University of Toronto
Department of Economics

Working Paper 305

Urban growth and transportation

By Gilles Duranton and Matthew A. Turner

December 19, 2007

Urban growth and transportation[§]

Gilles Duranton*
University of Toronto

Matthew A. Turner[‡]
University of Toronto

This draft: 19 December 2007

ABSTRACT: We estimate the effects of major roads and public transit on the growth of major cities in the US between 1980 and 2000. We find that a 10% increase in a city's stock of roads causes about a 2% increase in its population and employment and a small decrease in its share of poor households over this 20 year period. We also find that a 10% increase in a city's stock of large buses causes about a 0.8% population increase and a small increase in the share of poor households over this period. To estimate these effects we rely on an instrumental variables estimation which uses a 1947 plan of the interstate highway system and an 1898 map of railroads as instruments for 1980 roads.

Key words: urban growth, transportation, public transport, instrumental variables.
JEL classification: L91, N70, R11, R49.

[§]Thanks to Johannes Bröcker, Jan Brueckner, Laurent Gobillon, Andrew Haughwout, Vernon Henderson, Guy Michaels, Arthur O'Sullivan, Esteban Rossi-Hansberg, and seminar and conference participants at the Canadian Economic Association, Chicago Federal Reserve Bank, CORE, Homer-Hoyt School, UC Irvine, Kiel, Lincoln Institute, New York Federal Reserve Bank, Princeton, RSAI, University of British Columbia, and University of Wisconsin Madison for comments. Financial support from the Canadian Social Science and Humanities Research Council is gratefully acknowledged. We are also grateful to Magda Biesiada, Adam Found, Zhongfang He, and Michael Lackner, for their assistance in preparing the data used in this project.

*Department of Economics, University of Toronto, 150 Saint George Street, Toronto, Ontario, Canada M5S 3G7. Also affiliated with the Center for Economic Policy Research, and the Center for Economic Performance at the London School of Economics, gilles.duranton@utoronto.ca, http://individual.utoronto.ca/gilles/default.html.

[‡]Department of Economics, University of Toronto, 150 Saint George Street, Toronto, Ontario, Canada M5S 3G7. mturner@chass.utoronto.ca, http://www.economics.utoronto.ca/mturner/index.htm.

1. Introduction

We investigate how changes to a city's supply of major roads and public transit in 1980 affect its growth over the next 20 years. Our investigation leads to the following conclusions. First, that a 10% increase in a city's stock of roads causes about a 2% increase in its population and employment and a small decrease in its share of poor households over 20 years. Second, that a 10% increase in a city's stock of large buses causes about a 0.8% population increase and a small increase in the poverty rate. Third, a back-of-the-envelope calculation based on these estimates suggests that road provision does not constitute a cost-effective growth strategy for a city, and that reallocating money from the provision of roads to the provision of buses would be welfare improving at the margin. Fourth, that changes in transportation infrastructure do not affect the composition of industrial activity in a city. Finally, we find that an additional kilometer of major roadway allocated to a city at random is associated with a larger increase in population or employment than is a road assigned to a city by the prevailing political process. This is consistent with other evidence we uncover that local infrastructure spending rises when cities are hit by negative economic shocks. This last finding suggests that road construction may be a substitute for social assistance and that roads are built where land and labor are cheap rather than in the places where traffic is heaviest.

These findings are important for three reasons. First, transportation generally, and infrastructure in particular are large segments of the economy. According to the United States Bureau of Transportation Statistics (2004), the US spent 135.9 billion dollars on federal highways (or 1.3% of GDP) in 2002, while US households devote about 20% of their expenditures to road transport (Glaeser and Kahn, 2004; United States Bureau of Transportation Statistics, 2004). Also, there are frequent claims for the importance of these expenditures, for example, "*The development and implementation of transportation infrastructure projects ... is essential to the well-being of the American people and a strong American economy.*"[1] Given the magnitude of transportation expenditures it is important that the impact of these expenditures on economic growth and welfare be carefully evaluated and not assessed on the basis of the claims of advocacy groups.

Second, our results can provide useful guidance to policy makers charged with planning cities. Since changes in a city's transportation infrastructure cause changes to the city's population and poverty rate, new transportation infrastructure causes complementary changes in the demand for public utilities, schools and social assistance programs. Our results provide a basis for estimating the magnitude of such changes.

Finally, this research is important to furthering our understanding of how cities operate and grow. Transportation costs are among the most fundamental quantities in theoretical models of cities. However, only a few papers provide empirical evidence for the role transportation costs in shaping cities. Thus, our results provide a sounder footing for an important class of theoretical models.

To conduct our investigation we first develop a simple dynamic model of the relationship between transportation infrastructure and urban growth. This model implies a relationship between a city's population growth, its level of population and its supply of transportation infrastructure. It

[1] President G. Bush, September 18th, 2002.

also implies that the transportation infrastructure of a city depends on its past levels of population, its initial level of transportation infrastructure, and the suitability of its geography for building roads.

Our model, along with common sense, also suggests that a city's supply of new transportation infrastructure depends on current and predicted population growth of the city. If true then naive estimates of the effect of transportation infrastructure on growth will be confounded by the fact that transportation infrastructure depends on predicted population growth. This is the fundamental inference problem with which this paper is concerned. The resolution of this problem requires finding suitable instruments for transportation infrastructure. Our analysis suggests that such instruments should reflect either a city's level of transportation infrastructure at some time long ago, or the suitability of its geography for building roads.

To implement such an instrumental variables estimation, we gather data on US metropolitan statistical areas (MSAs). These data describe road infrastructure and provision of public transport, decennial population levels from 1920 until 2000, and the physical geography of cities. We also consider two instruments for transportation infrastructure. The first follows Baum-Snow (2007) and Michaels (2008) and is based on the 1947 plan of the interstate highway system. We derive our second instrument from a map of the US railroad network at the end of the 19th century.

The rest of this paper is as follows. Section 2 reviews the relevant literature. Section 3 introduces our theoretical framework. Section 4 describes the data and discusses our instruments. Section 5 presents our main results regarding the effect of roads on urban growth, while section 6 goes through a number of robustness checks and section 7 focuses on the effects of public transport. Finally, section 8 concludes.

2. Literature

This research contributes to several strands of literature. First, it adds to the work on the determinants of urban growth. Despite the central role of internal transportation in theoretical models of cities, the empirical literature has mostly ignored urban transportation. It has instead emphasized dynamic agglomeration effects (Glaeser, Kallal, Scheinkman, and Schleifer, 1992; Henderson, Kuncoro, and Turner, 1995), the presence of human capital (Glaeser, Scheinkman, and Schleifer, 1995; Glaeser and Saiz, 2004), and climate and other amenities (Glaeser, Kolko, and Saiz, 2001; Rappaport, 2007). We believe that this neglect of transportation variables results from a lack of data about urban transportation infrastructure, a lack of clear predictions regarding the effect of the *level* of transportation infrastructure on subsequent city growth, and the difficulty of dealing with the possible simultaneous determination of population growth and transportation infrastructure in cities — the three main innovations of this paper.

Taking the advice of Lucas (1988) seriously, it may be in cities that economic growth is best studied. Hence, this research is also related to the very large cross-country growth literature precipitated by Barro's (1991) landmark work. As will become clear below, our approach parallels cross-country regressions. However, cross-country regressions are afflicted by fundamental data and country heterogeneity problems which are much less important in the context of metropolitan areas within a country. Furthermore, growth regressions are also plagued by endogeneity problems which are often extremely hard to deal with in a cross-country setting (Acemoglu, Johnson, and Robinson, 2001; Durlauf, Johnson, and Temple, 2005).

There is a substantial empirical literature that investigates various aspects of the monocentric and multicentric model. Much of it is concerned with land use and land prices within cities, an issue not directly related to our work. Only a small a number of papers look at the relationship between transportation costs or infrastructure and the spatial distribution of population. With a (mostly) static perspective, Brueckner (1990) attempts to fit some aspects of the urbanization patterns in developing countries with the fundamental quantities of theoretical urban models, including commuting costs. More recently, Kopecky and Suen (2006) pursued a structural approach to examine the suburbanization of US cities. In what is probably the most closely related paper to our own, Baum-Snow (2007) uses instrumental variables estimation to investigate the effect of the interstate highway system on suburbanization. Put differently, Baum-Snow (2007) is concerned with the effects of transportation infrastructure on the distribution of population *within* cities while we look at the distribution of population *across* cities, a complementary inquiry. Finally, Burchfield, Overman, Puga, and Turner (2006) consider road infrastructure as a possible determinant of urban sprawl in US cities between 1976 and 1992.

Our work is also related to the large literature dealing with the effects of infrastructure investment. This literature was revived by the work of Aschauer (1989) who found extremely large returns to infrastructure investment in the US, and particularly to transportion infrastructure. Subsequent work revised Aschauer's numbers down to more plausible levels but still suffered from fundamental identification problems (see Gramlich, 1994, for a summary of the critiques of this line of research).[2] More recent work has moved away from the macroeconomic approach used in the 1980s and 1990s towards an explicit modeling of sub-national units such as cities or states (Haughwout, 2002). It also shifted its focus away from hard to measure variables such as productivity and developed models with predictions concerning the composition of economic activity and the distribution of population (Chandra and Thompson, 2000; Michaels, 2008). Finally, it has attempted to tackle the fundamental simultaneity problems that plagued earlier literature by either relying on plausibly exogenous developments such as the gradual expansion of the US interstate system (Chandra and Thompson, 2000; Michaels, 2008) or by an explicit modeling of infrastructure provision (e.g. Cadot, Roller, and Stephan, 2006).

Finally, and although this paper is mainly concerned with roads, we also look at the effects of public transit on urban growth and thus complement existing work interested in the effects of public transportation on cities (Baum-Snow and Kahn, 2000; Glaeser, Kahn, and Rappaport, 2007).

[2] In this stream of literature, Fernald (1999) provides the most convincing evidence about the productivity effects of road investment by showing that more transport-intensive industries tend to benefit more from road investment. It does not completely solve the simultaneity problem between road provision and productivity growth that plagues this literature but his approach is arguably less problematic than earlier work.

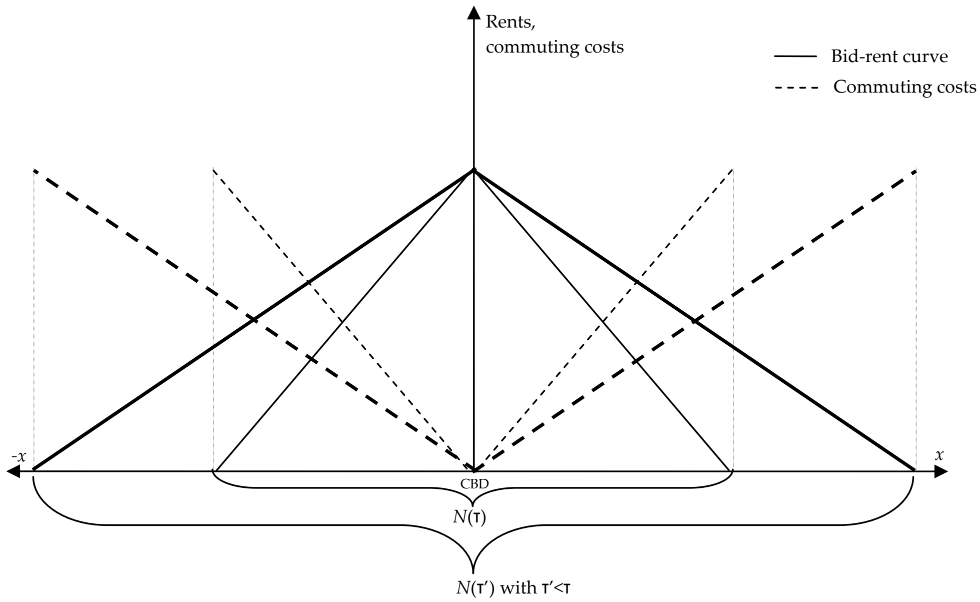


Figure 1. A monocentric city with linear commuting costs

3. Theory

To inform our estimation strategy we develop a theoretical model of the relationship between transportation infrastructure and urban growth. We begin with a simple static model of a monocentric city. In the spirit of Alonso (1964), Mills (1967), and Muth (1969), we consider a linear city where residents commute to a central business district (CBD) to receive a wage w. City residents occupy identical lots of unit size. A worker located at distance x from the CBD pays an endogenously determined land rent $R(x)$ to absentee landowners and incurs a commuting cost τ per unit of distance. Outside the city, land is used in agriculture with its rent is normalized to zero and workers receive net income $\underline{W}$.

In equilibrium, land rents in the city adjust so that workers are indifferent across all locations. Consequently, net income at any city location x is $w - 2\tau x - R(x) = \underline{W}$. Since land rent at the city's edge is equal to zero, it follows that equilibrium city population is

$$N^* = \frac{w - \underline{W}}{\tau}. \tag{1a}$$

That is, the population of a city increases as commuting costs falls. Figure 1 represents an equilibrium for two different levels of commuting costs, τ and τ', where $\tau' < \tau$.

While this model is rudimentary, the negative relationship between population and commuting costs is general. It holds in generalizations which allow for; two-dimensional cities, variable lot sizes, a variety of land ownership arrangements, positive agricultural land rent, heterogenous land users, multiple transport modes, and commuting paid in units of time rather than numéraire (see Brueckner, 1987, for a synthesis and Fujita, 1989, for an in-depth exposition). It is also robust to the possibility of multiple endogenously determined business districts (Anas, Arnott, and Small, 1998) and the existence of 'agglomeration economies' that lead the wage w to depend on the size of the city (Duranton and Puga, 2004).[3] In light of this, the relationship between population and unit commuting costs evident in equation (1a) can be written more generally as,

$$N^* = \frac{\tilde{A}}{\tau^a}, \tag{1b}$$

where $a > 0$ and $\tilde{A}$ describes a composite of wages and the monetary value of amenities available in the city.

Our empirical work investigates how transportation infrastructure contributes to the evolution of population. We concentrate on this issue for two reasons suggested by this model. First, although the standard empirical approach to economic growth suggests an investigation of the relationship between transportation infrastructure and wages or productivity, equation (1a) shows that this inquiry is problematic in the context of 'open' cities. Changes in commuting costs are not reflected in the wage w but are instead reflected in population. Second, the canonical measure of welfare in the monocentric city model is aggregate land rent: the total amount that city residents are willing to pay to live in the subject city rather than their best alternative. While aggregate land rent is extremely hard to measure (see e.g., Davis and Palumbo, 2008), it is clear from figure 1 that this quantity is directly related to the size of the city. Hence, an understanding of what makes cities larger leads to an understanding of what makes them more valuable, in aggregate, to their residents.

To generalize this model to a dynamic setting, we first allow commuting costs τ_t to vary with time, t. Second, we suppose that the intrinsic attractiveness of cities, $\widetilde{A}$, is subject to stochastic shocks. Formally, we substitute Ae_t for $\tilde{A}$ in (1b), where e_t is a non-negative multiplicative shock. All together, this gives,

$$N_t^* = \frac{A\, e_t}{\tau_t^a}. \tag{1c}$$

With costly labor mobility, we can think of N_t^* as the steady-state of a dynamic process. We suppose that the adjustment of a city's population to shocks in the city's attractiveness is given by,

$$N_{t+1} = N_t^{*b} N_t^{1-b}, \tag{2}$$

for $b \in (0,1)$. It is easy to check that N_t^* is a steady state of this equation and that the rate of convergence increases as b approaches unity.[4]

[3] The caveat, when considering agglomeration effects, is that the commuting costs parameter is often amalgamated with the parameter capturing the strength of agglomeration effect to derive equilibrium city size. In simple terms: Lower commuting costs lead to a larger city and, in turn, a larger city offer higher wages, which makes it grow again. It could also be that lower commuting costs directly affect the scope and magnitude of agglomeration effects. All this suggests that in empirical work it will be difficult to neatly separate 'pure' commuting effects from those combined with agglomeration.

[4] Two minor caveats apply here. First, migration in equation (2) depends on the size of a city relative to its steady state rather than differences in net incomes as typically assumed in the migration literature (Greenwood, 1997). However, using population size relative to its steady-state is consistent with the standard approach since, in our model, city population is a determinant of net income. In addition, the specification of equation (2) has two advantages over one directly based on differences in net incomes. First, it yields a simpler specification for city growth in (3) below. It is also empirically preferable because it implies an asymmetry in growth rates between cities smaller than their steady-state that can grow very fast and cities larger than their steady-state that will decline at a slower pace. This asymmetry in the adjustment process is consistent with the empirical evidence uncovered by Glaeser and Gyourko (2005). Our second caveat is that workers make myopic decisions. We believe that a fully dynamic model in which workers would make decisions based on their expected lifetime income would greatly complicate the model and offer no additional useful insight for our purpose (Matsuyama, 1992).

Taking the logs of (1c) and (2) and combining them yields:

$$\Delta \ln N_{t+1} = b \ln A - a\, b \ln \tau_t - b \ln N_t + b \ln e_t, \tag{3}$$

where Δ is the first-difference operator.

Our model so far describes the relationship between unit commuting costs and the evolution of population. However, we are interested in understanding the relationship between the level of transportation infrastructure and the evolution of population. Thus, to proceed we must specify the relationship between transportation infrastructure and unit transportation costs. We would like this relationship to satisfy three conditions. All else equal, commuting costs should increase with city population (as transportation networks become congested) and decrease with transportation infrastructure (as commuting becomes more direct and less congested). We also expect commuting costs within a city to be determined by nationwide technological trends, including for example, the quality of automobiles and the price of fuel. Specifically, we assume

$$\tau_t = K_t\; R_t^{-c}\; N_t^{d}, \tag{4}$$

where K_t measures the quality and extent of transportation technology apart from infrastructure, R_t is a measure of the extent of transportation infrastructure in the city, and c and d are non-negative constants.

Taking logs and inserting equation (4) into (3) gives,

$$\Delta \ln N_{t+1} = b \ln A - a\, b \ln K_t + a\, b\, c \ln R_t - b(1 + a\, d) \ln N_t + b \ln e_t. \tag{5a}$$

After indexing cities by i and allowing A, N_t, and R_t to vary across cities, we introduce the simplifying notation; $B_i \equiv b \ln A_i$ is a city-specific constant, $D_t \equiv a\, b \ln K_t$ is a time-specific constant, $C_1 \equiv a\, b\, c$ is the transportation infrastructure elasticity of population growth, $C_2 \equiv b(1 + a\, d)$ is the population size elasticity of population growth, and $\epsilon_{it} \equiv b \ln e_{it}$ is a random disturbance. We can now write equation (5a) as

$$\Delta \ln N_{it+1} = B_i + C_1 \ln R_{it} - C_2 \ln N_{it} - D_t + \epsilon_{it}. \tag{5b}$$

In the data, we observe initial and final levels of population, N_{it} and N_{it+1}, and the stock of transportation infrastructure, R_{it}. We can proxy for the unobserved city specific constant with a vector of observed city control variables, including historical population levels, and replace B_i in equation (5b) by $B \cdot \left(X_i, (\ln N_{it-j})_{j=0}^{t} \right)$. However, we do not observe the stochastic error, ϵ_{it}.[5]

Our principal goal in the remainder of the paper is to estimate equation (5b), and in particular to estimate the transportation infrastructure elasticity of population growth, C_1. This parameter describes the relationship between infrastructure and a city's growth, and thus appears to be

[5] Equation (5a) bears a strong resemblance to the standard estimating equation in the empirical growth literature, a.k.a., growth regressions (Barro and Sala-i-Martin, 1992). Three differences must be highlighted. First, the dependent variable differs (population rather than income per capita). Second, the state variable that slowly adjusts also differs (population rather than capital). Finally and more importantly, we will pay considerable attention below to the possible endogeneity of the predetermined variable, R_{it}, an issue seldom addressed in the growth literature (Durlauf *et al.*, 2005).

the quantity of most interest to policy makers.[6] However when estimating (5b), we expect that transportation infrastructure is assigned to a city, not at random, but on the basis of its past, current, and future ability to attract people. This suggests that OLS is not appropriate to estimate (5b) because of the probable correlation between transportation infrastructure and ϵ_{it}.

To think more carefully about the possibility that transportation infrastructure is not assigned randomly to cities, we require an explicit model of how this infrastructure in a city evolves. We would like our model of the evolution of transportation infrastructure to have the following properties: all else equal, a city with more people today will have more transportation infrastructure tomorrow; a city with more transportation infrastructure today will have more transportation infrastructure tomorrow; transportation infrastructure depreciates; the supply of transportation infrastructure may be subject to random shocks, either from natural events or from randomness in the appropriations process. Finally, the supply of transportation infrastructure depends on some fixed city characteristics, $\widetilde{Z}_i$, that describe the difficulty of building infrastructure or the city's initial stock of infrastructure. More formally, we suppose that

$$R_{it+1} = f\, N_{it}^{g}\, R_{it}^{h}\, \widetilde{Z}_i\, \widetilde{\mu}_{it}, \tag{6}$$

where f is a non-negative constant and g and h are constants in $(0,1)$ and $\widetilde{\mu}_{it}$ a disturbance term.[7]

Using (6) recursively and taking logs yields:

$$\ln R_{it} = \sum_{j>1}^{t} F_j \ln N_{it-j} + G \ln R_{i0} + H\widetilde{Z}_i + \mu_{it}, \tag{7}$$

where the F's are coefficients associated with past population levels, G is a coefficient associated with initial levels of roads, H is a coefficient associated with city characteristics, and μ_{it} an error term.

An inspection of the equations describing the evolution of population and infrastructure, (5b) and (7), makes clear that road infrastructure will be endogenous if μ_{it} and ϵ_{it} are correlated. That is, if the provision of roads anticipates population growth. We propose an instrumental variables estimation to deal with this possible endogeneity problem. From equation (7) we see that valid instruments will fall into one of two categories. Either they will measure R_0, the initial stock of roads in the city, or $\widetilde{Z}$, other characteristics of the city that makes it more or less suitable to the construction of roads.

Formally, letting Z denote our instrumental variables (measuring either the initial road network or physical characteristics of cities that do not determine directly urban growth), our estimating

[6] For more academic purposes, however, it may be of interest to decompose C_1 into its component parts: a, the overall effect of commuting (i.e., any direct effect as well as any indirect effect that might work through agglomeration); b the speed of convergence; and c the transportation cost elasticity of transportation infrastructure. This is not going to be possible to do so from (5b) since we are only be able to identify C_1 $(= a\,b\,c)$ and C_2 $(= b(1 + a\,d))$. We address the issue of convergence speed in section 6.

[7] The provision of transportation infrastructure in this equation could also have a forward-looking component. It would be straightforward to include it and it would only reinforce the case for our estimation strategy.

equations are:

$$\ln R_{it} = \sum_{j=0}^{t} F_j \ln N_{it-j} + H_1 Z_i + H_2 X_i + \mu_{it}\,, \tag{8}$$

$$\Delta \ln N_{it+1} = B \cdot \left(X_i, (\ln N_{it-j})_{j=0}^{t} \right) + C_1 \widehat{\ln R_{it}} - C_2 \ln N_{it} - D_t + \epsilon_{it}\,. \tag{9}$$

We now turn our attention to the construction of our data and instruments.[8]

4. Data

Our unit of observation is a US Metropolitan Statistical Area (MSA) within the continental US constructed from 1999 boundaries. MSAs are defined as a collection of counties. Since counties are systematically larger west of the Mississippi river than east, all else equal, western MSAs contain more roads than eastern MSAs. To correct this measurement problem we restrict attention to developable land within each MSA in 1980 according to the procedure described in Appendix A. This appendix also contains further details about the data presented in this section. Summary statistics for our main variables are reported in table 1.

Main variables

In a typical regression we predict MSA population growth between 1980 and 2000 as a function of 1980 MSA characteristics. This choice of study period is not arbitrary. 1984 is the date of the earliest available electronic inventory of public transit, and 2000 the most recent census year.

We use data from decennial censuses to construct the dependent variable for most of our regressions, change in log population between 1980 and 2000, or more formally, $\Delta_{00,80} \ln Pop = \ln Pop_{00} - \ln Pop_{80}$. We sometimes examine growth over subperiods of this time frame by constructing analogous measures for 1980–1990 and 1990–2000. We also use the natural logarithms of MSA population levels in decennial years between 1920 and 1980 as control variables.

To investigate the relationship between transportation infrastructure and employment growth we use changes in log employment between 1980 and 2000, $\Delta_{00,80} \ln Emp = \ln Emp_{00} - \ln Emp_{80}$, as a dependent variable. We make similar calculations for 1980 to 1990 and 1990 to 2000. Our source for employment data is County Business Patterns, and our use of these data is described in Appendix A.

Our measure of an MSA's stock of roads in 1980 is the logarithm of the number of kilometers of major roads in the MSA. To calculate this measure we use the USGS 1980 digital line graph, which reports major roads in the US as of 1980. The top panel of figure 2 shows a detail of 1980

[8] One might also estimate C_1 by taking the first difference of (5b). This would amount to estimating city population change between t and $t+1$ as a function of the changes in population and transportation infrastructure between $t-1$ and t. This would have the advantage of differencing out time-invariant city characteristics. However, this would also introduce three fundamental problems. First, with our data, changes in transportation infrastructure would be badly mismeasured. Second, changes in transportation infrastructure are even more likely to be endogenous than their levels and it will more difficult to find adequate instruments.Third, there is some uncertainty about the time horizon over which the transportation infrastructure affects urban growth. A first-difference approach makes it difficult to deal flexibly with this problem with limited data.

Table 1. Summary statistics for our main variables. Averages are across all 275 MSAs with 1999 boundaries.

	Mean	Std. dev.
1980 Population ('000)	648.3	1564.0
2000 Population ('000)	818.0	1908.6
1980-2000 Annual population growth (%)	1.1	1.2
1980 Employment ('000)	218.4	548.9
2000 Employment ('000)	349.6	790.3
1980-2000 Annual employment growth (%)	2.7	1.4
1980 Roads (km)	537.6	577.0
1980 Roads per 10,000 pop. (km)	15.9	8.1
1980 Peak service large buses	141.3	516.0
1980 Peak service large buses per 10,000 pop.	1.1	1.0
Aquifer (% area)	30.9	37.8
Elevation (m)	628.0	891.8
Ruggedness index	9.4	11.1
Heating degree days (days $\times$ F^o)	4580.8	2235.7
Cooling degree days (days $\times$ F^o)	1348.4	923.1
Planned 1947 highways (km)	88.6	109.5
1898 Railroads (km)	235.9	276.7

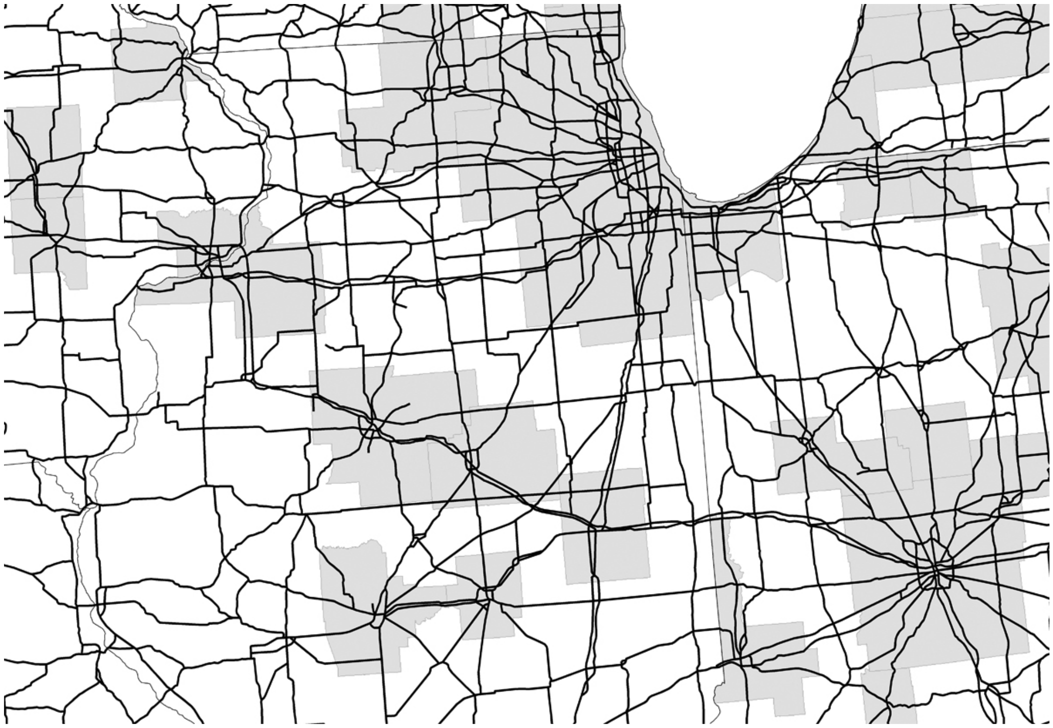
roads for the area surrounding Chicago. The bottom panel of figure 2 plots log 1980 kilometers of road against log 1980 population for all US MSAs. The slope of the regression line for that figure is 0.62. To measure public transit infrastructure, we use data from the 'Section 15 annual reports' mandated by the Urban Mass Transportation Act. Following a procedure described in Appendix A, this allows us to measure the daily average number of large buses operating at peak service in 1984 for each MSA.

In addition to historical population levels we use several controls for an MSA's physical geography. In light of the finding in Burchfield *et al.* (2006) that the availability of groundwater is an important determinant of the spatial structure of MSAs, we use the share of each MSA's land which overlays an aquifer to control for the availability of groundwater. Since terrain may impact both economic growth and the costs and effects of transportation infrastructure, we use MSA elevation range and an index of terrain ruggedness as control variables. Finally, since climate may affect both population growth and the costs of transportation infrastructure, we use heating degree days and cooling degree days as controls for climate. These five physical geography variables are described at greater length in Burchfield *et al.* (2006).

In some regressions we also use indicator variables for each of the nine census divisions and a variety of socio-demographic characteristics from the 1980 census as control variables.

Our first instrument for roads derives from the 1947 plan of the interstate highway system. To construct this variable we create a digital image of the 1947 highway plan from its paper record (United States House of Representatives, 1947) and convert this image to a digital map with the same format and projection as the map of 1980 roads. We then calculate kilometers of 1947 planned interstate highway in each MSA, just as we perform the corresponding calculation for 1980 roads. In figure 3, the top panel shows the original map of the planned interstate highway network and the bottom panel a detail from the digital map for the area around metropolitan Chicago.

Our second instrument for 1980 roads is based on railroad routes around 1898. To construct



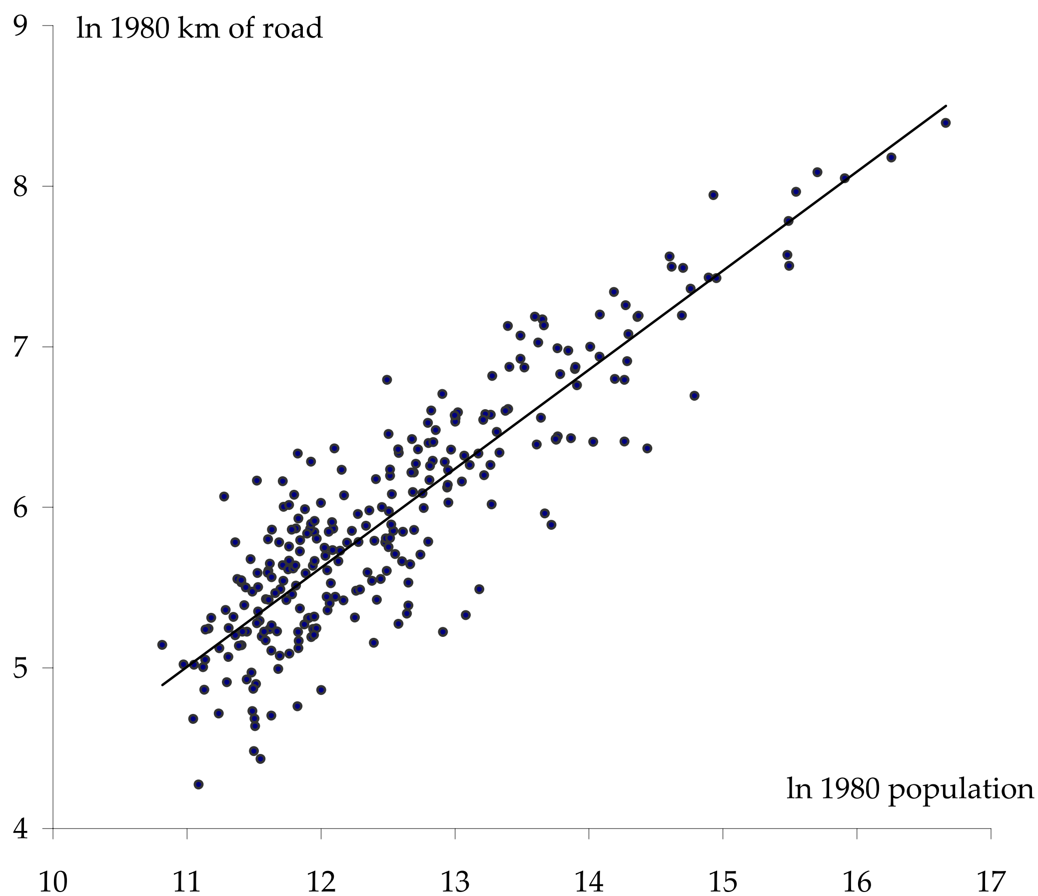
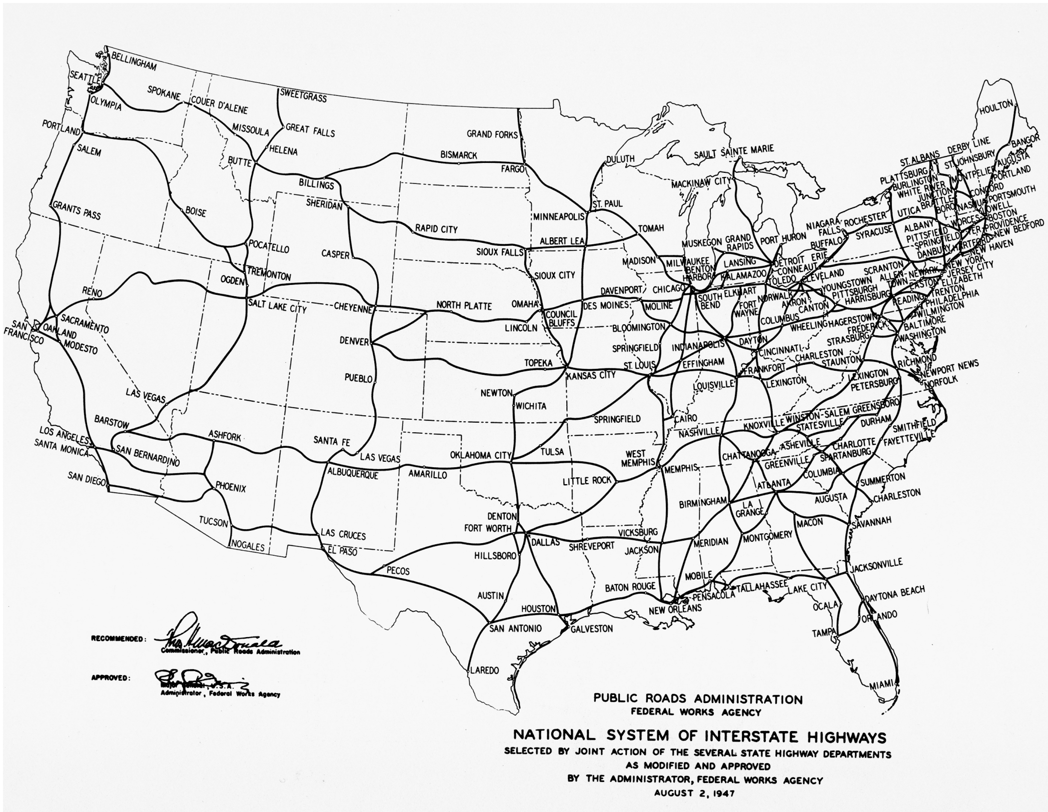


Figure 2. TOP: Roads around metropolitan Chicago from 1980 USGS digital line graph. Shaded areas indicate 1999 MSA boundaries. BOTTOM: scatterplot of log 1980 kilometers of road against log 1980 population.



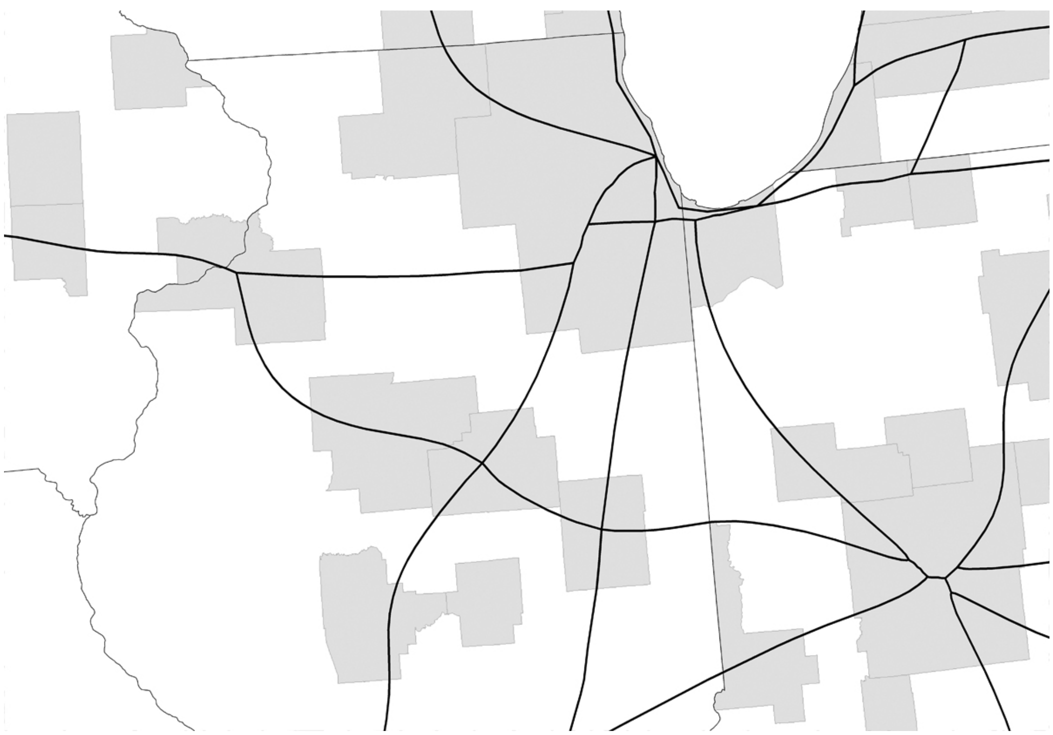


Figure 3. TOP: 1947 US interstate highway plan. BOTTOM: detail of area surrounding metropolitan Chicago from the 1947 highway plan. Shaded areas indicate 1999 MSA boundaries.

this variable we obtain a digital image of a map of major railroad lines from this year (Gray, c. 1898) and convert this image to a digital map with the same format and projection as the map of 1980 roads. We then calculate kilometers of 1898 railroad contained in each MSA just as for 1980 roads. Unless noted otherwise, our instrumental variables and our measure of roads are calculated for the developable land in the 1999 boundaries of each MSA. Figure 4 shows an image of the original railroad map (top panel) and a detail from the digital map for the area around metropolitan Chicago (bottom panel).

Relevance of the instruments

Estimating the system of equations (8) and (9) with instrumental variables estimators can yield an unbiased estimate of C_1 provided that our instrumental variables satisfy two conditions, relevance and exogeneity. Formally, these conditions are

$$\mathrm{Cov}(Roads, Z|.) \neq 0 \tag{10}$$

and

$$\mathrm{Cov}(\epsilon, Z) = 0. \tag{11}$$

We begin by discussing the ability of our instruments to predict 1980 kilometers of major roads in an MSA's developable land.

After some early planning by the bureau of public roads in 1921, President Franklin D. Roosevelt took an interest in a national highway system and in 1937 began planning such a system. Subsequently, a National Interregional Highway committee recommended a plan for the national highway system. This plan considered a strategic highway network suggested by the War Department, the location of military establishments, interregional traffic demand, and the distribution of population and economic activity at that time. In turn, this plan informed the 1944 Federal Aid Highway Act, which led to the 1947 highway plan shown in the top panel of figure 3.

Substantive funding for the interstate highway system, arrived with the Federal Aid Highway and Highway Revenue Acts of 1956, and by 1980, the federal interstate highways system was substantially complete. The relevance of the 1947 planned interstate highway system is obvious. First, the 1947 highway plan does describe many of the highways that were built after 1956, even though the federal interstate highway system in 1990 consisted of more than 43,000 miles of highways, as opposed to about 37,000 in the 1947 plan. Second, the federal interstate highway system constitutes an important part of the modern road network, representing about a quarter of person miles traveled in the US (United States Department of Transportation, Federal Highway Administration, 2005).[9]

Turning to railroads, there are two reasons to suspect that the 1898 railroad network will predict the modern road network. First, building both railroad tracks and automobile roads requires leveling and grading a roadbed. Hence, an old railroad track is likely to become a modern road because old railroads may be converted to automobile roads without the expense of leveling and

[9]The preceding description of the 1947 highway plan and the history of the interstate highway system borrows from Baum-Snow (2007) and Michaels (2008).

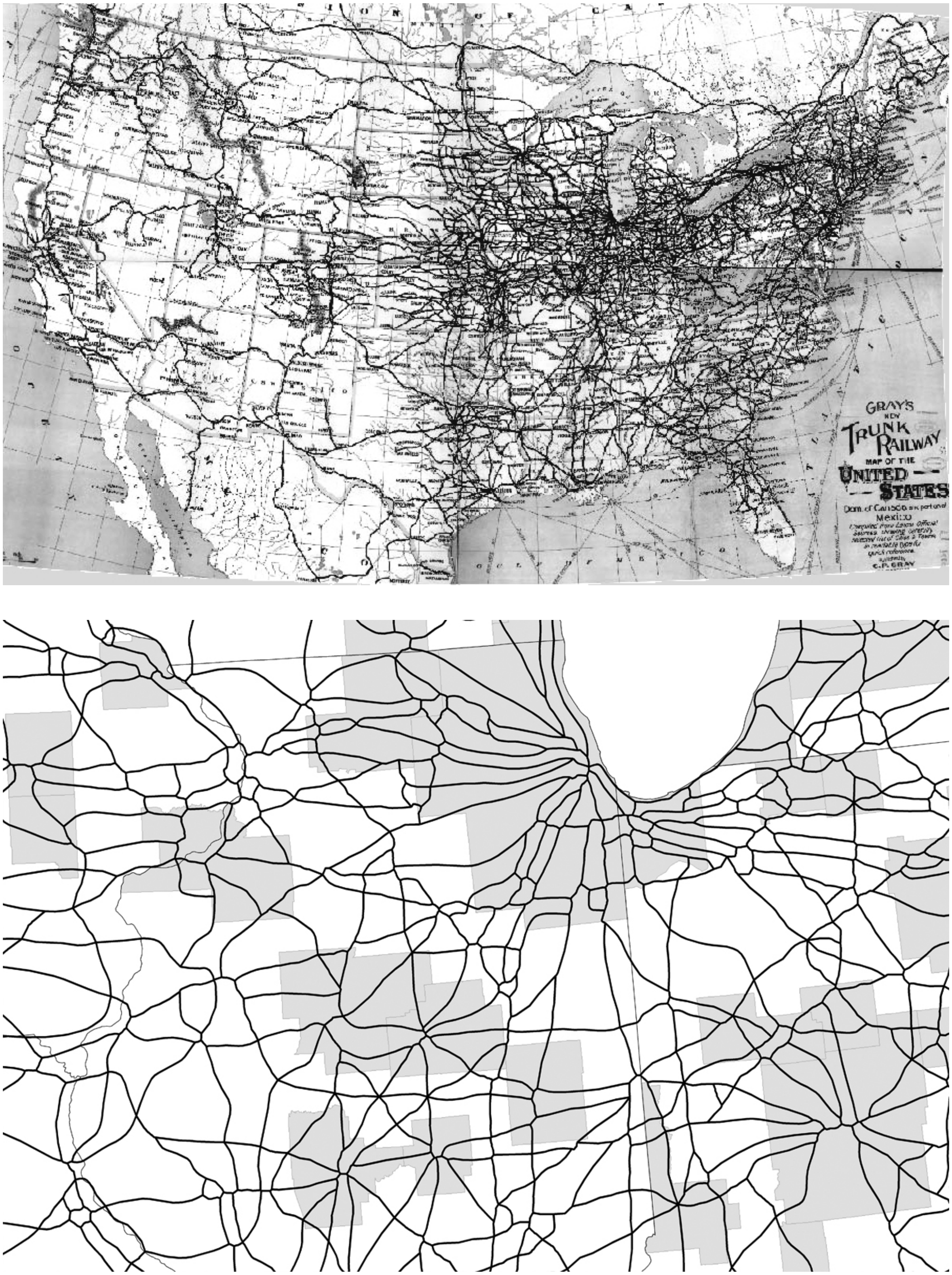


Figure 4. TOP: Gray's map of 1898 railroads. BOTTOM: Detail of digitized version of this map for the area around metropolitan Chicago. Shaded areas indicate 1999 MSA boundaries.

Table 2. Pairwise correlations: kilometers of modern roads and historical transportation networks

	ln(km 1980 roads)	ln(km 1947 highways)
ln(km 1947 highways)	0.63	-
ln(km 1898 railroad)	0.60	0.56

All variables computed for the developable area of each MSA drawn to 1999 boundaries.
275 observations.

Table 3. First stage

Variable	[1]	[2]	[3]	[4]	[5]	[6]	[7]
ln(Railroad routes)	0.064	0.107	0.098	0.108	0.122		0.114
	(0.028)^b	(0.033)^a	(0.031)^a	(0.030)^a	(0.030)^a		(0.032)^a
ln(Planned Interstate Hwy)	0.043	0.030	0.033	0.035		0.048	0.043
	(0.013)^a	(0.013)^b	(0.013)^b	(0.013)^a		(0.012)^a	(0.014)^a
$\ln(\text{Pop}_{80})$	Y	Y	Y	Y	Y	Y	Y
$\{\ln(\text{Pop}_t)\}_{t\in\{20,...70\}}$	N	Y	Y	Y	Y	Y	Y
Physical Geography	N	N	Y	Y	Y	Y	Y
Census Divisions	N	N	N	Y	N	N	N
R-squared	0.81	0.83	0.84	0.86	0.83	0.83	0.81
F-test (H_0 − All instruments zero)	11.01	11.23	12.28	16.11	16.33	16.09	17.76
Partial R-squared	0.08	0.10	0.10	0.12	0.07	0.05	0.14

Dependent variable: ln(1980 road km.).
All regressions include a constant. Robust standard errors in parentheses.
275 observations for each regression.
Measures of 1980 roads and instruments are calculated for the developable area of each MSA, except for columns 7 where calculations are based on the whole area of the MSA.
a, b, c: significant at 1%, 5%, 10%.

grading. Second, railroad builders and road builders are interested in finding straight level routes from one place to another. Thus, the prevalence of old railroads in an MSA is an indicator of the difficulty of finding straight level routes through the local terrain. In short, the extent of the 1898 railroad should predict the extent of the modern road network because old railroad beds are natural places to locate new roads and because an extensive old rail network may indicate terrain where it is easy and inexpensive to build roads. Note that these two arguments for the relevance of 1898 rail are consistent with the requirements of estimating equations (8) and (9) that an instrument for modern roads measure either the initial road network or the suitability of the MSA for road building.

The raw data confirms our priors that the 1947 highway plan and the 1898 railroad network predict the current road network. Table 2 presents pairwise correlations between our instruments and 1980 roads. This table shows that kilometers of 1898 rail and of 1947 planned highways are correlated with kilometers of roads in 1980.

While the correlations in table 2 are interesting, equation (10) makes clear that the validity of an instrument depends on the *partial* correlation of the instrumental variables and the endogenous regressor. To assess these partial correlations, table 3 presents the results of OLS regressions of log kilometers of 1980 roads on our instrumental variables and controls.

Column 1 of table 3 examines the partial correlation between 1980 roads, the 1947 highway plan and the 1898 railroad network. Columns 2, 3 and 4 augment this regression with controls for historical population, physical geography and census region dummies. As a robustness check, columns 5 and 6 duplicate the regression of column 3 using each of the instrumental variables alone. Coefficient estimates for the two instrumental variables, 1947 highways and 1898 railroads, are highly significant, have the expected positive signs and are stable across specifications. Finally, column 7 repeats column 3 using our measure of 1980 roads and instrumental variables calculated for entire MSAs, rather than developable land within MSAs. We see that removing our correction for county size actually increases the explanatory power of our instruments.

The partial R-squareds in table 3 suggest that our instruments are relevant in the sense of equation (10), however, to make a more formal assessment of the relevance of our instruments we turn to the weak instrument tests developed by Stock and Yogo (2005). Stock and Yogo (2005) provide two tests for weak instruments, both based on an F-statistic of the instrumental variables. The first of these tests is of the hypothesis that two-stage least square (TSLS) small sample bias is small relative to the OLS endogeneity bias ('bias test'). The second of these is that the size and level of a 2nd stage F-test are 'close' ('size test'). Note that instruments may be weak in one sense but not another, and instruments may be weak in the context of TSLS but not when using limited information maximum likelihood (LIML).

Table 3 reports the relevant F-statistics. Column 3 corresponds to the first stage of our preferred IV estimate below and has an F-statistic of 12.28. From tables 1-4 in Stock and Yogo (2005) we see that this regression passes both size and bias tests in the context of LIML estimation, and the size test in the context of the TSLS estimation (the bias test is not available for TSLS with two instrumental variables). Other regressions which use the 1947 highway plan or 1898 railroads, columns 1-3 and 5-7, have F-statistics that are near or above the critical values for the relevant weak instruments tests.

In sum, more formal testing of the strength of our instruments leads to us to conclude that 1898 rail and 1947 planned highways are not weak instruments in our preferred specification nor in other specifications of interest.[10]

Instrument exogeneity

Equation (11) gives the second condition that must be satisfied by a valid instrument: the instrument must be orthogonal to the error term. More heuristically, the difficulty in inferring the effect of roads on population growth arises because of the possibility that the assignment of roads to cities anticipates population growth. To overcome this problem, we require an instrument which affects population growth only through its effect on roads. We now develop *a priori* arguments that our instruments satisfy this condition.

[10]We also experimented with a third instrument based on exploration routes in early US history. The National Atlas of the United States of America (1970) describes the routes of major expeditions of exploration that occurred during each of five time periods; 1528–1675, 1675–1800, 1800–1820, 1820–1835, and 1835–1850. From this we calculated kilometers of exploration routes used between 1528 and 1850 in each MSA. Unfortunately this turned out to be a weak instrument. The first-stage F-statistics when using this variable alone in a specification similar to those of columns 5 or 6 of table 3 is only 5.8, well below Stock and Yogo's critical values for weak instrument. Given the poor ability of historical exploration routes to predict modern roads, we do not make use of this variable in our analysis.

We begin with 1947 planned highway miles. The 1947 plan was first drawn to *'connect by routes as direct as practicable the principal metropolitan areas, cities and industrial centers, to serve the national defense and to connect suitable border points with routes of continental importance in the Dominion of Canada and the Republic of Mexico'* (United States Federal Works Agency, Public Roads Administration, 1947, cited in Michaels, 2008).

From this statement and other sources we conclude that the 1947 highway plan was drawn to satisfy the needs of national defense and inter-city trade as of the mid-1940s.[11] There is no mention of future development. In particular, the mandate for the planned highways does not require planners to anticipate population growth. The fact that the interstate highway system quickly diverged from the 1947 plan is consistent with this mandated myopia: the 1947 plan was amended and extended from about 37,000 to 41,000 miles before it was funded in 1956, and additional miles were subsequently added. Some of these additional highways were surely built to accommodate population growth that was not foreseen by the 1947 plan. In sum, the 1947 highway plan appears to provide a way to resolve our inference problem: it predicts roads in 1980, but by construction, should not predict population growth between 1980 and 2000.

While this is a strong argument for the exogeneity of the 1947 highway plan, the 1947 highway plan can still be endogenous if two conditions hold. First, if our measure of the 1947 highway plan is correlated with some 1947 quantity that predicts both growth between 1980 and 2000 *and* 1980 roads, and this 1947 mystery variable is not among our control variables. As a hypothetical example, the 1947 highway plan would be endogenous if it assigned roads to cities with more commuting in 1947, and these cities grew faster after 1980. In fact, as Baum-Snow (2007) forcefully points out, commuting is not one of the intended functions of highways in the 1947 plan.[12] More generally, since we believe that commuting costs are the channel through which infrastructure affects population growth (see section 6 for more on this), it is reassuring that the 1947 plan was drawn up without the explicit intention to facilitate commuting.

A qualifying comment is in order. Equation (11) requires the orthogonality of the dependent variable and the instruments conditional on control variables, not unconditional orthogonality. This is an important distinction. Cities that receive more roads in the 1947 plan tend to be larger than cities that receive less. Since we observe that large cities grow more slowly than small cities, 1947 highway planned highway kilometers predicts population growth directly as well operating indirectly through its ability to predict 1980 road kilometers. Thus the exogeneity of this instrument hinges on having an appropriate set of controls, historical population variables in particular. This is consistent with our finding, presented below, that our regressions fail to pass over-identification tests when we do not control for historical population levels.

We now consider the 1898 railroad network. While the *a priori* case for the exogeneity of the 1947 planned highway network rests on the fact that the mandate for this map was to consider only contemporaneous economic activity and national defense, the *a priori* case for thinking that 1898 railroad kilometers is a good instrument rests on the length of time since these railroads were

[11]See Mertz (undated) and Mertz and Ritter (undated) as well as other sources cited in Chandra and Thompson (2000), Michaels (2008), and Baum-Snow (2007).

[12]This omission is understandable because the number of cars in the US in 1947 was less than 40 million against nearly four times as many in 1980.

built, and the fundamental changes in the nature of the economy in the intervening years, a very different foundation.

The United States Bureau of Statistics (1899) (p. 362) reports about 180,000 miles of railroad track in operation in the US in 1897. All but 10,000 miles were constructed after 1850 (United States Bureau of Statistics, 1879, p. 151) and nearly half after 1880. Thus, the rail network was built, for the most part, during and immediately after the civil war, and during the industrial revolution. At the peak of railroad construction, around 1890, the US population was 55 million (United States Bureau of Statistics, 1899, p. 10), while the agricultural population was 9 million, about 16% of the population (United States Bureau of Statistics, 1899, p. 23). By 1980, the population of the US was about 220 million (United States Bureau of the Census, 1981, p. 7) with only about 3.5 million, or 1.6% employed in agriculture (United States Bureau of the Census, 1981, p.406). Thus, while the country was building the 1898 railroad network the economy was much smaller and more agricultural than it was in 1980, and was in the midst of technological revolution and a civil war, both long completed by 1980.

Furthermore, the rail network was constructed by private companies who were looking to make a profit from railroad operations in a not too distant future. See Fogel (1964) and Fishlow (1965) for two classic accounts of the development of US railroads. It is difficult to imagine how a rail network built for profit could affect economic growth in cities 100 years later save through its effect on roads. As for the highway plan, the same important qualifying comment applies: instrument validity requires that rail routes need only be uncorrelated with the dependent variable conditional on the control variables.

5. Main Results

Table 4 presents our main results regarding the effect of roads on population growth in cities. In the first three columns we present OLS results. In column 1 we include only two regressors, the log of kilometers of 1980 roads in the developable land of each MSA, and the log of 1980 population. As expected, we find that large cities grow more slowly and that more roads are associated with higher levels of population growth. Columns 2 and 3 augment this first regression with controls for decennial population levels, physical geography, and census divisions. We see that the effect of roads on growth decreases dramatically.

In column 4, we present our preferred instrumental variables estimation. This TSLS regression is analogous to the OLS regression of column 2, but uses 1898 rail and 1947 planned highways as instruments for 1980 roads. We see that the coefficient of 1980 roads is 0.21, about five times the corresponding OLS estimate in column 2.[13] Column 5 duplicates the regression of column 4 with the addition of census region indicators. Column 6 also adds squares of our physical geography variables and some interactions between them. Column 7 duplicates 4, but drops controls for

[13]The exogeneity test (Anderson canonical correlation likelihood-ratio test) strongly rejects that the model is under-identified. Hence the instruments are relevant. The same holds for all the IV regressions in this table.

Table 4. Population growth rate 1980-2000 as a function of 1980 roads

Variable	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]
	OLS	OLS	OLS	TSLS	TSLS	TSLS	TSLS	TSLS	TSLS
ln(1980 road km.)	0.128	0.042	0.049	0.210	0.180	0.177	0.231	0.180	-0.286
	(0.042)^a	(0.021)^b	(0.024)^b	(0.069)^a	(0.060)^a	(0.062)^a	(0.069)^a	(0.061)^a	(0.195)
ln(Pop_{80})	-0.078	0.892	0.850	0.652	0.639	0.640	0.770	0.663	0.178
	(0.030)^b	(0.104)^a	(0.119)^a	(0.170)^a	(0.164)^a	(0.165)^a	(0.152)^a	(0.175)^a	(0.118)
$\{\ln(\text{Pop}_t)\}_{t\in\{20,\ldots70\}}$	N	Y	Y	Y	Y	Y	Y	Y	N
Physical Geography	N	Y	Y	Y	Y	Ext.	N	Y	N
Census Divisions	N	N	Y	N	Y	Y	N	N	N
Instruments used:									
ln(Planned Interstate Hwy.)	-	-	-	Y	Y	Y	Y	Y	Y
ln(Railroad routes)	-	-	-	Y	Y	Y	Y	Y	Y
First stage F-test	-	-	-	12.28	16.11	14.70	11.23	17.76	11.01
(H_0 − All instruments zero)									
Over-id test p-value	-	-	-	0.61	0.57	0.51	0.66	0.43	0.00
R-squared	0.04	0.74	0.77	-	-	-	-	-	-

Dependent variable: $\Delta_{00,80} \ln Pop$.
All regressions include a constant. Robust standard errors in parentheses.
275 observations for each regression.
Measures of 1980 roads and instruments are calculated for the developable area of each MSA, except for column 8 where calculations are based on the whole area of the MSA
a, b, c: significant at 1%, 5%, 10%.

physical geography.[14] Column 8 duplicates 4, but uses measures of 1980 roads and instrumental variables based on the whole extent of an MSA, rather than just developable land. The estimate of the effect of roads is stable at about 0.2 in all specifications.

Table 4 also reports the p-values for an over-identification test (Hansen's J statistic) for all of the IV regressions. For our preferred specification in column 4, the p-value of this statistic is 0.63. Thus, we fail to reject our over-identifying restriction. Each of columns 5, 6, 7, and 8, report similarly high p-values for this test statistic. Recall that this test is a test of *joint*-exogeneity. In particular, instruments can pass this test if they are both endogenous and the bias that this endogeneity induces is of similar sign and magnitude.[15] Given different rationales for the exogeneity of the planned highway network and the 1898 rail network, this is unlikely.

Finally, column 9 of table 4 reports an instrumental variables regression like our preferred specification of column 4, but with nearly all control variables omitted. As expected, the over-identification test indicates that our instruments are not valid in this regression. Consistent with our intuition, highway planners in 1947 and railroad builders in the 19th century did choose routes on the basis of factors like geography or contemporaneous population that affect 1980 to 2000 population growth independently of roads. Therefore, as expected, we reject the hypothesis that our instruments are exogenous when we do not control for historical population levels.

In sum, table 4 suggests that a 10% increase in an MSA's stock of roads in 1980 causes the MSA's population to increase by 2% over the course of the following 20 years. Put differently, and using

[14]The dummies for census divisions are usually not significant. Hence, we use them only to assess the robustness of our results. Among the geography variables only the elevation range is routinely significant. We believe that this is due to the strength of past populations as controls. Regressing the difference in log population between 1980 and 2000 on log population levels for all decades between 1920 and 1980 yields a R^2 above 70%.

[15]Endogenous instruments may also pass an over-identification because of sampling error.

our preferred estimate from column 4, an increase in log roads per capita by one standard deviation in 1980 (i.e., 0.55) leads to a metropolitan area population that is 12% larger in 2000. Thus, a one standard deviation change in roads per capita causes a change in the population growth rate of 0.5% per year. This is about half the mean or half the standard deviation for MSA population growth during the period.

To develop some intuition about these numbers, consider West Palm Beach on the Atlantic coast of Florida, and Naples, its smaller twin on Florida's Gulf Coast. While West Palm Beach is in the bottom quartile of roads per capita in 1980, Naples had the fifth highest. The difference between these two cities in roads per capita (1.42 log points) accounts for more than 75% of the differential in population growth between these two cities over the period. A similar calculation can also account for most of the growth differential between West Palm Beach and Miami, its low roads per capita southern neighbor.[16]

While this discussion indicates that the effects of roads on urban growth are large in absolute terms, they are also large relative to the three widely accepted drivers of recent urban growth in the US: good weather, human capital, and dynamic externalities. According to the findings of Glaeser and Saiz (2004) for US MSAs between 1970 and 2000, one standard deviation in the proportion of university graduates at the beginning of a decade is associated with a quarter of a standard deviation of population growth. In his analysis of the effects of climate for US counties since 1970, Rappaport (2007) finds that one standard deviation increases in January and July temperature are associated with, respectively, an increase of 0.6 standard deviation of population growth and a decrease of 0.2 of the same quantity. A direct comparison with the findings of Glaeser *et al.* (1992) on dynamic externalities is more difficult but a standard deviation of their measures of dynamic externalities is never associated with more than a fifth of a standard deviation of employment growth for city-industries. The effect of roads is thus stronger than that of human capital or dynamic externalities and about the same magnitude as that of climate. The main difference, of course, is that a city's road network is a policy variable while its climate is not.[17]

Independent evidence for countercyclical road building

Our prior was that the political process would assign roads to cities in anticipation of population growth, so that the OLS estimate of the effect of roads on growth would be larger than the instrumental variables estimates of this effect. Comparing OLS and TSLS regressions in table 4 shows that this prior was not correct. The estimated effect of roads on population growth increases when we correct for the endogeneity of roads. This means that a road assigned to a city at random is associated with higher rates of growth than a road assigned to a city by the prevailing political process. Since we are controlling for historical population shocks and physical geography, this

[16]These three cities were chosen because their geographies are very similar and their populations are small before 1940. Interestingly, assuming a coefficient of -0.07 for 1980 log population (i.e., something consistent with column 1 of table 5) shows that the growth differentials between these 3 cities is entirely accounted for by their 1980 roads and populations.

[17]It should also be said that a standard deviation of the share of university graduates is small at around one half of a percent whereas one standard deviation for 1980 roads corresponds to 8.1 km per 10,000, that is about half the sample mean.

Table 5. Evidence for road construction during bad times

Variable	[1]	[2]	[3]	[4]	[5]	[6]	[7]
$\Delta_{00,80}$Pop	-0.005	-0.005	-0.008	-0.009			
	(0.003)^c	(0.002)^b	(0.003)^b	(0.003)^a			
$\Delta_{80,70}$Pop					-0.318	-0.255	-0.194
					(0.07)^a	(0.092)^a	(0.113)^c
Share of Employment in non-road construction				0.293			
				(0.147)^b			
Physical Geography	Y	Y	Y	Y	N	N	Y
Census Divisions	N	Y	Y	Y	N	Y	Y
$\ln(\text{Pop}_{80})$	N	Y	Y	Y	N	N	N
$\{\ln(\text{Pop}_t)\}_{t\in\{20,...70\}}$	N	N	Y	Y	N	N	N
R-squared	0.19	0.30	0.34	0.39	0.06	0.20	0.26

Dependent variable in columns 1-4 is employment share in road construction.
Dependent variable in columns 5-7 is: log 1990 road km − log 1980 road km.
All regressions are OLS and include a constant. Robust standard errors in parentheses.
275 observations for each regression.
Measures of roads are calculated for the developable area of each MSA.
a, *b*, *c*: significant at 1%, 5%, 10%.

finding is equivalent to a finding that MSAs which grow more quickly than would be predicted from historical population shocks and physical geography are initially assigned fewer roads than MSAs which grow slowly.

The hypothesis that MSAs with slower conditional growth are assigned more roads may be tested directly. To conduct our first test of this hypothesis, we use detailed employment data in the County Business Patterns to calculate the share of an MSA's population which is employed in building roads during the 1977–1997 period.[18] We then check whether this employment share is negatively correlated with contemporaneous population growth in the MSA, conditional on physical geography and historical population levels. Column 1 of table 5 presents the results of a regression of the share of MSA employment in road construction on the change in log population from 1990 to 2000, controlling for physical geography. The partial correlation between population growth and employment in road construction is negative. Columns 2 through 4 find that this result is robust to the addition of controls for historical population levels, census division indicators, and the share of employment in other construction. Consistent with the difference between our OLS and TSLS results in table 4, we observe that MSAs experiencing negative population shocks have larger road building sectors.

To further test that roads are allocated to MSAs experiencing negative shocks, we look at the relationship between the population shock experienced by an MSA between 1970 and 1980, and the change to its stock of roads between 1980 and the mid 1990s. The first step in this exercise is to calculate the number of kilometers of major roads in each MSA in the 1990s. For this purpose, we use a digital line graph from Environmental Systems Research Institute Inc. (2000) that is compiled from the 1994-7 US National transportation atlas. This digital map reports major roads in the US as of the mid-1990s, and allows us to calculate kilometers of roads in an MSA in the mid-1990s analogously to the calculation for 1980 roads. With this done, we can calculate the change in log

[18]Our measure of employment in road building is based on SIC 16, "heavy construction contractors".

kilometers of an MSA's road network between 1980 and the mid-1990s.[19]

Column 5 of table 5 shows the partial correlation of change in roads between 1980 and the mid-1990s with change in log population between 1970 and 1980. Columns 6 and 7 repeat the calculation when adding controls for physical geography and census divisions. In all cases, we see that the partial correlation is negative. That is, MSAs which experience negative population shocks in one decade, experience positive shocks to their stock of roads in the next decade. In light of our results about road construction employment it is natural to suppose that the next decade's increment to roads follows from changes in the level of road construction contemporaneous with the population shock.[20]

In recent decades, cities that did badly experienced more road construction and faster growth of their road network. One may worry that a similar logic may at play with respect to the 1947 Interstate Highway map and thus possibly hijack our identification strategy. This is not the case. When regressing log 1947 kilometers of planned highway on 1950 population, the coefficient is exactly one. Adding controls for geography and past population growth from the 1920s, 1930s, and 1940s does not change this results. Past population growth controls never come close to being significant at conventional levels. The proportionality with 1950 population and the absence of correlation with past growth are reassuring with respect to the mandate of the Federal Highway System cited above.

In all, the data confirm the results of our instrumental variables estimation. Road building authorities wait for downturns in the local economy to build roads. This suggests both that road construction may serve as a substitute for social assistance, and that roads are built where land and labor are cheap rather than in the places where they are most needed. This political economy of road building was absent at the time of the construction of the Federal Highway System.

6. Further robustness checks

Robustness to changes of econometric strategy

A number of authors (e.g., Stock and Yogo, 2005) now argue for the superiority of the LIML estimator to the TSLS estimator, particularly in the case when instruments are weak. While we report the more familiar TSLS estimates, we have experimented with the LIML estimator. Column 1 of table 6 reports the LIML estimate of our preferred specification. Comparison with column 4 of table 4 shows that the TSLS and LIML estimates are very close. Note that table 6 also reports 95% confidence bounds calculated from the conditional likelihood ratio (CLR) method of Moreira (2003). The lower bound of the CLR is consistent with the TSLS and LIML estimates, although the upper bound is somewhat higher. More generally, we found that the LIML and TSLS estimators are virtually identical in every case.

[19] These two series of road data are not directly comparable but their difference can be used as the dependent variable in a regression provided there is no systematic difference in the data that is correlated with past population changes.

[20] That cities experiencing negative population shocks should receive relatively more new roads does not contradict the strong positive correlation documented above between population and roads. The reason is that this effect of negative population shocks is relatively small. The standard deviation of the *effect* of population changes during the 1970s in column 6 of table 5 is 0.03 whereas that of the change in log roads is 0.12 (and that of log 1990 road is 0.81).

Table 6. Robustness to changes of econometric strategy

Variable	[1]	[2]	[3]
	LIML	TSLS	TSLS
ln(1980 road km.)	0.210	0.232	0.174
	(0.079)[a]	(0.076)[a]	(0.103)[c]
Instruments used:			
ln(Railroad routes)	Y	Y	N
ln(Planned Interstate Hwy.)	Y	N	Y
Lower CLR	0.07	-	-
Upper CLR	0.42	-	-
First stage F-test	13.83	16.33	16.09
(H_0 − All instruments zero)			

Dependent variable: $\Delta_{00,80} \ln Pop$
All regressions include a constant and control for decennial population from 1920 to 1980 and physical geography. Robust standard errors in parentheses (except for LIML estimates).
275 observations for each regression.
a, b, c: significant at 1%, 5%, 10%.
Measures of 1980 roads and instruments are calculated for the developable area of each MSA.

Table 7. Robustness to change of specification

Variable	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
ln(1980 road km.)	0.145	0.066	0.192	0.121	0.071	0.311	0.240	0.204
	(0.050)[a]	(0.031)[b]	(0.108)[c]	(0.090)	(0.051)	(0.087)[a]	(0.116)[b]	(0.077)[a]
First stage F-test	12.28	12.28	12.28	12.28	12.28	4.32	6.77	11.22
(H_0 − All instruments zero)								
Over-id test p-value	0.62	0.71	0.34	0.37	0.61	0.05	0.84	0.57
Observations	275	275	275	275	275	81	194	253

Dependent variable by column: (1): $\Delta_{90,80} \ln Pop$, (2): $\Delta_{00,90} \ln Pop$, (3): $\Delta_{00,80} \ln Emp$, (4): $\Delta_{90,80} \ln Emp$, (5): $\Delta_{00,90} \ln Emp$, (6): $\Delta_{00,80} \ln Pop$ for cities with $Pop > 0.5$, (7): $\Delta_{00,80} \ln Pop$ for cities with $Pop \leq 0.5$m, (8): $\Delta_{00,80} \ln Pop$ for cities with $Pop > 2$m.
All regressions include a constant and control for decennial population from 1920 to 1980 and physical geography. Robust standard errors in parentheses.
In all regressions, roads variables are instrumented by 1898 railroads and 1947 highways.
Measures of 1980 roads and instruments are calculated for the developable area of each MSA.
a, b, c: significant at 1%, 5%, 10%.

We now investigate whether our finding that a 10% increase in roads causes a 2% increase in population over 20 years is robust to our instrumentation strategy. Table 6 presents these robustness checks. In each case; the dependent variable is the change in log population from 1980 to 2000, the road measure and instruments are calculated for the developable area of each MSA, and the control variables are our set of decennial population levels and our measures of physical geography. Columns 2 of table 6 uses only the 1898 rail measure as an instrument, while column 3 uses only the 1947 planned highway measure as an instrument. Both specifications produce estimates of the coefficient of modern roads on population growth that are statistically indistinguishable from 0.2.

Robustness to changes of specification

We now examine the robustness of our results to further changes in specification. The dependent variable in Column 1 of table 7 is the change in log population between 1990 and 1980 (as opposed to 2000 and 1980), but the regression is otherwise identical to our preferred specification. The dependent variable in column 2 is the change in log population between 1990 and 2000, with the regression otherwise identical to our preferred specification. These two regressions indicate that the effect of a change in 1980 roads on MSA population growth is about twice as large in the earlier decade as in the later decade.

As a further check of our results, columns 3, 4, and 5 look at the relationship between change in log *employment* and an MSA's stock of roads. Column 3 corresponds to our preferred specification, but with change in log employment between 1980 and 2000 as our dependent variable. Column 4 is the same, but looks at a change in log employment between 1980 and 1990. Column 5 looks at change in log employment between 1990 and 2000. These results are very similar to the results we obtain for population growth, and show the same pattern of decay.

Columns 6, 7, and 8 check whether our results about the effect of roads on population growth are driven by particular subsamples of our data. Column 6 reproduces our preferred specification for the 81 MSAs with 2000 population larger than 500,000. Column 7 restricts attention to the complementary set of cities with population less than 500,000. Column 8 drops the 22 MSAs with population above two million.[21] The coefficient estimates for the 1980 roads variable reported in columns 6-8 are statistically indistinguishable from our preferred estimate of 0.2 at standard confidence levels. Since the first stage *F*-test of the instrumental variables indicates that our instruments are weak in these specifications, we duplicate these estimations using LIML and CLR confidence bounds. The results are very similar to the reported TSLS results.

Finally, in results not reported here, we experimented with other possible determinants of MSA growth between 1980 and 2000: share of university graduates, mean household income, share of poor, share of households in the highest income bracket, share of university graduates, and average educational achievement. These variables are insignificant or only marginally significant and including them does not affect other coefficient estimates. That variables like educational attainment are insignificant suggests that historical population levels and physical geography are close to being sufficient statistics for variables describing the economic fundamentals of an MSA.

Comparison with the long-run effect of rail

Columns 1 and 2 of table 7 indicate that the effect of roads on population growth is about half as large in the second decade after a change in an MSA's stock of roads as in the first decade after a change. If we assume that this decay rate is constant over every 10 year period, i.e., so the effect of a change in roads in the third decade is half what it is in the second, we can then calculate a 'total effect' of an increase in roads, as opposed the 10 and 20 year effects that we have estimated so far. Using the 10 year effect estimated in column 1 of table 7 we calculate the total 1980 roads elasticity of population growth as $0.145\Sigma_{t=0}^{\infty}(1/2)^t$ or 0.290.

[21]We also experimented with other splits such as fast-growing vs. slow-growing cities, educated vs. less educated cities, institutionally-fragmented vs. non-fragmented cities, segregated vs. non segregated, sprawled vs. compact cities etc. We only found weak evidence that roads may have a stronger effect for more compact and more educated cities. Small sample sizes make it difficult to pursue this further.

Table 8. Long run effects of rail on population growth

Variable	[1]	[2]	[3]
ln(1898 railroad routes)	0.541	0.348	0.328
	(0.126)[a]	(0.085)[a]	(0.098)[a]
$\ln(\text{Pop}_{1920})$	-0.373	-0.192	-0.147
	(0.092)[a]	(0.064)[a]	(0.063)[b]
Physical Geography	N	Y	Y
Census Divisions	N	N	Y
R-squared	0.13	0.65	0.73
Observations	117	117	117

Dependent variable: $\Delta_{00,20} \ln Pop$.
All regressions include a constant. Robust standard errors in parentheses.
Measures of 1898 railroads are calculated for the developable area of each MSA.
a, b, c: significant at 1%, 5%, 10%.

As a further check on the reasonableness of our results, we can compare this number to the long run effect of railroads on the growth of city population. Table 8 presents these results. In each of the three regressions the dependent variable is the change in log population between 1920 and 2000. That is, the 80 year rate of population growth. We predict this long run rate of population growth as a function of the log population in 1920 in column 1. In column 2 we add controls for physical geography and in column 3 we control for physical geography and census divisions. These regressions indicate that the long run population growth elasticity of 1898 rail is between 0.35 and 0.55. While a direct comparisons between the long run effect of rail and the long run effect of 1980 roads is a bit strained, the two numbers appear to be of about the same magnitude.[22]

Market access vs. commuting

Our discussion and analysis assumes that changes in road infrastructure affect an MSA's population growth rate by changing the cost of commuting. However, it is possible that changes to the road network affect an MSA's population growth by increasing its access to markets.[23]

If roads affect an MSA's population growth by affecting access (i.e., reducing transportation costs of accessing the market) then we should see two effects. First, that an MSA's population growth increases with improvements to its own roads. Second that an MSA's population growth increases with improvements to in the road network of its trade partners. Such improvements also reduce the cost of accessing the market. Since the second effect is unique to the market access hypothesis, by checking whether changes to roads in neighboring MSAs affect population growth in the target MSA, we test whether roads affect an MSA's population growth by reducing commuting costs or by improving market access.

[22]Since small cities in 1920 will be counted as MSAs in 1999 only if they grow to at least 50,000 people, including cities that are small in 1920 over-samples small fast growing cities. As a crude way of correcting for this problem, the regressions of table 8 are based on the 117 MSAs with 1920 population of more than 100,000. Such cities could experience large increases or decreases of population and still be counted as MSAs in 1999. We experimented with 1920 population thresholds of 75,000 and 125,000 and find similar results.

[23]Indeed, it is precisely this hypothesis that Michaels (2008) investigates, although he is interested in the effect of interstate highways on small rural counties.

Table 9. Population growth rate 1980-2000 and network effects

Variable	[1]	[2]
ln(1980 road km.)	0.217	0.216
	(0.072)[a]	(0.072)[a]
ln(Neighbor road$_{80}$)	0.009	-
	(0.018)	-
ln(Neighbor gravity$_{80}$)	-	0.003
	-	(0.006)
First stage F-test (H_0 − All instruments zero)	12.44	12.24
Over-id test p-value	0.66	0.67

Dependent variable: $\Delta_{00,80} \ln Pop$.
All regressions include a constant and control for decennial population from 1920 to 1980 and physical geography. Robust standard errors in parentheses.
275 observations for each regression.
In all regressions, MSA roads variables are instrumented by 1898 railroads and 1947 highways.
Measures of 1980 roads and instruments are calculated for the developable area of each MSA, except for column 8 where calculations are based on the whole area of the MSA
a, b, c: significant at 1%, 5%, 10%.

We calculate two measures of changes in neighboring MSAs' stocks of roads. First, for each MSA we identify the largest MSA which is between 150 and 500 kilometers away, i.e., too far to commute but still within a day's drive.[24] For each such neighboring MSA we calculate two measures of roads. The first is simply the logarithm of kilometers of 1980 roads. The second is a 'gravity' based measure,

$$\text{Neighbor gravity} = \frac{\text{Neighbor pop} \times \text{Neighbor road km}}{\text{Distance to neighbor}}.$$

Table 9 presents the results of two regressions. Column 1 is our preferred specification, with the addition of our measure of the neighbor MSA's roads. Column 2 is our preferred specification with the addition of our gravity measure. In both cases we see that the measure of neighbor roads does not affect population growth in the subject MSA and does not affect the coefficient of own roads. While we cannot prove a negative statement, these results are consistent with our premise that the changes in road infrastructure affect city population growth by affecting commuting costs not by affecting market access.

Roads and specialisation of economic activity

The results above focus on the effect of roads on aggregate city population or employment. It might be argued that not all sectors are equally sensitive to roads and commuting costs. Poor road infrastructure may not matter much for footloose sectors that can locate close to residential areas so as to minimize commuting requirements. Other sectors such as business services might be more dependent upon central locations. Employment in such sectors may thus be more sensitive to the transportation infrastructure.

To test the hypothesis that the transportation infrastructure affects the composition of employment in a city, we use data from the County Business Patterns. These data allow us to calculate

[24]Distances are measured from centroid to centroid, where centroids are calculated on the basis of impermeable surface coverage using data from Burchfield *et al.* (2006).

the share of employment in manufacturing, business services, and wholesale trade, for each US metropolitan area. We can also use these data to calculate the share of employment within manufacturing sub-sectors such as electronics or high-tech sectors. This, in turn, allows us to calculate changes in sectoral employment in each of our MSAs between 1977 and 1997.[25] To test the hypothesis that roads affect industrial specialization we regress changes in MSA share of sectoral employment between 1977 and 1997 on the initial employment share, log city population in 1980, geographical controls, and the city's transportation infrastructure using the same instrumental variables estimation strategy as previously.[26]

Despite extensive experimentation, we found no evidence that the transportation infrastructure affects the composition of economic activity, with one exception. We observe a weak positive relationship between roads and the share of employment in high-tech sectors and electronics. However, this effect is not very strong and is likely to reflect the effect of transportation on the socio-economic characteristics of city population which are discussed below. These negative results confirm for an urban sample the result in Michaels (2008) that the Interstate Highway System had no effect on the specialisation of economic activity for rural counties close to an interstate.

7. Public transportation and urban growth

Instrumentation strategy

Our analysis so far focuses exclusively on roads. This focus is justified by the fact that cars account for an overwhelming share of intra-city trips, and close to 90% of daily commutes in 2000 (Glaeser and Kahn, 2004; Pucher and Renne, 2003). However, considerable resources are devoted to public transportation. According to the American Public Transportation Association (2006), the total subsidy for public transportation in the US in 2004 was close to 30 billion dollars.

In this section, we extend our results to public transportation. Our data, from the Section 15 annual reports, allow us to measure public transportation with the daily average peak service of large buses in 1984. Unfortunately, these data do not allow us to investigate other forms of public transportation, such as light rail, independently of buses.[27]

As is the case for roads, to assess the effect of public transportation on subsequent urban growth, determining the direction of causality is the fundamental inference problem that we must overcome. For instance, it might be that population growth expectations formed the basis of the 1984 level of provision of public transportation. It could also be that some urban policies in the early 1980s affected both the local level of public transportation provision and future growth.

To deal with this issue, we again implement an instrumental variables estimation. Our instrument is the MSA share of democratic vote in the 1972 presidential election. The 1972 US presidential

[25] To accomodate changes in in the industrial classification system we perform our analysis for the 1977-1997 period.

[26] Compared to the main regressions performed above, there are three differences. First we use the change in the share of sector employment rather than the change in log total population as dependent variable. Second, we add the initial share of employment in the sector under consideration as control. Third, we no longer control for decennial population between 1920 and 1970 as we see no strong theoretical reason for doing so.

[27] There were simply too few MSAs with light rail in 1984 to permit informative cross-sectional analysis. In the regressions below, we sometimes sum large buses and rail cars to construct an index of public transport.

election between Richard Nixon and George McGovern was fought on the Vietnam War and McGovern's very progressive social agenda. It ended with Nixon's landslide victory. Places where McGovern did well are also arguably places that elected local officials with a strong social agenda. Importantly, this election also took place shortly after the 1970 Urban Mass Transportation Act and it only briefly predates the first oil shock and the 1974 National Mass Transportation Act that followed. While total federal support for public transportation was less than 5 billion dollars (in 2003 dollars) for all of the 1960s, the 1970 act appropriated nearly 15 billion dollars and the 1974 act appropriated 44 billion dollars. Similar levels of funding persist until the time of this writing (see Weiner, 1997; Baldwin Hess and Lombardi, 2005, for a history of US public transportation). More generally, during the 1970s public transit expanded and evolved from a private fare-based industry to a quasi-public sector activity sustained by significant subsidies.

In order for a 1972 election to predict 1984 levels of public transit infrastructure, public transit funding must be persistent. In fact, the 'stickiness' of public transit provision is widely observed (Gomez-Ibanez, 1996) and is confirmed in our data. The Spearman rank correlation of bus counts between 1984 and 2004 is 0.90. Our data also suggest that MSAs which voted heavily for McGovern in 1972 made a greater effort to develop public transit in the 1970s, and these high levels of public transit persisted through our study period. Furthermore, the raw data confirms the relevance of our instrument. The pairwise correlation between log 1984 buses and 1972 democratic vote is 0.34. This partial correlation is robust to adding controls for geography and past population. In a nutshell, the 1972 share of democratic vote is a good predictor of the initial MSA provision of buses which then grew proportionately to population.[28]

Turning to exogeneity, the *a priori* argument for the exogeneity of the 1972 democratic vote is less strong than that for the road instruments. Nonetheless, a good argument can be made that funding for public transportation in American cities in the early 1970s was a response to contemporaneous social needs. More specifically, the provision of buses at this time did not seek to accommodate population growth over the 1980-2000 period. However, it is also likely that a high share democratic vote in 1972 was associated with a variety of other policies and local characteristics that affected subsequent urban growth. In response to this, note first that many of these other policies may not have fostered population growth. For instance, Detroit, who gave McGovern one of its highest shares of vote in 1972, also elected Coleman Young as mayor the following year and his policies certainly contributed to Detroit's population decline (Glaeser and Shleifer, 2005). Coleman Young was an extreme case and we obviously acknowledge that many cities where McGovern received a high share of vote also adopted some pro-growth policies in the early 1970s. Since we control for 1980 population (and thus implicitly for growth between 1970 and 1980), we would need these policies to have long-lasting effects. In this respect, Glaeser *et al.* (1995) find very weak or no association between a number of urban policies (though not public transport) and urban growth between 1960 and 1990. In addition, recent work by Ferreira and Gyourko (2007) could find no evidence of any partisan effect with respect to the allocation of

[28] We also considered 1902 streetcar ridership as an instrument for contemporary buses. Unfortunately, this instrument is weak in our context because of the strong correlation of 1902 street cars with past levels of population. We do not use it in what follows.

Table 10. Population growth rate 1980-2000 as a function of 1984 buses and 1980 roads

Variable	[1] OLS	[2] OLS	[3] OLS	[4] TSLS	[5] TSLS	[6] TSLS	[7] TSLS	[8] TSLS
ln(1984 buses)	-0.031	0.007	0.004	0.078	0.069	0.069		0.068
	(0.011)[a]	(0.007)	(0.008)	(0.040)[b]	(0.044)	(0.035)[b]		(0.029)[b]
ln(1984 transit)							0.078	
							(0.040)[b]	
ln(1980 road km.)	0.115	0.043	0.050	0.239	0.201	0.189	0.244	
	(0.042)[a]	(0.021)[b]	(0.024)[b]	(0.089)[a]	(0.080)[b]	(0.071)[a]	(0.090)[a]	
$\ln(\text{Pop}_{80})$	Y	Y	Y	Y	Y	Y	Y	Y
$\{\ln(\text{Pop}_t)\}_{t\in\{20,...70\}}$	N	Y	Y	Y	Y	Y	Y	Y
Physical Geography	Y	Y	Y	Y	Ext.	Y	Y	Y
Census Divisions	N	N	Y	N	Y	N	N	N
Instruments used:								
ln(Planned Interstate Hwy.)	-	-	-	Y	Y	Y	Y	N
ln(Railroad routes)	-	-	-	Y	Y	Y	Y	N
1972 share of democratic vote	-	-	-	Y	Y	Y	Y	Y
First stage statistics (H_0 − All instruments zero)	-	-	-	5.06	3.94	5.62	5.02	17.27
Over-id test p-value	-	-	-	0.81	0.50	0.71	0.83	-
R-squared	0.06	0.75	0.77	-	-	-	-	-

Dependent variable: $\Delta_{00,80} \ln Pop$.
All regressions include a constant. Robust standard errors in parentheses.
275 observations for each regression.
Measures of 1980 roads and instruments are calculated for the developable area of each MSA, except for column 6 where calculations are based on the whole area of the MSA
a, b, c: significant at 1%, 5%, 10%.

municipal expenditure.

Three facts strengthen the case for our empirical strategy. First, as we show below, the results for public transportation are robust and stable as we change specifications. Second, when it is possible to conduct overidentification tests, our results always pass these tests. Finally, a further implication of our public transportation results, which we describe below, is confirmed by observation.

Results

Table 10 reports our main results regarding the effects of public transportation on urban growth between 1980 and 2000. In column 1 we use buses, 1980 roads in the developable land of each MSA, and 1980 population as explanatory variables in an OLS regression. The association between buses and subsequent growth is negative. Adding further controls for geography, past populations, and census divisions in columns 2 and 3 raises the coefficient on 1984 buses to zero.

Column 4 of table 10 presents our preferred specification. In this TSLS regression we instrument 1984 buses and 1980 roads with 1972 democratic vote share, planned kilometers of 1947 interstates, and kilometers of 1898 railroads. Except for the addition of public transportation, the specification is identical to our preferred estimation of column 4 in table 4 and the 0.24 coefficient of instrumented roads is consistent with our previous findings. At 0.08, the elasticity of 1984 buses on population growth from 1980 to 2000 is statistically significant and one third the size of the corresponding road elasticity. This regression passes the over-identification test easily. With a Cragg-Donald statistic of 5.1, our instruments are not weak in the context of TSLS estimation.

However, they are close to the critical values given in Stock and Yogo (2005). In light of this, we note that LIML estimates for the these specifications are similar to reported TSLS estimates.

The remainder of table 10 examines the robustness of our preferred specification. Column 5 adds census division indicator variables and quadratic physical geography variables. Column 6 reproduces column 4 with road variables and instruments calculated for the MSAs rather than just their developable land. In column 7, we use a public transit index which takes the log of the sum of buses and light rail cars. In column 8, we drop 1980 roads from the regression and use only 1972 democratic vote share as an instrument. We see that this variable is a very strong instrument for 1984 buses. These regressions establish the robustness of our preferred estimate. In each regression the elasticity of 1984 buses on population growth from 1980 to 2000 is close to 8%, and is statistically significant in all specifications save one where it is marginally insignificant.

As was the case for our estimates of the effect of roads on population growth, we find in table 10 that the coefficient on buses is much larger when using instrumental methods than with OLS. This means that cities which grew slowly during the 1980s and 1990s relative to what would be predicted from our control variables also had more buses in 1984. Consistent with this, regressing log 1984 number of buses on log 1980 population and the change in log population during the 1970s yields a negative and significant coefficient for population growth during the 1970s with a coefficient close to -2. This negative association is robust to introducing controls for geography and past population.

To corroborate these findings further note that if buses make cities grow it is because they attract bus riders, and the link between public transit usage and poverty is very strong (Pucher and Renne, 2003). Conversely, if roads make cities grow it is because they attract drivers, who tend to be less poor than bus riders. Given this, an implication of our results so far is that more buses should lead to an increase in the share of poor residents in an MSA, while more roads should lead to a decrease.

To test this hypothesis we use data on poverty rates from the 1980 and 2000 censuses to investigate the determinants of the change in the MSA share of poor households (using the same definition of poverty as the US census). Table 11 presents results of regressions which predict the share of poor residents in an MSA. Column 1 reports an OLS regression which reveals that after we control for the 1980 poverty rate and log 1980 population, the partial correlation between 1984 buses and the change in poverty cannot be distinguished from zero. Column 2 reports the results of a TSLS regression that uses the 1972 share of democratic vote as an instrument for 1984 buses. We see that the coefficient of buses increases to 0.01 and is statistically significant. Columns 3 and 4 report results for the corresponding exercise with 1980 roads, where we use 1947 highways and 1898 railroads as instruments. The OLS estimate in column 3 is negative at -0.01 and increases in absolute size to -0.04 in the TSLS regressions. Columns 5 and 6 look jointly at roads and buses and yield similar estimates.[29] In column 7, we duplicate the regression of column 6, but replace the change in the share of poor by the change in the share of MSA high-school dropouts as the dependent variable. This yields similar coefficients. Consistent with the implication of our other findings and the established relationship between public transit usage and socio-economic status,

[29] Adding past populations from 1970 and before and geographical controls yields similar results.

Table 11. Transportation and the social composition of cities

Variable	[1] OLS	[2] TSLS	[3] OLS	[4] TSLS	[5] OLS	[6] TSLS	[7] TSLS
ln(1984 buses)	0.001	0.009			0.001	0.007	0.008
	(0.002)	(0.004)^b			(0.002)	(0.004)^c	(0.004)^b
ln(1980 road km.)			-0.013	-0.037	-0.013	-0.044	-0.039
			(0.005)^b	(0.016)^b	(0.005)^b	(0.016)^a	(0.016)^a
ln(Pop_{80})	-0.001	-0.013	0.009	0.024	0.008	0.017	0.014
	(0.003)	(0.007)^c	(0.004)^b	(0.010)^b	(0.005)	(0.012)	(0.013)
Share poor 1980	-0.586	-0.560	-0.586	-0.580	-0.585	-0.555	
	(0.035)^a	(0.042)^a	(0.036)^a	(0.037)^a	(0.035)^a	(0.040)^a	
Share dropouts 1980							-0.444
							(-0.054)^a
Instruments used:							
ln(Planned Interstate Hwy.)	-	-	-	Y	-	Y	Y
ln(Railroad routes)	-	-	-	Y	-	Y	Y
1972 share of democratic vote	-	Y	-	-	-	Y	Y
First stage statistics (H_0 − All instruments zero)	-	58.36	-	13.41	-	10.03	9.85
Over-id test p-value	-	-	-	0.30	-	0.18	0.11
R-squared	0.72	-	0.72	-	0.72	-	

Dependent variable: $\Delta_{00,80}$Share poor in columns 1–6 and $\Delta_{00,80}$Share dropouts in column 7.
All regressions include a constant. Robust standard errors in parentheses.
275 observations for each regression.
Measures of 1980 roads and instruments are calculated for the developable area of each MSA.
a, b, c: significant at 1%, 5%, 10%.

our data confirm that buses make a city relatively more attractive to the poor, while roads make it relatively more attractive to the rich.

While our results do indicate that buses disproportionately attract poor people to a city, this effect is small. A one standard deviation increase in log buses per capita corresponds to only a tenth of the standard deviation for the change in MSA poverty. We can also calculate the share of the bus-induced migration which is poor. To begin, consider an MSA with a 1980 share of poor equal to 27.8%, the cross-MSA average for that year. Using our preferred bus elasticity of 0.08 from table 10, a one standard deviation increase in buses per capita for an average MSA causes a 3.7% increase in population. According to table 11, this one standard deviation increase in bus provision also causes an increase of 0.5% in the share of poor to 28.3%. Consistency then implies that around 41% of the newcomers must be poor, compared to an initial average of 27.8%. Hence, although our results imply that an increase in public transportation provision tends to attract more poor people, this effect is small.

Interpretation

Table 10 suggests that a 10% increase in an MSA's provision of buses causes the MSA's population to increase by 0.8% over the following 20 years. Put differently, an increase in 1984 buses per capita by one standard deviation (i.e., 0.47 or one bus per 13,000 at the mean) leads to a metropolitan area that is 3.7% larger in 2000. This is about one sixth of the standard deviation of MSA growth during the period. Viewed from this perspective, the contribution of public transportation to urban growth is small. However, for the mean MSA this increase corresponds to around 485 people for each extra bus. In this light the effect of public transportation provision is much bigger, though not implausibly large.

It is also of interest to compare the effects of roads and buses on an MSA's population growth. With a cross-MSA mean of 1.1 buses and 15.9 kilometers of roads per 10,000, our estimates imply that an extra bus per 10,000 people has about the same effect on population growth as an extra 5.4 kilometers of road per 10,000 people. While this comparison of real units is interesting, the relevant comparison is between a dollar of expenditure on buses and a dollar of expenditure on roads.

The cost of a new bus is around 350,000 dollars. Assuming a 20 year lifetime and a 5% cost of capital this works out to *less than* 35,000 dollars per year. At a reasonable operating cost of 50 dollars per hour for 12 hours a day and 350 days a year, the annual operating cost of a bus stands at 182,000 dollars. Getting costs data for major roads is of course more difficult. According to the Congressional Budget Office, the average kilometer of interstate completed after 1970 came at a cost of nearly 21 million of 2007 dollars.[30] Even using a low 5% per annum cost of capital, this gives an annual capital cost of about 1 million dollars per kilometer of interstate. Around 136 billion dollars per year are spent on maintaining the federal road system. The interstate highway system accounts for about one quarter of all passenger miles. If we suppose that about one quarter of all maintenance dollars are directed to the 75000 kilometers of interstate highways, maintenance of these roads is about 450,000 dollars per km annually. We saw above that our preferred estimates for the elasticities of population to roads and to buses imply that an extra bus has the same effect as 5.4 extra kilometers of road. *Taken together these numbers imply that buses are more than 40 times more cost effective than roads as drivers of urban growth*.[31]

It is also interesting to compare these numbers to the costs associated with other urban growth strategies. The most popular one is arguably to use direct subsidies to attract manufacturing plants or headquarters. Greenstone and Moretti (2004) report a one-off cost per manufacturing job of around $120,000 in a series of examples. Assuming a 10% discount rate (vs. 5% for roads) and that each manufacturing job attracts 5 persons (a complete household and some induced demand for local non-tradable good), we reach an annual cost per extra person of $2,400. This is significantly more than the annual cost of attracting an extra person through increased bus provision ($430) but also an order of magnitude less than the annual cost of attracting an extra person through increased road provision ($16,800). The large difference in bang for dollar between road provision and manufacturing subsidies had to be expected given the very large federal subsidy associated with roads. The difference between buses and subsidies is more puzzling. The first argument is that increased bus provision is not usually viewed as a way to boost local growth, though we argue it is. The second argument is that increased bus provision lacks the political visibility of a new large plant or a new major road.

[30]Keeler and Small (1977) provide estimates more than 50% higher for major roads in the San Francisco Bay Area.

[31]Details are as follows. Annual capital cost per km of interstate: m\$20.73 $\times$ 0.05 $=$ m\$1.04. Annual maintenance costs per km of interstate: Bn\$135.9 $\times$ 25%(share of interstate traffic)/75376(km of network) $=$ m\$0.45. Hence the total cost of an extra 5.4 km of major road is estimated to be $5.4 \times (1.04 + 0.45) =$ m\$8.0 per year. This is more than 40 times the cost of an extra bus.

8. Conclusion

Federal highway spending alone was some 135.9 billion dollars in 2004, while the subsidy to public transit is about 30 billion dollars. In order to conduct these massive resource allocations wisely, we must understand the implication of these investments for the evolution of cities over the course of a generation: the analysis of these issues should not be left to advocacy groups.

Up until now, however, this question has escaped rigorous analysis. This reflects the difficulty of assembling data which measure roads and transit infrastructure, the absence of a theoretical model relating infrastructure to growth, and the difficulty of finding suitable instruments to correct for the endogeneity of infrastructure provision. This paper address all three of these issues to estimate the effect of roads and public transit on cities.

Over a 20 year period, we find that the major road elasticity of city population is 20%. There are several reasons to believe this estimate is accurate. Our instrumental variables estimation strategy is consistent with a simple model of urban growth. There are plausible a priori arguments for the exogeneity of our instruments. Both of our instruments yield the same elasticity estimate. Our estimate is robust to the specification and estimation strategy. Our estimate of the road elasticity of population growth is consistent with a crude estimate of the long run effect of rail infrastructure on population growth. Finally, we find provide out-of-sample verification for our differences between the OLS and IV results.

Over the same 20 year period, we find that the public transit elasticity of city population is 8%. There is also some reason to believe this estimate is accurate. In particular, our estimate is robust to a variety of specifications, and is consistent with the evidence we provide about the evolution of the socio-economic composition of cities in response to changes in road and transit infrastructure.

Our findings are important because they help to inform us about how cities evolve and grow, because they provide a sounder empirical basis for workhorse theoretical models of cities, and because they provide guidance to policy makers who must plan complementary public health infrastructure and social services for the population growth caused by increases in roads and buses.

Our results also shed light on the process by which roads are allocated to cities. In particular, they indicate that roads are allocated to cities, in part, in response to negative population shocks. This suggests that road construction may be a substitute for social assistance and that roads are built where land and labor are cheap rather than in the places where they are most needed. It is unlikely that this is an optimal use of infrastructure dollars.

Finally, while our estimates appear to suggest that the effect of transit is small relative to roads (elasticity of 0.08 vs. 0.20), in fact they lead to the opposite conclusion. Given that road infrastructure is orders of magnitude more expensive than transit infrastructure, our back of the envelope calculation suggests that a dollar spent on buses has the same impact as about 40 dollars spent on roads. While there is reason to be suspicious of our estimate of the effect of buses on population growth, our estimate would need to be wrong by a factor of more than 40 before roads had a bigger impact on a city's population growth than do buses. While we would like to repeat the economist's traditional endorsement of congestion taxes, our results suggest that, at the margin, policies to improve bus service in cities will improve welfare.

References

Acemoglu, Daron, Simon Johnson, and James A. Robinson. 2001. The colonial origins of economic development: An empirical invetsigation. *American Economic Review* 110(5):1369–1401.

Alonso, William. 1964. *Location and Land Use; Toward a General Theory of Land Rent*. Cambridge, MA: Harvard University Press.

American Public Transportation Association. 2006. *Public Transportation Factbook*. Washington, DC: APTA.

Anas, Alex, Richard Arnott, and Kenneth A. Small. 1998. Urban spatial structure. *Journal of Economic Literature* 36(3):1426–1464.

Aschauer, David A. 1989. Is public expenditure productive? *Journal of Monetary Economics* 23(2):177–200.

Baldwin Hess, Daniel and Peter A. Lombardi. 2005. Governmental subsidies for public transit: History, current issues, and recent evidence. *Public Works Management Policy* 10(4):138–156.

Barro, Robert J. 1991. Economic growth in a cross section of countries. *Quarterly Journal of Economics* 106(2):407–443.

Barro, Robert J. and Xavier Sala-i-Martin. 1992. Convergence. *Journal of Political Economy* 100(2):223–251.

Baum-Snow, Nathaniel. 2007. Did highways cause suburbanization? *Quarterly Journal of Economics* 122(2):775–805.

Baum-Snow, Nathaniel and Matthew E. Kahn. 2000. The effects of new public projects to expand urban rail transit. *Journal of Public Economics* 77(2):241–263.

Brueckner, Jan K. 1987. The structure of urban equilibria: A unified treatment of the Muth-Mills model. In Edwin S. Mills (ed.) *Handbook of Regional and Urban Economics*, volume 2. Amsterdam: North-Holland, 821–845.

Brueckner, Jan K. 1990. Analyzing third world urbanization: A model with empirical evidence. *Economic Development and Cultural Change* 38(3):587–610.

Burchfield, Marcy, Henry G. Overman, Diego Puga, and Matthew A. Turner. 2006. Causes of sprawl: A portrait from space. *Quarterly Journal of Economics* 121(2):587–633.

Cadot, Olivier, Lars-Hendrik Roller, and Andreas Stephan. 2006. Contribution to productivity or pork barrel? The two faces of infrastructure investment. *Journal of Public Economics* 90(6-7):1133–1153.

Chandra, Amitabh and Eric Thompson. 2000. Does public infractsructure affect economic activity? Evidence from the rural interstate highway system. *Regional Science and Urban Economics* 30(4):457–490.

Davis, Morris A. and Michael G. Palumbo. 2008. The price of residential land in large US cities. *Journal of Urban Economics* 63(forthcoming).

Duranton, Gilles and Diego Puga. 2004. Micro-foundations of urban agglomeration economies. In Vernon Henderson and Jacques-François Thisse (eds.) *Handbook of Regional and Urban Economics*, volume 4. Amsterdam: North-Holland, 2063–2117.

Durlauf, Steven N., Paul A. Johnson, and Jonathan W. Temple. 2005. Growth econometrics. In Philippe Aghion and Steven N. Durlauf (eds.) *Handbook of Economic Growth*, volume 1A. Amsterdam: North-Holland, 555–677.

Environmental Systems Research Institute Inc. 2000. *Data and Maps, Major Roads of the* US. Redlands, CA.

Fernald, John G. 1999. Roads to prosperity? Assessing the link between public capital and productivity. *American Economic Review* 89(3):619–638.

Ferreira, Fernando and Joseph Gyourko. 2007. Do political parties matter? Evidence from US cities. Processed, Wharton School.

Fishlow, Albert. 1965. *American Railroads and the Transformation of the Ante-Bellum Economy*. Cambridge (MA): Harvard University Press.

Fogel, Robert. 1964. *Railroads and American Economic Growth: Essays in Econometric History*. Baltimore (MD): Johns Hopkins University Press.

Fujita, Masahisa. 1989. *Urban Economic Theory: Land Use and City Size*. Cambridge: Cambridge University Press.

Glaeser, Edward L. and Joseph Gyourko. 2005. Urban decline and durable housing. *Journal of Political Economy* 113(2):345–375.

Glaeser, Edward L. and Matthew E. Kahn. 2004. Sprawl and urban growth. In Vernon Henderson and Jacques-François Thisse (eds.) *Handbook of Regional and Urban Economics*, volume 4. Amsterdam: North-Holland, 2481–2527.

Glaeser, Edward L., Matthew E. Kahn, and Jordan Rappaport. 2007. Why do the poor live in cities? *Journal of Urban Economics* 62(forthcoming).

Glaeser, Edward L., Heidi Kallal, José A. Scheinkman, and Andrei Schleifer. 1992. Growth in cities. *Journal of Political Economy* 100(6):1126–1152.

Glaeser, Edward L., Jed Kolko, and Albert Saiz. 2001. Consumer city. *Journal of Economic Geography* 1(1):27–50.

Glaeser, Edward L. and Albert Saiz. 2004. The rise of the skilled city. *Brookings-Wharton Papers on Urban Affairs* 5(0):47–94.

Glaeser, Edward L., José A. Scheinkman, and Andrei Schleifer. 1995. Economic growth in a cross-section of cities. *Journal of Monetary Economics* 36(1):117–143.

Glaeser, Edward L. and Andrei Shleifer. 2005. The Curley effect: The economics of shaping the electorate. *Journal of Law, Economics, and Organization* 21(1):1–19.

Gomez-Ibanez, Jose A. 1996. Big-city transit, ridership, deficits, and politics. *Journal of the American Planning Association* 62(1):30–50.

Gramlich, Edward M. 1994. Infrastructure investment: A review essay. *Journal of Economic Literature* 32(3):1176–1196.

Gray, Charles P. c. 1898. *Gray's New Trunk Railway Map of the United States, Dom. of Canada and Portion of Mexico. Compiled from latest official sources, showing carefully selected list of cities & towns in readable type for quick reference.* New York, NY. Library of congress catalogue # G3701.P3 1898 G7 RR 67.

Greenstone, Michael and Enrico Moretti. 2004. Bidding for industrial plants: Does winning a 'million dollar plant' increase welfare? Processed, University of California Berkeley.

Greenwood, Michael J. 1997. Internal migrations in developed countries. In Mark R. Rosenzweig and Oded Stark (eds.) *Handbook of Population and Family Economics vol. IB*. North-Holland: Elsevier Science, 647–720.

Haughwout, Andrew F. 2002. Public infrastructure investments, productivity and welfare in fixed geographical areas. *Journal of Public Economics* 83(3):405–428.

Henderson, J. Vernon, Ari Kuncoro, and Matt Turner. 1995. Industrial development in cities. *Journal of Political Economy* 103(5):1067–1090.

Horan, Patrick M. and Peggy G. Hargis. 1995. *County Longitudinal Template, 1840–1990*. Ann Arbor, MI: Inter-university Consortium for Political and Social Research (ICPSR 6576).

Keeler, Theodore E. and Kenneth A. Small. 1977. Optimal peak-load pricing, investment, and service level on urban expressways. *Journal of Political Economy* 85(1):1–25.

Kopecky, Karen A. and Richard M. H. Suen. 2006. Suburbanization and the automobile. Processed, University of Rochester.

Lucas, Robert E. Jr. 1988. On the mechanics of economic development. *Journal of Monetary Economics* 22(1):3–42.

Matsuyama, Kiminori. 1992. A simple model of sectoral adjustment. *Review of Economic Studies* 59(2):375–387.

Mertz, W. Lee. Undated. Origins of the Interstate. Processed, Federal Highway Administration (United States Department of Transportation).

Mertz, W. Lee and Joyce Ritter. Undated. Building the Interstate. Processed, Federal Highway Administration (United States Department of Transportation).

Michaels, Guy. 2008. The effect of trade on the demand for skill - Evidence from the Interstate Highway System. *Review of Economics and Statistics* 90(forthcoming).

Mills, Edwin S. 1967. An aggregative model of resource allocation in a metropolitan area. *American Economic Review (Papers and Proceedings)* 57(2):197–210.

Moreira, Marcelo J. 2003. A conditional likelihood ratio test for structural models. *Econometrica* 71(4):1027–1048.

Muth, Richard F. 1969. *Cities and Housing*. Chicago: University of Chicago Press.

Pucher, John and John L. Renne. 2003. Socioeconomics of urban travel: Evidence from the 2001 NHTS. *Transportation Quarterly* 57(3):49–77.

Rappaport, Jordan. 2007. Moving to nice weather. *Regional Science and Urban Economics* 37(3):375–398.

Stock, James H. and Motohiro Yogo. 2005. Testing for weak instruments in linear IV regression. In Donald W.K. Andrews and James H. Stock (eds.) *Identification and Inference for Econometric Models: Essays in Honor of Thomas Rothenberg*. Cambridge: Cambridge University Press, 80–108.

United States Bureau of Statistics. 1879. *Statistical abstract of the United States: First Number 1878*. Washington, DC: US Government printing office.

United States Bureau of Statistics. 1899. *Statistical abstract of the United States: First Number 1898*. Washington, DC: US Government printing office.

United States Bureau of the Census. 1981. *Statistical abstract of the United States 1980*. Washington, DC: US Government printing office.

United States Bureau of Transportation Statistics. 2004. *Transportation Statistics Annual Report 2004*. Washington, DC: US Government printing office.

United States Department of Transportation, Federal Highway Administration. 2005. *Highway Statistics 2005, Functional System Travel, Table VM-2*. Washington, DC.

United States Department of Transportation, Urban Mass Transit Administration. September 1986. *National Urban Mass Transit Statistics, 1984 Section 15 report*. Washington, DC: US Government printing office.

United States Federal Works Agency, Public Roads Administration. 1947. *Press release*.

United States Geological Survey. 1970. *The National Atlas of the United States of America*. Washington, DC.

United States House of Representatives. 1947. *A Report on the National Interregional Highway Committee, Outlining and Recommending a National System of Interregional Highways*. Washington, DC: US Government printing office.

Weiner, Edward. 1997. *Urban Transportation Planning in the United States: An Historical Overview*. Fifth edition. Washington, DC: Department of Transport.

Appendix A. Data

Buffers for the road data: To identify developable land in an MSA, we first impose a regular grid of one kilometer cells on the continental US. We then use the data developed in Burchfield *et al.* (2006) to identify all cells that are at least 50% in developed cover in 1976. Next, we construct a 20km radius disk around each developed cell. Finally, we take the union of all such disks. The resulting set of one kilometer grid cells describes all land in the continental US which is either intensively developed or close to intensively developed land. Burchfield *et al.* (2006) show that nearly all new development between 1976 and 1992 occurred in this buffer region, and so the intersection of this region with an MSA's boundaries describes an MSA's developable land.

Consistent MSA *definitions:* For each MSA in our sample we calculate population at each decennial census over the period 1920-2000. Since MSAs are defined as aggregations of counties, constructing these population series requires tracking changes in county boundaries over time. We did this using a revised version of the County Longitudinal Template of Horan and Hargis (1995) which was provided to us by Vernon Henderson and Jordan Rappaport.

Employment data: To measure employment we use the County Business Patterns data from the US Census Bureau. These data are available annually from 1977 to 2003. Since MSAs are defined as aggregations of counties, these data allow us to construct measures of total MSA employment for 1980, 1990, and 2000. We also construct disaggregated employment data at the two digit-level (with 81 sectors) for two purposes. First, we want to investigate whether the transportation infrastructure affects the structure of MSA economic activities such as its specialisation (and not only its level). Second, we also pay close attention to employment in one particular sector, road construction (SIC 16), to provide out-of-sample corroboration of our main result. Between 1977 (the first year of CBP availability) and today, three different industrial classifications have been used in the US: the standard industrial classification (SIC) which remained unchanged at the two-digit level between 1977 and 1997, the 1997 North American Industry Classification System (NAICS) from 1998 to 2002, and the 2002 NAICS for 2003. While these changes of classification make very little difference to the computation of aggregate MSA employment, they can matter when computing MSA employment at the two digit level. To avoid comparability problems, we run regressions with sectoral data only over the 1977-1997 period.

Road infrastructure 1980: To measure stock of roads in each MSA in 1980, we use the USGS 1980 digital line graph. This graph assigns each road to one of several categories: Interstate highway, Limited access/divided highway, Other U.S. highway, Other state primary highway, State secondary highway, Improved road, Unimproved road, Parallel highway, Toll road, Tunnel. We have experimented extensively with different measures of roads, e.g., kilometers of interstate highway rather than all roads, and have found that it does not affect our results.

We suspect that the irrelevance of the road class data arises because of sampling issues which govern the inclusion of roads in the map. With the exception of 'Improved road' and 'Unimproved road', both small classes, all of the road classes appear to describe important arterial roads, and even these two classes could in principle also be important roads. Indeed visual inspection of the 1980 USGS map leads us to suspect that it is a map of 'important roads' independent of class.

It should also be noted that these data record gross kilometers rather than lane kilometers. Since a road with several lanes does not provide the same service as a road with one lane, if roads with more lanes are not randomly assigned across MSAs then it is possible that this may bias our estimates of the relationship between kilometers of MSA roads and city growth. While this is a substantive concern, it is formally equivalent to the endogeneity problem that we address with our instrumental variables estimation. For this problem to persist in our instrumental variables estimates, we would need this measurement error to be correlated with city growth between 1980 and 2000 and with our instrumental variables. This seems improbable.

Road infrastructure 1994–1997: The 1994-7 US National Transportation Atlas also provides a digital line graph of major roads in the US as of 1994–1997 (Environmental Systems Research Institute Inc., 2000). This allows us to compute the number of kilometers of major roads in each MSA in the mid 1990s. Given that only 3 to 6 years elapse between this measure of road and the 2000 population census, it is hard to use this variable as an explanatory variable for subsequent urban growth. However, it can be used to investigate the changes in roads since 1980, keeping in mind that the data sources are different.

Public transit infrastructure: To comply with Section 15 of the Urban Mass Transportation Act, all public transit districts in the US submit annual reports to the federal government detailing their assets and activities over the course of the year. Our data for 1984 bus service comes from table 3.6, p3-308, of United States Department of Transportation, Urban Mass Transit Administration (September 1986). The section 15 reports are available in electronic form starting in 1984. While these reports do not assign transit districts to an MSA, they contain enough geographic information, e.g., zipcode, so that about 700 of the 740 transit districts that operate during 1984, 1994, or 2004 can be assigned to a non-MSA county or to an MSA.

With this correspondence constructed, we count all 'large buses' in each MSA at peak service for 1984. We use this daily average number of large buses operating at peak service in 1984 to measure an MSA's stock of public transit infrastructure. In our definition of large buses we include buses in the following Section 15 reporting classes: articulated bus; bus A (>35 seats); bus B (25-35 seats); bus C (<25 seats); double deck bus; motor bus; motor bus (private); street car; trolley bus.

The section 15 data also record the daily average number of light or commuter rail cars in service at peak service. Our data indicate that there are only 11 MSAs with any light rail at all in 1984, and of these only 6 had more than 100 rail cars. The situation is only marginally better in 1994 when 21 MSAs had light rail or commuter rail service and 7 had more than 100 cars. While it is of considerable interest to separately estimate the effect of light rail and bus based public transit, there are simply not enough MSAs with light rail that cross-section variation will be informative. With this said, we have experimented with an index of public transit infrastructure which simply sums large buses and rail cars, and found no qualitative change to our results.

Socio-demographic characteristics: To measure MSA socio-demographics we use aggregated county level data from the 1980 and 2000 US census. These data record a wide variety of characteristics such as the share of poor residents in the MSA, the educational attainment of MSA residents, their earnings, race, age group distribution, etc. The 1980 level for these characteristics can be used as extra controls in our main regressions. The changes from 1980 to 2000 can be used to check whether different types or levels of transportation infrastructure cause MSAs to specialize in employing and housing different types of people.

Other variables: The share of the democratic vote in the 1972 presidential election is calculated from the General Election Data for the United States, 1950-1990, from the Inter-university Consortium for Political and Social Research(ICPSR). We also use a range of socio-economic variables from the 1980 and 2000 decennial censuses. These variables include the share of university graduates, mean household income, average educational attainment, share of poor households, share of households in the highest income bracket, etc.