Urban Transport Expansions, Employment Decentralization, and the Spatial Scope of Agglomeration Economies*

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Abstract

This paper investigates the relationships between urban highway construction and the decentralization of jobs and workers' residential locations by industry between 1960 and 2000. Estimates indicate that highways cause significantly greater amounts of residential than job decentralization. Identification of these treatment effects relies on exogenous variation available from planned portions of the federal highway system and variation across cities in the number of highways received due to these cities' relative locations. Each radial highway displaced an estimated 16 percent of the central city working population but only 6 percent of the jobs to the suburbs. These estimates are fairly consistent across industry. These results support the idea that local spillovers remain an important incentive for firms to to cluster spatially, even in the face of transportation cost reductions.

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1 Introduction

A large literature going back to Marshall (1898) argues that the existence of agglomeration economies is crucial to explaining why cities exist and their spatial structures. Despite many theories, many of which are summarized in Duranton & Puga (2005), relatively little is known empirically about the most relevant mechanisms through which agglomeration economies operate. The focus of this paper is to understand the extent to which agglomeration economies operate locally versus at the metropolitan area level in various industries using data on the universe of workers in U.S. metropolitan areas in 1960 and 2000. This paper also presents new facts about the degree of decentralization that has occurred by industry and how improvements to urban transportation infrastructure have shaped such industry-specific decentralization of workers and firms.

This paper uses exogenous shocks to within-metropolitan area transport costs to help separate out the relative importance of productivity spillovers that operate within central cities or suburbs versus those that operate at a broader metropolitan area scale. Estimated causal effects of new highways on the decentralization of working populations' place of residence are stronger than those on these populations' place of work in each broad industry category. Over the study period, the modal commute changed from occuring within central cities to being within suburban areas. Indeed, the fact that the post-WWII period has seen any job decentralization at all is an indication that many firms have taken the opportunity to trade off the higher local productivity spillovers available near city centers for lower input costs available by locating closer to suburbanized workers. Therefore, local spillovers are not essential for firm survival and can be substituted for lower costs in the presence of metropolitan area wide agglomeration spillovers. This causal evidence confirms that while local spillovers are economically important, they are not the only determinants of firm location. A simple core-periphery model confirms this intuition and provides some context for interpreting estimated treatment effects.

This is not the first paper to investigate the spatial scope of agglomeration economies. Rosenthal & Strange (2003) and Arzhagi and Henderson (2008) also do so. However, this is the first paper to use exogenous shocks in city environments to aid in identification of the relative importance of productivity spillovers that operate at local versus market scales. Because of limits on the spatial detail in available data from 1960, this analysis is necessarily more spatially rough than these earlier studies. However, this analysis examines all employment simultaneously and provides evidence by industry. Therefore, it provides an analysis of this phenomenon for a broader set of workers.

In addition to its inherent interest, a better understanding of the spatial scale at which agglomeration economies operate has the potential to improve land use modeling. The influential class of models from Fujita & Ogawa (1982) to Lucas & Rossi-Hansberg (2002) have as a central feature a limited spatial extent of local positive production externalities. Key determinants of equilibrium structure in these models are the strength of this local agglomeration force relative to the transportation cost. Therefore, more accurate specification of the strength and spatial scope of local productivity spillovers has the potential to improve the extent to which such models can reproduce equilibria seen in the data.

This paper proceeds as follows. Section 2 documents decentralization patterns of residences and workers by industry between 1960 and 2000. These patterns indicate the importance of both local and MSA-wide agglomeration spillovers. Section 3 discusses the empirical strategy for estimating causal effects of highway infrastructure. Section 4 presents the results. Section 5 presents a simple model that facilitates interpretation of estimated treatment effects of highways on job and resident worker location. Finally, section 6 concludes.

2 Descriptive Evidence and Data

2.1 Patterns of Decentralization of Workers, Firms and Commutes

Table 1 gives an overview of the extent of decentralization of working residents and jobs that occurred between 1960 and 2000. For the 100 metropolitan areas of over 250,000 in 1960, it shows aggregate counts of workers in central cities and 1960-definition SMSAs. The final row gives the count of people who either work or live in SMSAs and is calculated from commuting data. Table 1 indicates large shifts in the location of both employment and residences between 1960 and 2000. The fraction of SMSA jobs and working residents in central cities each fell by about 25 percentage points over this period. It is interesting to note that the relative extent of centralization of jobs and workers remained almost constant over time. Both decentralized at rapid rates with jobs more clustered in central cities than residences in both years.

The relative centralization of jobs over people is prima facie evidence that local agglomeration spillovers existed in both 1960 and 2000. Without this force, firms would seek to lower their costs by locating closer to workers in areas with lower rents. However, it is notable that job centralization declined as much as it did despite the declines in commuting costs that occurred during the study period. Indeed, land use models with endogenous employment location typically indicate that sufficiently low commuting costs supports a monocentric equilibrium in which firms all cluster in one location to take advantage of their mutual agglomeration spillovers. In this environment, firms do not face as much of a burden in compensating workers for longer commutes. That is, evidence in Table 1 indicates that giving up very local agglomeration spillovers are not dealbreakers impeding employment decentralization. Therefore, it is reasonable to believe that reductions in transport costs also allowed agglomeration spillovers to operate over greater distances.

Table 2 examines the extent to which industries differ in their patterns of decentralization. From left to right, one digit industries (the finest detail for which data is available in 1960) are listed in order of 1960 SMSA employment shares.[1] Evidence in Rows 5 through 8 of Table 2 indicate overall trends in SMSA working residents and jobs by industry respectively between 1960 and 2000. They indicate the well-known facts that manufacturing and retail/wholesale trade were declining industries while services and finance, insurance and real estate were growing. While recognizing these trends is important for understanding where the denominators come from, they are not central to this analysis.

More relevant to the current analysis is the comparison across industries of relative decentralization rates of jobs and the residential location of their workers. Comparison of numbers in Rows 2 and 4 reveals less variation in the changes in central city fraction of working residents than jobs across industries. Perhaps this is not surprising, as workers in each industry have experienced the same set of incentives (apart from potential differential changes in job access) to suburbanize. How-

[1] Because of inconsistencies across census years in the classification of different types of services, I was forced to combine all services into one broad industry category in order to make valid comparisons.

ever, differences between results in Row 4 from Row 2 provides some evidence about the differences across industries in the ease of decentralization. In particular, manufacturing, trade, TCPU and FIRE experienced more rapid than average job decentralization, and less rapid population decentralization. Given these observed patterns, it is natural to conclude that very local agglomeration forces that do not depend on transport infrastructure are less important in these industries than in services and construction.

As is discussed in Baum-Snow (2010), the primary way that decentralization of firms and workers manifested itself was in shifts of modal commutes from being entirely within central cities to being entirely within suburban regions. Table 3 demonstrates this pattern for this sample of large SMSAs. It shows that while 43 percent of SMSA workers or jobs involved commutes within central cities in 1960, this share fell to just 16 percent by 2000. Over the same period, the fraction living and working in the suburban ring rose from 28 percent to 43 percent of the total. Particularly notable is that the only types of commutes with declining shares of the total were those within central cities and those from suburbs to central cities. This evidence, coupled with the slight uptick in reverse commute shares, is consistent with declines in the types of agglomeration forces that keep firms in central cities.

2.2 Data

This analysis uses journey to work tabulations based on the 1960 and 2000 censuses. For 1960, commuting flows by industry are reported within and between central cities, SMSA remainders and other regions for each of the 100 largest SMSAs nationwide. I aggregate these into counts of workers and working residents for central cities and SMSA remainders. Unfortunately, the 1960 census does not in most cases report data in a way that makes it possible to break out information for different central cities. Therefore, all central cities in SMSAs with multiple central cities were necessarily treated as one.

In 2000, the Census Transportation Planning Package reports counts of workers and working residents by industry at various small levels of geography depending on state.[2] This analysis

[2] Unfortunately, the 2000 CTPP does not report commuting flows by industry of employment.

maintains the 1960 spatial units over time. In order to do this, digital maps of 1960 central cities and SMSAs were created so that year 2000 census units could be spatially allocated.[3] Year 2000 microgeographic units of tabulation, typically traffic analysis zones but sometimes census block group or census tract, were allocated to 1960 geographies and analogous counts were calculated through aggregation.

As an illustration of the issues that sometimes arose in building this data set, Figure 1 shows the Davenport-Rock Island-Moline IA-IL SMSA with its central city geographies in 1960 and 2000 and traffic analysis zones, at which employment data in 2000 is reported. As seen in the figure, each of these central cities expanded geographically over time. Also note that the extent of the SMSA geography is somewhat constrained. For this reason, I also use information on commutes into and out of the SMSA for the analysis.

The highway data used is an expanded version as that used in Baum-Snow (2007). Actual counts of radial limited access highways serving primary central cities' central business districts were recorded for 1950, 1960 and 2000. (Additional counts of other types of highways were also recorded but are not used here due to difficulty in instrumenting for them.) As in Baum-Snow (2007), Michaels (2008), Baum-Snow (2010) and Duranton & Turner (2011), I instrument for the number of radial highways constructed between 1960 and 2000 with the number in a 1947 plan of the interstate highway system. As is discussed in more detail in Baum-Snow (2007), this plan was developed to aid in intercity trade and national defense and was not developed to facilitate commuting. Furthermore, while planned highways are correlated with 1950 vintage population levels, lagged population growth cannot predict the number of planned highways. All of these features support the contention that the plan is a valid instrument for highway construction of the subsequently built 90 percent federally funded interstate system.

There is some question as to the appropriate starting year for measuring highways. With interstate highway construction begun at a rapid rate after the passage of federal legislation in 1956, many cities had planned, partially completed or just opened segments in 1960. It is unlikely that the urban spatial equilibria would have come close to fully responding to this new transport

[3] This creation of constant spatial units is a crucial feature of the data since more than half of central cities significantly expanded over time.

infrastructure in such a short time.[4] Therefore, I focus on using the number of new radial highways serving central cities constructed between 1950 and 2000 in the main analysis.

Results in Table 4 show that this decision on how to count highways is if anything conservative. Table 4 presents first stage results of the effects of planned radial highways on the number actually built. Panel A shows results using 1950 as a base while Panel B presents results using 1960 as a base. Included control variables can be justified by a typical land use model as in Lucas & Rossi-Hansberg (2002) and their inclusion does not affect coefficients on planned rays.[5] Coefficients of interest are smaller by 0.13 to 0.17 when using 1960 as a base rather than 1950. As a result, second stage estimates always end up larger if 1960 is used as the base. Furthermore, there may be some concern that the timing of highway construction is endogenous to commuting demand. Therefore, in order to be conservative, results in the remainder of the paper use 1950 to 2000 radial highway construction as the endogenous variable of interest, instrumented with the number of rays in the 1947 plan.

3 Empirical Strategy

The empirical goal is to recover average treatment effects of radial highways on the decentralization of central city working residents and jobs in broad industry categories. Existing research as in Baum-Snow (2007), Baum-Snow (2010) and Baum-Snow et al. (2011) has utilized estimating equations similar to Equations (1) and (2) to estimate similar parameters. I implement the stated goal by capturing the causal effects of highways on central city jobs emp_{ki}^{CC} or working population pop_{ki}^{CC} in each industry k holding the total number of SMSA jobs or working population in that

[4] In Baum-Snow (2007), I find that about two-thirds of the long run response to the highway system had occurred by 1970.

[5] Beyond the set of controls included in the table, a broader set was tried including 1960 log employment and simulated income and employment growth measures. Results in no cases were appreciably affected and these controls always have insignificant coefficients.

industry constant, where i indexes SMSA:[6]

$$\Delta \ln(emp_{ki}^{CC}) = \rho_{0k} + \rho_{1k}\Delta(hwy_i) + \rho_{2k}\Delta \ln(emp_{ki}^{SMSA}) + X_i \varrho_k + \upsilon_{ki} \quad (1)$$

$$\Delta \ln(pop_{ki}^{CC}) = r_{0k} + r_{1k}\Delta(hwy_i) + r_{2k}\Delta \ln(pop_{ki}^{SMSA}) + X_i R_k + u_{ki} \quad (2)$$

The potential endogeneity of $\Delta \ln(hwy_i)$ discussed above is addressed by instrumenting with the number of radial highways in the 1947 national plan. One additional difficulty with recovering consistent estimates of parameters of interest ρ_{1k} and r_{1k} is the fact that highways may not only cause decentralization, but they may also cause the industry mix to change. That is, $\Delta \ln(emp_{ki}^{SMSA})$ and $\Delta \ln(pop_{ki}^{SMSA})$ may be endogenous, or correlated with the error term, even after instrumenting for $\Delta(hwy_i)$ with planned highways from 1947. This occurs because $\Delta \ln(emp_{ki}^{SMSA})$ and $\Delta \ln(pop_{ki}^{SMSA})$ may themselves respond to the instrument, thereby violating the standard exclusion restriction required for IV to provide consistent estimates. There are of course additional identification concerns in Equations (1) and (2). These are discussed below in the context of equations whose parameters I actually estimate.

To get around inclusion of industry-specific SMSA employment as a predictor for identifying parameters of interest ρ_{1k} and r_{1k}, I proceed in two steps. The first step generates estimates of the effects of highways on the mix of SMSA employment across industries. The results of this step are interesting in their own right, but are not the focus of this analysis. Similar estimates have been explored in existing research with more detailed and appropriate data as in Duranton, Morrow & Turner (2011). The second step is to recover the reduced form effects of highways on central city employment and working residents by industry taking as given only the evolution of total metropolitan area employment between 1960 and 2000. Combining estimates from these two steps yields effects of highways on this set of outcomes holding the evolution of total metro area employment by industry fixed.

[6] It is possible that the allocation of jobs or working population to central cities versus suburbs may additionally depend on the jobs or working population in other industries. Unfortunately, given this setup it is impossible to econometrically identify such spillovers. However, the empirical strategy is designed such that if these spillovers are small, they will not appreciably affect estimated coefficients of interest.

In step one of the empirical analysis, I estimate regressions of the form:

$$\Delta \ln(emp_{ki}^{SMSA}) = \alpha_{0k} + \alpha_{1k}\Delta(hwy_i) + \alpha_{2k}\Delta \ln(popemp_i^{SMSA}) + X_i\beta_k + \varepsilon_{ki} \quad (3)$$

$$\Delta \ln(pop_{ki}^{SMSA}) = a_{0k} + a_{1k}\Delta(hwy_i) + a_{2k}\Delta \ln(popemp_i^{SMSA}) + X_iB_k + e_{ki} \quad (4)$$

As in Equations (1) and (2), i indexes SMSA and k indexes industry. Rather than use either SMSA employment or working population, I control for $\Delta \ln(popemp_i^{SMSA})$, which is the change in the log of the number of workers or residents in the SMSA.[7] Controlling for total SMSA employment or working population is necessary to recover the effects of highways on SMSA industry composition rather than simply the level of employment in each industry. The reduced form causal effect of highways absent this control variable would partially reflect the effect on total SMSA population or employment, overstating the effect of highways holding SMSA population constant. X_i is a vector of additional control variables whose inclusion can be motivated by a typical land use model. I use the same set of controls in each equation so that any potential differences in coefficients across equations can be attributed only to differences in the outcome variable.

Several potential identification concerns arise in estimating Equations (3) and (4). First, is the endogeneity of $\Delta \ln(hwy_i)$ which is addressed by instrumenting with the number of radial highways in the 1947 national plan. Second is the potential endogeneity of $\Delta \ln(popemp_i^{SMSA})$. If highways are an amenity, then these variables should respond positively to the number of highways, either actual or in the national plan. On the other hand, inclusion of $\Delta \ln(popemp_i^{SMSA})$ (without instrumenting) may introduce a correlation with the error term since shocks to one sector of employment will affect employment in all sectors as well. In practice, results in the next section indicate that the bias from excluding this control is likely to be small since it does not respond much to highways. Moreover, attempts to instrument for it yield almost identical estimates of α_{1k} and a_{1k} as when it is included or excluded from the regression equation.

The final issue is considering which variables belong in additional controls X. There are two

[7] I use this measure only when measuring SMSA counts not broken out by industry because I do not observe this object by industry in 2000. By industry, I only observe the closely related variables SMSA working population and SMSA jobs.

justifications for including variables in this control set. First, from an econometric perspective, any variable correlated with the number of planned highways that may cause the SMSA industry mix to change must be included for an IV estimator to yield consistent estimates of a_1 and α_1. Second, in the estimation equations specified below that describes changes in the allocation of workers and jobs between central cities and suburbs, there are theoretical justifications to include any exogenous variables that appear in typical closed city land use models. Strictly speaking, given an ideal instrument for highways that is unconditionally random, we would not need to include any such variables. However, it turns out that one such model inspired variable also is correlated wtih planned rays and thus must be included in regressions by both criteria. This is the size of the central city. Larger area central cities received more planned highways and (all else equal) had less loss of population and jobs to the suburbs.[8]

It should be noted that with ideal data in a world perfectly described by land use models, Equations (3) and (4) would be identical. That is, conceptually we typically define metropolitan areas as commuting zones that are fully self-contained. In practice, as seen in Table 3, 8 percent of SMSA workers or residents either lived or worked outside their SMSA in 1960, rising to 19 percent by 2000. Results reported in the next section will reveal, however, that SMSA counts of jobs and working residents are sufficiently similar such that we cannot statistically distinguish between estimated parameters of interest α_{1k} and a_{1k}.

Armed with estimates of a_1 and α_1, the next step is to specify equations that allow us to recover the impacts of highways on urban decentralization by industry holding the total SMSA industry composition constant. In order to avoid including endogenous variables, I specify these equations as the following "reduced forms" in which the prediction variables are exactly the same as in Equations (3) and (4) and the outcomes are for 1960 definition central cities.

$$\Delta\ln(emp_{ki}^{CC}) = \omega_{0k} + \omega_{1k}\Delta(hwy_i) + \omega_{2k}\Delta\ln(popemp_i^{SMSA}) + X_i D_k + \varpi_{ki} \quad (5)$$

$$\Delta\ln(pop_{ki}^{CC}) = w_{0k} + w_{1k}\Delta(hwy_i) + w_{2k}\Delta\ln(popemp_i^{SMSA}) + X_i\delta_k + v_{ki} \quad (6)$$

[8] Checks reveal that planned rays is not correlated with SMSA size, measures of SMSA income or income distribution, or the 1940 SMSA industry mix.

In estimating parameters of these equations, once again rays in the 1947 plan serve as an instrument for $\Delta \ln(hwy_i)$ and the same justifications hold for inclusion of additional control variables.

Substitution of (3) and (4) into (1) and (2) yields a pair of equations that resemble (5) and (6). After solving, given consistent estimate of α_{1k}, a_{1k}, ω_{1k} and w_{1k} causal effects of highways on decentralization of jobs or working resident population by industry are given by the following expressions respectively:

$$\rho_{1k} = \omega_{1k} - \frac{\omega_{2k}}{\alpha_{2k}}\alpha_{1k} \tag{7}$$

$$r_{1k} = w_{1k} - \frac{w_{2k}}{a_{2k}}a_{1k} \tag{8}$$

These expressions represent the intuition that the structural effect of a highway on decentralization within a given industry is the effect on central city industry employment or working population with an adjustment for the effect on industry composition whose size depends on the importance of the industry in the economy. The following section discusses IV regression estimates of these four sets of elements used to build the ultimate parameters of interest.

4 Estimated Treatment Effects

4.1 Effects of Highways on SMSA Employment and Industry Mix

Table 5 reports regression results of Equations (3) and (4) in which planned highways enters as an instrument for the total number of radial highways. Results in the first column reveals no evidence of a significant effect of highways on total SMSA population or employment, though the point estimate for total employment is slightly positive.[9] The remaining columns of Table 5 show that the only industry that has a significant response to new transport infrastructure at the SMSA level is manufacturing. Each radial highway is estimated to cause about 10 percent of the manufacturing jobs and working residents to depart an SMSA most likely for rural areas. As should be expected

[9] This result is in contrast to evidence in Baum-Snow (2007) and Duranton & Turner (2011b) that metro areas building more highways experienced population increases. The reason for the discrepancy is that samples in the other two papers included many metropolitan areas that were smaller than 250,000 in 1960, and these metropolitan areas drive this result.

given that the only difference in outcomes is from relative changes in the number of commuters into versus out of SMSAs, rays coefficients in Panel A are very similar to those in Panel B.

While Table 5 only reports one specification of control variables, results are robust with indicated statistical significance levels to inclusion of additional controls including 1960 log SMSA population or employment, log SMSA median income growth and proxies for income and employment growth using national trends and 1940 industry shares. As is discussed above, the square root of 1960 central city area is included because it both belongs as a predictor in the decentralization equations and is correlated with the planned rays instrument.

4.2 Effects of Highways on Decentralization by Industry

Table 6 contains the central results of this paper. It reports estimated effects of radial highways on central city employment by industry in Panel A and working population in Panel B. Because most coefficients of interest in Table 5 are about 0, coefficients in Table 6 for all industries except manufacturing can be directly interpreted as average treatment effects of one radial highway on the allocation of that industry's jobs or resident workers between the central city and the suburbs.

Before exploring heterogeneity in effects across industries, it is instructive to examine results in the first column, for all workers. Baum-Snow (2007) estimated highway treatment effects analogous to that reported in column 1, Panel B. This estimate, that each ray causes 16 percent of the working population of central cities to move to the suburbs heavily overlaps with the confidence interval of the Baum-Snow (2007) estimate of -0.12. It should be noted that this estimate applies to only about half of the full population used in Baum-Snow (2007). The effect of each ray on the total number of jobs is a much smaller statistically insignificant -0.06. This difference of 0.10 is statistically significant. Note that this gap exceeds the gap that would be needed for a highway to move the same number of workers and jobs to the suburbs. The fact that the allocation of jobs between central cities and suburbs does not respond as much (in percentage or numerical terms) to new transport infrastructure as the allocation of people is expected. New highways allow for population decentralization while at the same time lowering input costs to firms conditional on their locations. Firms face a tradeoff between decentralizing themselves (and further lowering input costs) or maintaining some level of clustering and continuing to take advantage of local agglomeration economies. If local agglomeration economies are strong enough and reduction in transport costs are high enough (as in a Fujita-Ogawa (1982) type framework), then firms will respond to transportation cost reductions by centralizing even as people are decentralizing. The fact that the coefficient in Panel A is less negative than that in Panel B reflects this additional force pushing for firm centralization.

Absent some complicated cross-industry interactions, this same logic carries through when considering employment and working population in individual industries. In each industry, estimated effects of highways on the decentralization of jobs is smaller than the estimated effects of highways on the decentralization of workers. The relative magnitudes of these coefficients provide some clues about the relative force of agglomeration economies that push toward centralization. Agriculture and the military are the only two industries in which local agglomeration forces were sufficiently strong such that highways actually caused centralization. These are also the two industries which had the largest gaps between location responses of workers and firms to new highways.[10] Other industries had gaps more similar to the 0.10 that was experienced for the typical worker. Note that since estimates of α_{1k} and a_{1k} are identical at -0.1 and $\frac{\omega_{2k}}{\alpha_{2k}} \approx 1 \approx \frac{w_{2k}}{a_{2k}}$ for manufacturing, we can compare the manufacturing coefficients across Panel A and Panel B just like we can the coefficients describing effects for other industries.[11]

4.3 Commuting Mechanisms

For understanding the mechanisms through which reductions in transport costs have caused worker and firm decentralization, I next explore how highways changed commuting patterns to change. For this exercise, I examine the effects of radial highways on the 8 types of commuting flows described in Table 3. These results, reported in Table 7, indicate that highways were very important in shaping the changing commuting patterns in U.S. metropolitan areas reported in Table 3. Highways had significant effects on 3 of the 8 commuting flows considered. Each highway caused an estimated 15

[10] These are clearly two atypical industries that only capture a small amount of employment market share in cities.

[11] Results are almost identical if potentially endogenous growth in SMSA employment in industry k replaces total SMSA employment growth, after implementing the necessary adjustments given in (7) and (8).

percent fewer commutes within central cities and 10 percent more commutes within SMSA suburban rings. Each highway caused the number of commuters from outside of SMSAs to the suburban ring to increase by about 25 percent. Interestingly, the point estimate for traditional suburb to central city commutes is negative, at -0.08, but is not statistically significant. This is in contrast to the prediction of a standard moncentric city model.[12]

The real value of learning about the effects of transportation costs on the distribution of commutes in this context is its indications about how comparative statics should look in the model. In particular, it indicates that transport cost reductions may precipitate decentralization of a sufficient number of firm-worker pairs such that the number of commutes from the suburbs to the city actually declines.

5 Model and Interpretation

The goal of the model is to provide some interpretation behind the effects of transport improvements on employment decentralization and how they relate to those for population decentralization. This model is sufficiently stylized such that it has clear analytical implications, particularly in regards to comparative statics involving transport costs. It is also simple enough such that it has a unique equilibrium given transport cost and agglomeration forces, unlike typical land use models with endogenous firm location. The model formalizes the intuition that has already been developed above. As transport costs fall, input costs to firms fall given commuting distances. This allows firms and workers to spread further apart. In short, this section shows that a very simple model can generate the starkest patterns in the data.

This is a closed metropolitan area model with two regions the city and the suburbs. The model is in the spirit of Rosen (1979) and Roback (1982) in which only two locations are considered. However, this model additionally incorporates spillovers of two forms that exist between these two regions. First, there is commuting from the suburbs to the city. This allows the number of workers

[12] Similar regression results are reported in Baum-Snow (2010). While the two sets of results provide the same general picture of commuting decentralization, they are not identical. There are two reasons for discrepancies. First, this paper uses all central cities whereas that paper uses just the primary central city. Second, that paper uses a broader sample of metropolitan areas.

not to equal the number of firms. Second, there are agglomeration economy spillovers between the two regions which themselves may also depend on the transportation cost.In the city

5.1 Setup and Equilibrium

There is an exogenous amount of land L_c that workers and firms compete for with a market price r per unit. The suburbs extend as far out as necessary to satisfy firm and worker demand such that there is no competition for space in this region. As such, suburban land rent is determined exogenously, and is denoted $\underline{r}$. Of the exogenous population of the metro area N, N_c work in the city and N_s work in the suburbs. Q_c of the total population live in the city.

Firms produce a traded good of price 1 using a constant returns to scale technology with land and labor. Firms also benefit from a Hicks neutral agglomeration force that is increasing in the number of workers in the region in which the firm is located and also includes a spillover from the other region with some decay that is a function of the unit time cost of travel t.[13] Because of the constant returns to scale technology, we can conceptualize each firm as operating on one unit of space and denote n_c as workers per unit space in the city and n_s as workers per unit space in the suburbs. Labor and location are the only choice variables for the firm. Profit functions for city and suburban firms respectively are thus:

$$\begin{aligned}\pi_c &= A_c(N_c,t)f(n_c) - r - w_c n_c \\ \pi_s &= A_s(N_s,t)f(n_s) - \underline{r} - w_s n_s\end{aligned}$$

In these expressions, the functions $f(n_c)$, $A_c(N_c)$ and $A_s(N_s)$ are increasing and concave in their arguments. For some purposes, I specify $f(n_c) = n_c^{\gamma}$. Because firms are mobile, they must earn the same profit in each location. This equal profit condition will allow for recovery of an equilibrium relationship between wages and rents that resembles a Rosen (1979) and Roback (1982) type model.

Each person in this economy is identical and has prefences over the traded consumption good z of price 1 and land l. Each individual is endowed with one unit of time that is spent working

[13] The time cost t is specified such that it is 0 if it is costless to travel everywhere and 1 if it takes the worker's full time endowment to travel between home and work within the city.

or commuting. People have the option of commuting to a firm in their residential region at time cost t within the city, $c_s t$ within the suburbs and $c_{sc} t$ between the suburbs and the city, where $c_{sc} > c_s > 1$.[14] In equilibrium, all people have the same utility level, but this utility level is endogenous since population is fixed. Therefore, we can write indirect utilities of city commuters, suburban commuters, and suburb to city commuters respectively as:

$$\begin{aligned} V_c &= \max_{z,l} [U(z,l) + \lambda_c(w_c(1-t) - z - rl)] = V(r, w_c(1-t)) \\ V_s &= \max_{z,l} [U(z,l) + \lambda_s(w_s(1-c_s t) - z - \underline{r}l)] = V(\underline{r}, w_s(1-c_s t)) \\ V_{sc} &= \max_{z,l} [U(z,l) + \lambda_{sc}(w_c(1-c_{sc} t) - z - \underline{r}l)] = V(\underline{r}, w_c(1-c_{sc} t)) \end{aligned}$$

I ignore the possibility of reverse commuters as it has a small market share and would be hard to rationalize at the same time as suburb to city commutes in a simple model.

Notice that since all suburban residents face the same prices and have the same utility, they must consume the same bundle (z_s, l_s) and therefore have the same income net of commuting cost. Analogously to Ogawa and Fujita (1980), who explore a continuous city, this pins down that the relative wage must equal the difference in commuting cost across these two locations. If commuting times are small fractions of total time available, or are near 0, then we can approximate the city-suburban log wage difference as the difference in commuting times for suburban residents:

$$d \ln w \approx \ln(w_c) - \ln(w_s) \approx (c_{sc} - c_s)t \tag{9}$$

Given equal utility between city and suburban residents, without even considering the production side of the model it is clear that there are two reasons why cities have higher rents than the suburbs. First, wages are higher and second, commuting costs are lower. If rents were not higher to compensate, everyone would choose to live in the city.

This observation about relative rents can be quantified by imposing the $V_c = V_{sc}$. Differentiating this equality yields in general that the percent difference across locations in rents has to equal the

[14] Empirically in the 2000 census, suburb-city commutes are the longest, followed by suburb-suburb commutes and finally city-city commutes.

percent difference across location in wages net of commuting costs. Using this equality implies an expression for city rents:

$$\ln r - \ln \underline{r} \approx (c_{sc} - 1)t \tag{10}$$

In considering the firm side of the market below, these two conditions will prove useful.

The analogous intuition should be clear that the higher wages and rents being paid by the city firms must compensate for higher productivities there. Indeed, through differentiation of the profit function it is straightforward to derive that the productivity gap across locations equals a convex combination of the percent wage gap and the percent rent gaps, with factor expenditure shares as weights. Writing the labor share as ϕ_N and the land share as ϕ_L, we thus have:

$$d \ln A \approx \ln A_c(N_c, t) - \ln A_s(N - N_c, t) = (c_{sc} - \phi_N c_s - \phi_L)t \tag{11}$$

One remarkable feature of this expression is that it provides a solution for the number of workers in the city, but does not depend on the level of suburban rents or the amount of space available in the city. If there are additional inputs beyond labor and land that require shipping, there would be additional terms on the right hand side of this equation. However, by the same logic as that used for commuting, they will not depend on the level of rents. The next subsection will work with this expression to evaluate how it relates to estimates of something like $\frac{dN_c}{dt}$ reported above.

Imposing market clearing for space in the city allows us to pin down the number of residents in the city. This is the one equation that connects locations in the firm and consumer sides of the model.

$$N_c \left[\frac{(1-\gamma)A_c(N_c,t)}{\underline{r}e^{(c_{sc}-1)t}} \right]^{\frac{1}{\gamma}} + Q_c l^d(\underline{r}e^{(c_{sc}-1)t}, [A_c(N_c,t)]^{\frac{1}{\gamma}} \gamma \left[\frac{(1-\gamma)}{\underline{r}e^{(c_{sc}-1)t}} \right]^{\frac{1-\gamma}{\gamma}} (1-t)) = L_c \tag{12}$$

The first term in this expression describes the amount of city land used in production. Since each firm uses one unit of space, this is equivalent to the total number of central city workers divided by the number of workers per firm. Notice that unlike N_c the amount of space used by firms does depend on the level of suburban rent. If land rent $\underline{r}e^{(c_{sc}-1)t}$ is higher, firms will hire more workers per unit space and consume less space. The second term is the product of the number of city residents and consumer demand for land. Notice that as suburban land rent increases, that will reduce household demand through price and income effects, thereby attracting more residents to the city. The expressions for the total land area taken up by firms and the wage of city residents are derived by working through the firm's problem.

5.2 Interpretation of Regression Coefficients

Because it is more straightforward, I first focus on interpreting the estimated effects on central city jobs before considering effects on central city working residents.

Regression estimates reported in the previous section indicate that $\frac{\partial N_c}{\partial t} \geq 0$. The theoretically analogous comparative static on the generic equilibrium condition (11) is:

$$\frac{\partial \ln N_c}{\partial t} = \frac{\frac{\partial \ln A_s(N_s,t)}{\partial t} - \frac{\partial \ln A_c(N_c,t)}{\partial t} + (c_{sc} - \phi_N c_s - \phi_L)}{\frac{\partial \ln A_c(N_c,t)}{\partial \ln N_c} + \frac{N_c}{N_s}\frac{\partial \ln A_s(N_s,t)}{\partial \ln N_s}}$$

The two partial derivatives in the denominator are likely to be positive. As more workers are added close by, the existence of any local production externalities will increase firms' total factor producivities. However, the two partial derivatives in the numerator are likely to be negative. That is, increases in transportation costs should make it more difficult to interact with other firms, pushing the agglomeration spillover down.[15] The third term in the numerator captures the fact that as travel costs increase, the cost of accessing workers (which is capitalized into the wage) also increases, pushing firms to locate in the city, where commuting costs are lower. That is, this third term is the general equilibrium impact on firms' choices over N_c in response to an increase in the travel cost. Based on information on commute times from the 2000 CTPP and estimates from the literature of factor intensity, this term can be calibrated to 0.4. Given the empirical evidence, we can conclude that $\frac{\partial \ln A_c(N_c,t)}{\partial t} - \frac{\partial \ln A_s(N_s,t)}{\partial t} \leq 0.4$, which does maintain the possibility that both of these elements are 0. The regression results focused on responses to declines rather than increases

[15] Land use models typically assume that $\frac{\partial A}{\partial t}$ is 0, but this is an ad-hoc assumption that is useful for solving such models.

in t. Therefore, we can conclude that as t declined, the relative agglomeration force in the suburbs increased enough more than that in the city to overcome the percent difference in commuting costs between these two locations faced by suburban residents.

Now that we have established that $\frac{dN_c}{dt} > 0$, we are equipped to consider responses of the number of city residents to changes in transportation costs. The amount of land used by firms, the first term in Equation (12) is likely to decrease with an increase in t. In reality, there are two effects here that go in opposite directions. First, the total number of city workers increases, pushing up firms' demand for space. However, land costs also increase, pushing firms to increase the density of workers. However, if (as we have seen) this effect on the number of city jobs is small and as a result city firms' total factor productivities do not increase much, then this second effect dominates.

For residents, an increase in t increases rents and decreases wages net of commuting costs in the city if the quantity $\frac{\partial A_c(N_c,t)}{\partial N_c}\frac{\partial N_c}{\partial t}$ is not too large. This implies that workers throughout the metropolitan area become worse off. As a result, land consumed per person falls. The observation of a larger responses of resident workers than jobs to central city transport costs is thus a natural implication of this model.[16] In future work, examination of the effects on the amount of land in use for production and housing will help to better pin down the mechanisms behind estimated responses of city population to changes in transport costs.

6 Conclusions

This paper has demonstrated that new radial highways have caused significantly greater amounts of residential than job decentralization. Each radial highway displaced an estimated 16 percent of the central city working population but only 6 percent of the jobs to the suburbs. These estimates are fairly consistent across industry, though are larger in absolute value for retail and wholesale trade. Using the structure of a model, these results show that local spillovers remain an important incentive for firms to to cluster spatially, even in the face of transportation cost reductions.

[16] It is common to allow consumers to additionally have preferences over a local amenity. If this local amenity is a normal good and is greater in the suburbs, it will end up as an additional force pushing people to the suburbs and reducing their demand for space in the city.

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Table 1: Changes in Residential and Work Locations, 1960-2000
100 Metropolitan Areas of Over 250,000 in 1960

	1960	2000	Percent Change	Change in Fraction
Live in Central City	18.7	21.4	0.14	-0.25
(fraction of total)	(0.49)	(0.24)		
Work in Central City	23.3	30.6	0.31	-0.26
(fraction of total)	(0.61)	(0.35)		
Live in SMSA	36.3	76.6	1.11	-0.08
(fraction of total)	(0.95)	(0.87)		
Work in SMSA	36.8	81.7	1.22	-0.03
(fraction of total)	(0.96)	(0.93)		
Live or Work in SMSA	38.1	87.8	1.30	

Note: Counts are aggregates from the 100 metropolitan areas of over 250,000 in 1960 and are in millions of workers. Counts are calculated using 1960 and 2000 census journey to work data using 1960 SMSA definitions. Those contributing to residential counts may work anywhere. Those contributing to worker counts may live anywhere. Data from 1960 incorporate the author's imputations for nonreported work locations while the 2000 data incorporates such imputations done by the Census Bureau and the author.

Table 2: Changes in Residential and Work Locations by Industry: 1960-2000

	All	Manuf-acturing	Services	Trade	TCPU	Const-ruction	Public Admin.	FIRE	Military	Agric-ulture
Live in Central City										
1 1960 Fraction in CC	0.52	0.49	0.56	0.54	0.55	0.45	0.56	0.57	0.39	0.20
2 1960-2000 Change in CC Fraction	-0.24	-0.24	-0.25	-0.29	-0.26	-0.20	-0.28	-0.30	-0.17	-0.03
Work in Central City										
3 1960 Fraction in CC	0.63	0.60	0.64	0.67	0.73	0.56	0.68	0.79	0.40	0.21
4 1960-2000 Change in CC Fraction	-0.26	-0.33	-0.23	-0.38	-0.32	-0.23	-0.15	-0.36	-0.08	-0.01
Live in Entire SMSA										
5 1960 Fraction of All	1.00	0.30	0.22	0.19	0.08	0.06	0.06	0.05	0.02	0.02
6 1960-2000 Change in Fraction of All	0.00	-0.17	0.21	-0.04	0.01	0.00	-0.01	0.03	-0.01	-0.01
Work in Entire SMSA										
7 1960 Fraction of All	1.00	0.30	0.22	0.19	0.08	0.06	0.06	0.05	0.02	0.02
8 1960-2000 Change in Fraction of All	0.00	-0.17	0.21	-0.04	0.01	0.01	-0.01	0.03	-0.01	-0.01

Notes: See the notes to Table 1 for sample and data sources. Because the 2000 Census Transportation Planning Package does not report commuting flows by industry, changes in counts of people who either live or work in an SMSA are not available.

Table 3: Changes in Commuting Patterns: 1960-2000

		1960	2000	Change
Live in CC	Work in CC	16.5	13.6	-18%
		(0.43)	(0.16)	-0.27
Live in CC	Work in Ring	1.8	5.7	219%
		(0.05)	(0.07)	0.02
Live in CC	Work Outside SMSA	0.4	1.0	141%
		(0.01)	(0.01)	0.00
Live in Ring	Work in CC	5.9	12.3	110%
		(0.15)	(0.15)	-0.01
Live in Ring	Work in Ring	10.8	36.2	235%
		(0.28)	(0.43)	0.15
Live in Ring	Work Outside SMSA	0.9	4.4	378%
		(0.02)	(0.05)	0.03
Live Outside SMSA	Work in CC	1.0	3.7	272%
		(0.03)	(0.04)	0.02
Live Outside SMSA	Work in Ring	0.9	7.5	744%
		(0.02)	(0.09)	0.07
	Total	38.1	84.3	121%

Notes: Counts are built analogously to those in Table 1. The 2000 sum does not match that in Table 1 because the Census Bureau omits some difficult to impute flows in its Census Transportation Planning Package tables.

Table 4: First Stage Results

Panel A: 1950 Base Year

Planned Rays	0.53***	0.47***	0.47***
	(0.10)	(0.11)	(0.11)
Square Root of 1960		0.11	0.10
Central City Area		(0.08)	(0.08)
Change in Log Total			0.34
Employment			(0.37)
Constant	1.13***	0.80**	0.65
	(0.32)	(0.39)	(0.43)
R-Squared	0.23	0.24	0.25

Panel B: 1960 Base Year

Planned Rays	0.36***	0.34***	0.33***
	(0.10)	(0.11)	(0.11)
Square Root of 1960		0.04	0.03
Central City Area		(0.08)	(0.08)
Change in Log			0.30
MSA Employment			(0.38)
Constant	0.94***	0.81**	0.68
	(0.33)	(0.41)	(0.44)
R-Squared	0.11	0.12	0.12

Notes: Regression results are of changes in actual radial highways constructed between 1950 and 2000 (Panel A) or 1960 and 2000 (Panel B) on the listed variables.

Table 5: Effects of Highways on SMSA Workers by Industry
IV Estimates

	All	Manuf-acturing	Services	Trade	TCPU	Const-ruction	Public Admin.	FIRE	Military	Agric-ulture
Panel A: SMSA Workers										
Change in Rays	0.03	-0.10**	0.00	-0.01	0.02	0.03	-0.05	0.04	0.05	-0.01
1950 to 2000	(0.06)	(0.04)	(0.02)	(0.02)	(0.03)	(0.03)	(0.05)	(0.03)	(0.14)	(0.06)
Square Root of 1960	0.04	0.03*	-0.00	-0.02**	-0.01	0.00	-0.03*	-0.04***	-0.12**	0.03
Central City Area	(0.03)	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)	(0.02)	(0.01)	(0.06)	(0.02)
Change in Log Total		1.39***	0.79***	0.91***	1.11***	0.77***	0.81***	0.85***	0.54**	0.39***
Employment		(0.07)	(0.03)	(0.03)	(0.05)	(0.04)	(0.07)	(0.05)	(0.24)	(0.10)
Constant	0.43***	-0.89***	0.84***	-0.07*	0.07	0.11*	0.31***	0.63***	-0.37	-1.13***
	(0.14)	(0.09)	(0.04)	(0.03)	(0.07)	(0.06)	(0.10)	(0.07)	(0.32)	(0.13)
R-Squared	0.07	0.81	0.90	0.93	0.83	0.79	0.55	0.75	0.07	0.17
Panel B: SMSA Residents										
Change in Rays	-0.00	-0.10**	-0.00	-0.02	0.02	0.01	-0.06	0.03	-0.03	-0.03
1960 to 2000	(0.06)	(0.04)	(0.02)	(0.02)	(0.03)	(0.03)	(0.04)	(0.03)	(0.14)	(0.06)
Square Root of 1960	0.05*	0.03*	-0.00	-0.01**	-0.01	0.00	-0.02	-0.03***	-0.09	0.02
Central City Area	(0.02)	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)	(0.02)	(0.01)	(0.06)	(0.02)
Change in Log		1.39***	0.82***	0.94***	1.10***	0.82***	0.79***	0.90***	0.56**	0.46***
MSA Employment		(0.07)	(0.03)	(0.03)	(0.05)	(0.04)	(0.08)	(0.05)	(0.23)	(0.10)
Constant	0.44***	-0.86***	0.82***	-0.08**	0.04	0.08	0.29***	0.61***	-0.37	-1.16***
	(0.14)	(0.10)	(0.04)	(0.03)	(0.07)	(0.06)	(0.10)	(0.07)	(0.31)	(0.13)
R-Squared	0.05	0.80	0.91	0.94	0.82	0.79	0.54	0.78	0.08	0.18

Notes: Regressions are of the change in the log of outcomes listed in column headers on variables listed at left. The sample includes the same 100 MSAs used for Tables 1 through 4. The change in the number of rays is instrumented with rays in the 1947 national plan. Estimated effects on all SMSA workers plus residents yield identical coefficients as for all workers with the exception of the constant term (not reported).

Table 6: Effects of Highways on Central City Workers and Residents by Industry
IV Estimates

Panel A: Central City Workers in Listed Industry

	All	Manuf-acturing	Services	Trade	TCPU	Const-ruction	Public Admin.	FIRE	Military	Agric-ulture
Change in Rays	-0.06	-0.16**	-0.07**	-0.15**	-0.06	-0.05	-0.04	-0.02	0.07	0.15*
1950 to 2000	(0.04)	(0.07)	(0.04)	(0.06)	(0.04)	(0.04)	(0.05)	(0.06)	(0.16)	(0.09)
Square Root of 1960	0.05***	0.11***	0.05***	0.10***	0.06***	0.05***	-0.04**	0.05**	-0.11*	-0.01
Central City Area	(0.01)	(0.03)	(0.01)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.07)	(0.04)
Change in Log Total	0.80***	1.02***	0.57***	0.77***	0.85***	0.57***	0.77***	0.58***	0.50*	0.36**
Employment	(0.06)	(0.12)	(0.06)	(0.10)	(0.07)	(0.07)	(0.08)	(0.09)	(0.28)	(0.15)
Constant	-0.52***	-1.68***	0.40***	-1.11***	-0.54***	-0.40***	0.09	-0.17	-0.69*	-1.42***
	(0.08)	(0.16)	(0.08)	(0.13)	(0.10)	(0.10)	(0.11)	(0.12)	(0.37)	(0.20)
R-Squared	0.66	0.45	0.51	0.45	0.63	0.47	0.50	0.36	0.05	0.13

Panel B: Central City Residents Working in Listed Industry

	All	Manuf-acturing	Services	Trade	TCPU	Const-ruction	Public Admin.	FIRE	Military	Agric-ulture
Change in Rays	-0.16***	-0.26***	-0.16***	-0.21***	-0.14**	-0.22***	-0.16***	-0.12**	-0.13	-0.07
1960 to 2000	(0.05)	(0.08)	(0.05)	(0.06)	(0.06)	(0.07)	(0.06)	(0.05)	(0.18)	(0.09)
Square Root of 1960	0.08***	0.11***	0.09***	0.08***	0.09***	0.11***	0.05**	0.07***	-0.00	-0.04
Central City Area	(0.02)	(0.03)	(0.02)	(0.02)	(0.02)	(0.03)	(0.02)	(0.02)	(0.07)	(0.03)
Change in Log Total	0.61***	1.01***	0.40***	0.51***	0.63***	0.60***	0.26**	0.40***	-0.49	0.16
Employment	(0.08)	(0.13)	(0.09)	(0.10)	(0.09)	(0.11)	(0.10)	(0.08)	(0.30)	(0.15)
Constant	-0.48***	-1.46***	0.32***	-0.63***	-0.53***	-0.42***	-0.28**	-0.09	-0.49	-0.66***
	(0.10)	(0.18)	(0.11)	(0.14)	(0.13)	(0.15)	(0.13)	(0.11)	(0.40)	(0.19)
R-Squared	0.33	0.23	0.06	0.01	0.31	0.05	0.01	0.20	0.01	0.04

Notes: Regressions are of the change in the log of outcomes listed in column headers on variables listed at left. The sample includes the same 100 MSAs used for Tables 1 and 2. The change in the number of rays is instrumented with rays in the 1947 national plan.

Table 7: Estimated Effects of Highways on Aggregate Commuting Flows

	Work in Central City	Work in Ring	Work Outside SMSA
Panel A: Central City Residents			
Change in Rays	-0.15***	-0.05	-0.01
1950 to 2000	(0.05)	(0.06)	(0.09)
Square Root of 1960	0.14***	0.08***	0.04
Central City Area	(0.02)	(0.02)	(0.04)
Change in Log Total	0.50***	0.78***	0.24
Employment	(0.09)	(0.10)	(0.16)
Constant	-1.10***	0.25*	0.09
	(0.12)	(0.13)	(0.21)
R-Squared	0.38	0.46	0.05
Panel B: Suburban Residents			
Change in Rays	-0.08	0.10*	0.13
1950 to 2000	(0.09)	(0.05)	(0.08)
Square Root of 1960	0.10***	0.02	0.01
Central City Area	(0.03)	(0.02)	(0.03)
Change in Log Total	1.09***	1.25***	0.95***
Employment	(0.15)	(0.09)	(0.14)
Constant	-0.32	-0.10	0.48**
	(0.20)	(0.12)	(0.19)
R-Squared	0.44	0.70	0.36
Panel C: Residents Outside SMSA Who Work in SMSA			
Change in Rays	-0.09	0.25***	
1950 to 2000	(0.07)	(0.09)	
Square Root of 1960	0.11***	0.01	
Central City Area	(0.03)	(0.03)	
Change in Log Total	0.99***	1.37***	
Employment	(0.11)	(0.15)	
Constant	0.16	0.34*	
	(0.15)	(0.19)	
R-Squared	0.52	0.51	

Figure 1: Davenport SMSA