis that the error terms are serially uncorrelated; the calculated Durbin-Watson statistic for fixed-effects models is found to be in the neighborhood of two. The only industry that violates this result is government, where we find significant evidence of serial-correlation. In Tables 2–4 we also report the results of an F-test on the appropriateness of the fixed-effects model, based on whether the estimated P-values were less that 0.0001. We find that the fixed-effects framework is supported in all the models that we estimated and that a formal Hausman test rejected a random-effects specification. The rest of this section discusses our results in detail[16].

4.1. Effect on the regional economy

As can be seen in Table 2, for the pooled (highway and adjacent combined) group of counties, our results do not indicate that new highway investments increase aggregate earnings in these counties as a group, but do support the contention that highway investments increase earnings in selected industries. As such, we confirm Holtz-Eakin's (1994) findings, but also make the case for studying the sectorial decomposition of public infrastructure investments. For this pooled group of counties, the highway age coefficients for total earnings alternate between being positive and negative and in general are not significant individually (however a joint F-test on these coefficients did not allow us to reject the null hypothesis that they were jointly zero; the P value was less than 1%)[17]. Beyond these aggregate effects, the estimates in Table 2 indicate that the location of a highway can lead to a loss in earnings in three major sectors of the regional

[16] As specification tests to detect the presence of leverage points in our data, we obtained normal OLS as well as jack-knifed residuals (the jack-knife sampled only treatment counties) from the estimation of Eq. (7). Using both Shapiro-Wilk and Shapiro-Francia tests we were unable to reject the null hypothesis of normality of the residuals. A more detailed version of our results, including coefficient standard errors, is available from the authors on request.

[17] One reader of this paper correctly pointed out that we have run a regression that includes observations for two different treatment groups (highway plus adjacent counties) and that this exercise yields an estimator that converges in probability to a matrix-weighted average of the parameters for the two treatment groups. Finding that such an estimator is not significantly different from zero does not necessarily test whether the sum of the effects for the two treatment groups is zero. To address this issue we used the fitted equations for the highway and adjacent counties and summed up the predicted gains and losses in economic activity. We were able to reject the one-sided hypothesis that the net change in economic activity was greater than or equal to zero at the 1% significance level. These results are available from the authors on request.

economy: farming, retail trade, and government. The estimated loss of earnings in farming is in the range of 10% to 30%, depending on the age of the new interstate highway. The decline in earnings in retail trade and government is in the range of 3% to 6%. These results are all statistically significant jointly, as well as individually for many of years. The location of a new interstate also was estimated to increase earnings in the manufacturing industry where earnings were predicted to increase from 2% to 10%, depending on the age of the interstate. The increase in manufacturing earnings and decline in farm earnings suggests that increased opportunities in manufacturing draw workers and farm operators away from farming. Earnings also were estimated to increase in TCPU, services, and FIRE (finance, insurance, and real estate). Additionally, we note the importance of controlling for the ''run-up'' phase of a new highway's opening. This is clearly evident in the results for the construction industry where a joint F-test on the construction phase of the project (the first five age dummies) was significant with a P-value of less that 1%.

4.2. Effect on highway counties

Regression results for total earnings in Table 3 indicate that total earnings in highway counties eventually increase after the opening of a new interstate highway. Coefficients on the age dummy variables are positive in all years and turn individually significant after 13 years[18]. The estimated total earnings increase ranges 3–10% more than counties that did not receive a highway. Furthermore, the opening of an interstate highway positively and significantly effects earnings in a number of individual industries. Our theoretical model predicts this effect. The impact on services, TCPU (transportation, communications, and public utilities),

[18]The REIS data contain data on total earnings by place of work (which we use) and total earnings by place of residence. If, as an anonymous referee suggested, highways reduce residents commuting costs in the same way that they reduce transportation costs, then by increasing the range over which residents may search for jobs, highways may also increase the income of residents. If highways lead to greater commutes to metropolitan areas, then we may see a decrease in earnings by firms located in non-metropolitan countries, even though residents may be doing better. To explore this issue further we re-estimated the regressions for highway counties, adjacent counties and the pooled group of counties by using earnings by place of residence as the dependent variable. These regressions provided the same results as those obtained from using earnings by place of work as the dependent variable. The new regression coefficients have the same magnitude and sign as those previously obtained. Regression results for this exercise are available from the authors on request. What this suggests is that residents of areas affected by new highway construction do not adjust their commute patterns to work in response to a new highway. The REIS data do not contain earnings by industry by place of residence, so while this result holds in the aggregate for total earnings, it may or may not hold for a given industry. In future work we hope to explore this question further, and we are grateful to an anonymous referee for encouraging this line of inquiry.

and FIRE is positive and significant in most years (jointly, all the age-dummies are highly significant, with P-values less than 1%). The impact on retail sales is positive and significant 4 years after the highway opens. Earnings in these industries increased from 3% to 10% in most years. Additionally, we find a significant positive effect on the construction industry during the period of new interstate construction. These results suggest that highway counties enjoy growth in many non-manufacturing industries after the interstate opens. The impact on the manufacturing industry of highway counties is positive in most years, but not jointly statistically significant. The point estimates were consistent with our theoretical model. The only industry with a significant and negative impact of new highway infrastructure is farming.

These overall positive results from highway investments on many industries may form the political basis for politicians who campaign aggressively for new highways in their districts. However, as our theoretical model predicts, there may be a simultaneous contraction of economic activity in counties adjacent to the directly affected ones. We now turn to a study of these effects.

4.3. Effect on adjacent counties

Table 4 reports regression results for adjacent to highway counties. The results of the regression for total earnings in Table 4 indicate that total earnings in highway counties fall a few years after the opening of a new interstate highway. Whereas the decline is not individually significant in many years, joint F-tests on the age-dummies found that there was a systematic contraction over time. Twenty-five years after a new highway opens, total earnings fall by 1–3% in adjacent counties. Within individual industries, manufacturing is the sector that consistently gains earnings in the years after the interstate highway opens, although earnings in FIRE also increase for the first 10 years. Farming, retail trade, and government are the individual industries that are estimated to experience the greatest and most consistent decline in earnings. The decline in retail earnings in adjacent counties was predicted by our theoretical model; the industry is found to contract by 2–12% in the years after a new highway is opened (in contrast it grows by a similar percent in highway counties). Overall, these results suggest that while the more export-oriented manufacturing sector in adjacent to highway counties expands due to the opening of the interstate, many large non-manufacturing sectors lose employment, perhaps to nearby highway counties or metropolitan areas.

4.4. Are highways endogenous?

The above sets of regression results provide an interesting picture of the impact of new interstate investments on the regional economy. However, as previously discussed it is important to rule out spurious causation between county growth and new interstates: if new highways are being constructed in areas of high growth (i.e. growth causes new highways and not vice-versa), then any inferences made from our results would be entirely suspect. Table 5 provides evidence that new highways are not being constructed in areas with high economic growth. The results are obtained from estimating Eq. (9) through logistic regression with the appropriate covariance matrix correction. We include the previous four annual growth rates as explanatory variables; they are found to be individually as well as jointly insignificant. By rejecting the endogeneity hypothesis we also find empirical support for choosing to focus only on non-metropolitan counties. As previously stated, interstate highways typically connect two metropolitan areas, therefore, the non-metropolitan counties that they pass through may be thought of having received a new highway as an exogenous event. This finding simplified our empirical work considerably, as we did not have to search for instruments to control for the potential endogeneity of highway construction.

4.5. Extensions

In addition to the above models we also estimate an extension of the model implied by Eq. (7) and estimate a seemingly-unrelated fixed-effects regression

Table 5
Logit estimates of the probability of receiving a new interstate highway[a]

Dependent variable is whether highway construction began in year t in county i	Highway counties	Adjacent counties	Pooled counties
Earnings growth between t and $t-1$	−0.1475	−0.1516	−0.282
	(0.4509)	(0.3175)	(0.2875)
Earnings growth between $t-1$ and $t-2$	−0.4944	−0.1411	−0.241
	(0.5190)	(0.3503)	(0.3433)
Earnings growth between $t-2$ and $t-3$	−0.7541	−0.2609	0.0035
	(0.5270)	(0.3768)	(0.3135)
Earnings growth between $t-3$ and $t-4$	−0.6970	−0.3795	0.3015
	(0.3887)	(0.3884)	(0.3015)
Sample size	25 634	25 986	26 343
Log-likelihood	−450.077	−807.200	−1202.9398

[a] The sample for the above regression included the set of all county–year observations during which construction on a new highway began and the set of all county–year observations which never received a highway. Those county–year observations during which a highway was actually open were excluded from the sample. Robust standard errors in are reported parenthesis and are adjusted for the non-iid clustering of observations. None of the coefficients are individually or jointly significant. See text for details.

(SUFER) model[19]. This model allows (unobservable) shocks to output to be correlated across industries, and produces more efficient estimates than the standard fixed-effects model if the residuals are indeed correlated. We note that SUFER is equivalent to OLS in the case of having identical regressors across all equations, however, the inclusion of the *STATE* and *US* variables that vary across industries allows us to exploit the power of the seemingly-unrelated approach. Empirical estimates of the SUFER are presented in Table 6. We first recovered the residuals from the estimation of Eq. (7) and analyzed their covariance matrix. Based on this analysis we found that only the residuals for the services and retail industries were significantly correlated. We therefore estimated our SUFER on a system of three equations, one each for services and retail, and another for all the other industries besides services, retail, manufacturing, and farming. At the bottom of Table 6 we also report a Breusch-Pagan test of independence which rejects the hypothesis that the residual correlations are zero.

The results from the SUFER model are consistent in both magnitude and direction to those obtained from the standard fixed-effects model. Interstate highways are found to have significant and positive effects on earnings growth in services, retail and all other industries in highway counties (the cumulative impacts were jointly significant for each industry). The cumulative impact over 25 years since opening is found to be approximately 8% over the control group of counties. The retail and services industries in adjacent counties are found to do significantly worse after the opening of an interstate, however there is essentially

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[19]Our method follows that of Avery (1977) and the exposition in Baltagi (1995). Assume that we have M industries. Then, in general we can write:

$$y_j = Z_j \delta_j + u_j$$

where $j = 1, \ldots, M$. Here y_j is $NT \times 1$, Z_{jj} the design matrix is of order $NT \times k_j'$ (therefore $Z_i = [i_T \; X_i$ *STATE US*]), $\delta_j' = [\alpha \beta_j' \eta \gamma]$. β_j in turn is $k_j \times 1$, and k_j' is $k_j + 1$. We define the error vector to assume the following structure:

$$u_j = Z_\mu \mu_j + v_j$$

where $Z_\mu = (I_N \times i_T)$, and $\mu_j' = (\mu_{1j}, \ldots, \mu_{Nj})$ and $v_j' = (v_{11j}, v_{12j}, \ldots v_{1Tj}, \ldots, v_{N1j}, \ldots v_{NTj})$. Furthermore, $E(\mu_j') = E(v_j') = 0$. Therefore, we may express their covariance matrix as:

$$E\begin{pmatrix} \mu_j \\ v_j \end{pmatrix} (\mu_l \quad v_l)' = \begin{bmatrix} \delta^2_{\mu jl} I_N & 0 \\ 0 & \delta^2_{vjl} I_{NT} \end{bmatrix}$$

Following Baltagi (1995), and with Ω representing the variance covariance matrix for all M equations it can also be shown that:

$$\Omega^{-1/2} = \sum\nolimits_1^{-1/2} \otimes P + \sum\nolimits_v^{-1/2} \otimes Q$$

Here, $\Sigma_1 = T\Sigma_\mu + \Sigma_v$; $\Sigma_\mu = [\sigma^2_{\mu jl}]$ and $\Sigma_v = [\sigma^2_{vjl}]$; P is the standard projection matrix which averages observations over time for each equation and is defined as $P = Z_\mu (Z'_\mu Z_\mu)^{-1} Z_\mu$; $Q = I_{NT} - P$. We can estimate Σ_v by $U'QU/N(T-1)$ and Σ_1 by $U'PU/N$. Here, $U = [u_1, \ldots u_M] = aNT \times M$ matrix of residuals obtained after the 'within' transformation.

Table 6
SUFER estimates of the impact of a new interstate highway on earnings by industry[a]

Age of highway	Highway counties			Adjacent counties			Pooled counties		
	Services	Retail	All other	Services	Retail	All other	Services	Retail	All other
−5	−0.0077	0.0292	0.0077	0.0381	0.0100	0.0367	0.0238	0.0174	0.0265
−4	−0.0048	0.0407	0.0367	0.0182	0.0102	0.0279	0.0138	0.0214	0.0311
−3	−0.0065	0.0155	0.0189	0.0124	0.0062	0.0152	0.0108	0.0107	0.0168
−2	0.0174	0.0191	0.0404	0.0008	−0.0009	0.0059	0.0109	0.0070	0.0176
−1	0.0303	0.0252	0.0444	0.0131	−0.0024	0.0153	0.0233	0.0077	0.0253
0	0.0317	0.0029	0.0268	0.0058	−0.0150	−0.0064	0.0190	−0.0076	0.0049
1	0.0159	−0.0031	0.0220	0.0030	−0.0177*	−0.0042	0.0118	−0.0116*	0.00456
2	0.0321	0.0012	0.0182	0.0076	−0.0213*	−0.0032	0.0203	−0.0126*	0.0040
3	0.0259	0.0113	0.0303	0.0175	−0.0250*	0.0063	0.0251*	−0.0117*	0.0141
4	0.0246	0.0138	0.0285*	0.0129	−0.0321*	0.0045	0.0216*	−0.0162*	0.0123
5	0.0269	0.0127	0.0294*	0.0094	−0.0412*	0.0068	0.0197*	−0.0231*	0.0139
6	0.0291	0.0298*	0.0360*	0.0069	−0.0561*	0.0164	0.0191*	−0.0281*	0.0228
7	0.0423*	0.0317*	0.0294*	0.0049	−0.0629*	0.0052	0.0221	−0.0322*	0.0132*
8	0.0420*	0.0322*	0.0383*	0.0013	−0.0717*	−0.0001	0.0196	−0.0383*	0.0122
9	0.0445*	0.0421*	0.0414*	0.0007	−0.0681*	0.0107	0.0199	−0.0330*	0.0206
10	0.0348*	0.0370*	0.0328*	−0.0078	−0.0771*	0.0080	0.0108	−0.0408*	0.0161
11	0.0417*	0.0333*	0.0404*	−0.0062	−0.0825*	0.0093	0.0135	−0.0460*	0.0195
12	0.0448*	0.0408*	0.0404*	−0.0149	−0.0793*	0.0099	0.0083	−0.0416*	0.0196
13	0.0481*	0.0484*	0.0402*	−0.0175*	−0.0801*	0.0049	0.0071	−0.0406*	0.0163
14	0.0594*	0.0471*	0.0561*	−0.0190*	−0.0797*	0.0104	0.0090	−0.0414*	0.0246
15	0.0643*	0.0499*	0.0521*	−0.0245*	−0.0836*	0.0163	0.0061	−0.0438*	0.0272
16	0.0665*	0.0598*	0.0571*	−0.0225*	−0.0862*	0.0038	0.0080	−0.0435*	0.0196
17	0.0619*	0.0500*	0.0695*	−0.0274*	−0.0911*	0.0014	0.0032	−0.0499*	0.0218*

18	0.0863*	0.0836*	0.0878*	−0.0280*	−0.0875*	−0.0022	0.0103	−0.0374*	0.0248*
19	0.0784*	0.0640*	0.0667*	−0.0196*	−0.0809*	−0.0044	0.0133	−0.0390*	0.0165
20	0.0564*	0.0569*	0.0621*	−0.0284*	−0.1000*	−0.0042	0.0004	−0.0550*	0.0150
21	0.0887*	0.0990*	0.0894*	−0.0434*	−0.1237*	−0.0141	−0.0002	−0.0596*	0.0167
22	0.0695*	0.0885*	0.0945*	−0.0576*	−0.1320*	−0.0195	−0.0156	−0.0682*	0.0144
23	0.0879*	0.0996*	0.0791*	−0.0402*	−0.1180*	−0.0202	0.0019	−0.0557*	0.0090
24	0.1066*	0.1632*	0.1261*	0.0127	−0.0855*	0.0169	0.0449	−0.0159*	0.0483
County–Year Observations	31 609	31 609	31 609	36 207	36 207	36 207	40 416	40 416	40 416
F-test for joint significance of Highway-Age Dummies (significant at a *P*-value of 0.010 or less)	Yes	Yes	Yes	Yes	Yes	No	No	Yes	No
BP test of independence: $\chi^2(3)$	10 401.27			10 902.468			12 691.058		

[a] Dependent variable is the natural log of population or industry earnings (in 1993 dollars). The reported coefficients have been transformed into percentage growth rates using the appropriate transformation for semi-log equations: $\beta = \exp[0.5\ (\text{var (Estimated Coefficient)})] - 1$. Other controls included the log of the state and national level industry earnings. Asterisk indicates individual statistical significance at a 10% significance level. See text for details.

no effect on other industry earnings (joint F-tests revealed that the age-coefficients in the 'All Other' regression were not significantly different from zero). For the region as a whole, as defined by the highway and adjacent counties together, we find that there was no effect on earnings growth in the services sector, or in other industries excluding retail (joint F-tests on the age coefficients found that they were collectively significant only for the retail industry, however recall that the retail industry is contracting by a cumulative 6–7% 25 years after the highway opened!).

To the extent that there are diminishing returns to public infrastructure, the above results might suggest that the economic impact of new highway construction would be larger for the pre-1969 period than for the post 1969 period. In order to test this proposition indirectly, we re-estimated our model for two different periods: counties that received a new interstate between 1969 and 1975, and those that received one after 1975. If the stated hypothesis is correct, we should observe a smaller impact for the post-1975 sample than the 1969–1975 construction sample. We were unable to reject the null-hypotheses that the estimates from each of these models were identical to those obtained from the full sample (1969–1993) regression. These results are available from the authors on request and suggest that at least for the post-1969 sample there do not appear to be diminishing returns to infrastructure investments. If this pattern holds for the pre-1969 period then a similar inference may be made implying that it is not the case that the post-1968 interstate system has smaller earnings impacts than the earlier construction. The point of our paper is to suggest that *future* highway construction in the context of the Transportation Equity Act may have little economic impact. To demonstrate this argument it seems appropriate to consider the experience of counties that have *recently* received interstates.

5. Concluding comments

Our research has focused on the impact of new interstate highways on economic growth using historical data from the U.S. experience from 1969 to 1993 as evidence. These data, on the opening dates of new interstate highways, were obtained from U.S. Department of Transportation records and carefully validated using Rand-McNally atlases. Unlike previous studies that have pursued a state-level analysis, we exploit variation in the construction of new interstate highways over time and space as a source of identification. We use these data to test whether the new interstate highways we studied were built through areas already experiencing high growth, and reject this hypothesis. We find empirical support for our theoretical hypothesis that highways have a differential impact across industries: certain industries grow as a result of reduced transportation costs, but the impact is ambiguous for other industries. Additionally, we find that highways affect the spatial allocation of economic activity within regions; highways raise the level of economic activity in the counties that they pass directly through, but draw activity away from adjacent counties, thereby leaving the net level of economic activity unchanged in non-metropolitan areas. In contrast to the partial-equilibrium findings of Keeler and Ying (1988) these results caution against focusing exclusively on regions or specific industries. There are also significant ''run-up'' effects in local economic activity in the years immediately preceding the opening of a new interstate. Our findings also provide both theoretical and empirical support for the literature on the ''leakage'' effects of public-infrastructure along the lines hypothesized by Munnell (1992), and Rephann and Isserman (1994). In addition, because aggregate-output data masks inter-industry differences in the effects of public-infrastructure, we caution against the use of such data, and recommend that the literature use industry-level data to uncover the relationship between infrastructure and sectorial growth dynamics.

More specifically, we find that the construction of a new interstate highway raises economic growth, as measured by total earnings, in counties that the highway directly passes through. These counties were also found to experience an increase in earnings in the manufacturing, retail trade, services, and TCPU industries. Manufacturing earnings were also found to increase in counties that were adjacent to highway counties. However, adjacent counties were found to experience a reduction in retail trade and government earnings due to the highway's opening. These results are consistent with our theoretical model of spatial competition whereby regional highway investments aid the nationally oriented manufacturing industry but lead to the reallocation of economic activity in more regionally oriented industries.

Our empirical estimates were for non-metropolitan counties but may be instructive regarding the impact of highway infrastructure on metropolitan area economies. Our industry level findings regarding the manufacturing industry suggest that manufacturing might be expected to grow in metropolitan areas receiving a new interstate highway. A metropolitan area also might not be expected to see the losses in the retail industry that occurred in non-metropolitan regions, in part due to the leakage of retail activity down the highway to nearby metropolitan areas. These factors suggest the potential for new highways located in metropolitan areas to lead to net increases in economic activity. However, metropolitan areas also may experience the same sort of rearrangement of economic activity within the region and among industries that were identified in this study. Further, recall that statewide studies by Holtz-Eakin (1994) and others found no statewide impact of public infrastructure on state output. This suggests that highways may bring no net gain in economic activity to metropolitan areas, given no statewide impact and the finding in this study of no net impact in non-metropolitan regions.

The results from our paper suggest that opening new interstate highways will not increase net economic activity in non-metropolitan regions. The dual effects of economic activity moving away from adjacent counties towards highway counties, and the intra-county reallocation of industrial structure lead to a rearrangement, but no increase, in economic activity. This result, in conjunction with the fact that interstate highway construction estimates range from 18.04 to 20.27 million dollars per mile, questions the logic of viewing highways as the panacea for growth in non-metropolitan America[20]. Given that we have focused on the impact of recent highways on economic activity, our findings become especially significant in the light of the recently passed 200 billion-dollar Transportation Equity Act.

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[20]We obtained cost estimates from the Kentucky Transportation Cabinet (see Commonwealth of Kentucky (1998)). We selected the Commonwealth of Kentucky because the state is considering the construction of a new interstate through the southern corridor of the state, and therefore had amongst the latest set of cost estimates. Interstate highway construction costs vary by terrain and design speed. The numbers that we report apply to design speed of 130 Km/h, and a typical Kentucky county that consisted of 13% flat terrain, 58% rolling terrain, 29% mountainous terrain.

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