

# 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 each radial highway displaced 16 percent of central city working residents but only 6 percent of jobs to the suburbs. These estimates are fairly consistent across industry. Identification of these treatment effects relies on exogenous variation available from planned portions of the federal highway system. Viewed in the context of an urban spatial equilibrium model, these estimates indicate that agglomeration spillovers that operate at sub-metropolitan area spatial scales remain an important incentive for firms to cluster spatially in most industries, even in the face of transportation cost reductions. Moreover, such local spillovers represent a large fraction of overall agglomeration spillovers. Among one-digit industries, results indicate that finance, insurance & real estate experiences the strongest productivity advantages of density and spatial centrality while wholesale & retail trade experiences the smallest.

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# 1 Introduction

It is well documented that the spatial structure of metropolitan areas in the United States has changed dramatically over the past century. While much of the existing empirical literature on urban spatial structure examines population distributions, this paper jointly examines decentralization patterns of jobs and working residents by industry. Evidence indicates that jobs and working residents decentralized apace, such that their relative concentrations in central cities remained remarkably unchanged between 1960 and 2000. Using planned portions of the interstate highway system as a source of exogenous variation, I report causal effects of each radial urban highway on job locations and workers' residential locations by industry. I consistently find that the effect of radial urban highways on the number of working residents in central cities is significantly greater in absolute value than that on the number of jobs, with partial elasticities of -0.16 and -0.06 respectively for all workers. A greater effect of highways on residential than job location is also found in each broad industry category. Using the structure of a simple model, I use estimated treatment effects and calibrated parameters to quantify the relative magnitudes of agglomeration spillovers within versus between metropolitan area sub-regions in each industry. This exercise indicates that the elasticity of central city total factor productivity with respect to central city employment is 0.015 to 0.051 greater than the elasticity of central city TFP to suburban employment, depending on parameters used for calibration. This full range of estimates indicates that a sizeable fraction of the overall metropolitan area level agglomeration economies documented in the literature is achieved through relatively local spillovers. Among one-digit industries not dominated by public sector workers, finance, insurance & real estate exhibits the strongest productivity advantages of density and spatial centrality while wholesale & retail trade exhibits the least.

This paper provides the first estimates of the causal effects of highways on the spatial organization of economic activity by industry within metropolitan areas and is the first to employ exogenous shocks to metropolitan area environments in a large set of cities to facilitate recovery of productivity spillovers that operate at local spatial scales. The empirical analysis expands on Glaeser & Kahn (2001) and Baum-Snow (2007, 2010), which relate documented changes in the spatial dis-

tributions of employment, population and commuting patterns in U.S. metropolitan areas during the past century to highway construction. This analysis' use of exogenous shocks to metropolitan area transportation costs to recover agglomeration parameters complements Rosenthal & Strange (2003) and Arzaghi & Henderson (2008) which instead employ revealed preference approaches of firm location choices in specific industries to better understand the spatial scope of productivity spillovers across firms. This analysis also complements Ahlfeldt et al. (2012), which recovers structural estimates of agglomeration spillovers across workers in all industries using the rise and fall of the Berlin Wall as a source of variation in nearby economic activity. Brinkman et al. (2012) and Brinkman (2013) similarly do so for individual U.S. cities, with identification off of the structures of firm entry and land use models respectively. Because of limits to the spatial detail available in data from 1960, this analysis necessarily uses more aggregated spatial units than most other empirical studies of local agglomeration spillovers.

In addition to researchers' inherent interest in the magnitudes of agglomeration spillovers that operate at sub-market scales, such spillovers represent a central element of modern land use models. A key determinant of equilibrium urban spatial structure in the influential class of models with endogenous firm and residential locations, as developed by Fujita & Ogawa (1982) and Lucas & Rossi-Hansberg (2002) for example, is the strength of local agglomeration forces relative to transportation costs. This class of models predicts that if agglomeration spillovers that are independent of transportation costs exist at sub-market spatial scales, a reduction in transport costs is likely to cause firms to decentralize less than residents. This ordering of comparative statics is consistent with empirical evidence reported in this paper. Both price and income effects push residents to decentralize in search of more space, while at the same time reducing commuting times conditional on work locations. By following workers to the suburbs, firms can achieve wage and rent reductions. However, commuting cost reductions also facilitate lower cost access to far away workers, making it less costly for firms to agglomerate in central cities.

This paper proceeds as follows. Section 2 presents the data and documents decentralization patterns of residences and jobs by industry between 1960 and 2000. Section 3 develops the empirical strategy for estimating causal effects of highway infrastructure on residential and job decentral-

ization by industry. Section 4 presents the empirical results. Section 5 develops an urban spatial equilibrium model that is used in Section 6 to derive quantitative implications about the local strength of agglomeration economies and the mechanisms that drive residential location responses to new highways. Finally, Section 7 concludes.

## 2 Data and Descriptive Evidence

### 2.1 Data on Worker and Job Location

This analysis uses journey to work tabulations from the 1960 and 2000 censuses and 1960 census tract data. Commuting flows by industry within and between central cities, SMSA remainders and other regions for each of the 100 largest SMSAs nationwide are reported in the journey to work supplement of the 1960 Census of Population. I aggregate this information 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 such information for different central cities. Therefore, all central cities in SMSAs with multiple central cities are necessarily treated as one spatial unit. For the 78 fully tracted large SMSAs in 1960, I also construct counts of residents by location and commuting flows to the primary central city.<sup>1</sup>

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.<sup>2</sup> It also reports the total count of commuters between all pairs of these microgeographic units nationwide. This analysis maintains the 1960 definition central cities and SMSAs 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.<sup>3</sup> Year 2000 microgeographic units of tabulation, typically traffic analysis zones but sometimes census block groups or census tracts, were allocated to 1960 geographies and

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<sup>1</sup>The 1960 census does report some commuting flow information for the 89 SMSAs with populations between 100,000 and 250,000. Unfortunately, the total number of SMSA workers cannot be determined for these smaller SMSAs, nor is place of work broken out by industry.

<sup>2</sup>The 2000 CTPP does not report commuting flows by industry of employment.

<sup>3</sup>This creation of constant spatial units is a crucial feature of the data since more than half of central city jurisdictions more than doubled in area between 1960 and 2000.

analogous counts were calculated through spatial 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. Traffic analysis zones, at which data in 2000 are reported, are bounded by thin lines. Each of the three central cities expanded geographically over time. The 1960 tracted region of the SMSA includes only the central cities. Also note that the extent of the SMSA geography is somewhat constrained. For this reason, I find it important to make use of information about commutes into and out of each SMSA for the analysis.

## 2.2 Decentralization of Working Residents, Employment and Commutes

Baum-Snow (2007a) documents that population decentralization out of central cities occurred in almost all U.S. metropolitan areas between 1950 and 1990. Figure 2 shows that similar patterns hold for working residents. Panel A shows the cumulative distribution functions of working residential population in 1960 and 2000 as functions of distance to SMSA central business districts (CBDs). I restrict this analysis to the 78 SMSAs that were fully tracted in 1960. In order to make SMSAs of different shapes and sizes comparable, I index location such that 0 is the CBD and 1 is the furthest census tract in the SMSA's primary central city. In Panel A we see that working residents live in much more dispersed locations in 2000 than in 1960. In Panel B, I break out residential location into primary central cities and suburbs. It shows that even within each geography, working residents became more decentralized during the study period.<sup>4</sup> Figure A1 shows similar trends for residents working in each major 1-digit industry.

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 locations of both employment and residences between 1960 and 2000.

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<sup>4</sup>While it would be instructive to examine a similar figure showing changes in the full spatial distribution of jobs over time, no such data exists for 1960.

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 fact that employment locations remain more centralized than residential locations 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.<sup>5</sup> Rows 5 through 8 of Table 2 report overall trends in SMSA working residents and employment by industry between 1960 and 2000. They show that manufacturing and retail/wholesale trade were declining industries while services and finance, insurance and real estate were growing. More relevant to the current analysis is the comparison across industries of relative decentralization rates of jobs and workers' residential locations. Comparisons of numbers in Rows 2 and 4 reveal 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. However, differences between results in Row 4 from Row 2 provides some evidence

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<sup>5</sup>Because of inconsistencies across census years in the classification of different types of services, I am forced to combine all services into one broad industry category in order to make valid comparisons between 1960 and 2000.

about the differences across industries in the ease of decentralization.

As is discussed in Baum-Snow (2010), the primary process through which decentralization of firms and workers occurred was by the modal commute shifting from being entirely within central cities to being entirely within suburban regions. Figure 3 presents plots of the average fraction commuting to primary central cities in 1960 and 2000 as functions of residential location in the same 78 SMSAs used to construct Figure 2 using the same location index. Whether examined for SMSAs overall (Panel A) or with central cities broken out separately from suburbs (Panel B), we see secular declines in the fraction of working residents commuting to central cities at all residential locations. Figure A2 shows that very similar changes in commuting patterns also hold for six individual large metropolitan areas.

Table 3 quantifies the associated changes in commuting patterns for the full sample of 100 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.

The final two columns of Table 3 give average one-way commuting times by type of commute in 2000. Unfortunately such data are not available in 1960 as the commute time question did not appear until the 1980 census. Results in Table 3 show that the longest commutes other than those involving crossing SMSA boundaries are traditional suburb-central city commutes, at 24 to 46 percent longer (depending on weighting procedure) than within central city commutes, which took 27 minutes for the average worker and 19 minutes when averaged across SMSAs. Within suburban ring commute times are notably similar to within central city commute times, though workers presumably enjoy a rent discount which ends up capitalized into lower wages. This commuting time data will be used in Section 5 to help calibrate agglomeration spillover parameters in the model.

## 2.3 Highway Data

I use an expanded version of the highway data in Baum-Snow (2007a). Actual counts of radial limited access highways serving primary central cities' central business districts were recorded for 1950, 1960 and 2000.<sup>6</sup> As in Baum-Snow (2007a), Michaels (2008), Baum-Snow (2010) and Duranton & Turner (2012), there is an econometric concern that highways were not allocated randomly to metropolitan areas. Instead, highway construction certainly responded to commuting demand increases because of metropolitan area population and economic growth. In addition, Duranton & Turner (2012) provide evidence that the federal government bankrolled additional highways beyond those in pre-1956 plans for economically struggling regions to achieve fiscal redistribution and to stimulate their local economies.

To address such potential endogeneity concerns, I instrument for the number of radial highways constructed prior to 2000 with the number in a 1947 plan of the interstate highway system. As is discussed in more detail in Baum-Snow (2007a), this plan was developed by the Federal Bureau of Public Roads based on observed levels of intercity traffic and defense needs to promote intercity trade and national defense. This highway plan was not developed to facilitate commuting. While the 1960 geography central city area and radius are significantly positively correlated with the number of planned highways, neither 1960 SMSA employment, SMSA population growth prior to 1950, nor the 1940 share of SMSA employment in any 1-digit industry significantly predicts the number of planned highways conditional on either measure of central city size. More important central cities were larger, and got allocated more planned highways as a result. Virtually the entire planned system (and more) was constructed because the federal government provided 90 percent matching funding to an initial 10 percent covered by individual states. This compendium of evidence supports the contention that the plan is a valid instrument for highway construction of the subsequently built interstate system conditional on some measure of central city or SMSA size and SMSA fixed effects. Inclusion central city radius in regressions throughout this analysis controls for the fact that more important cities, which are also larger, received more planned highways.<sup>7</sup>

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<sup>6</sup>Additional counts of other types of highways were also recorded but are not extensively used due to difficulties in isolating exogenous variation in them.

<sup>7</sup>I also tried using the number of radial highways serving each city in a 1922 federal war department plan of the



Table A1 presents summary statistics about the highway and demographic data used in this analysis. It shows that sampled metropolitan areas received an average of 2.7 radial highways between 1950 and 2000, with 2.0 of these built after 1960. The mean number of planned highways is 2.9. Because of the high cost of building highways to serve central business districts, cities with many planned highways often consolidate them into fewer central arteries that serve the downtown area.

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 infrastructure in such a short time.<sup>8</sup> 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.<sup>9</sup> With 1950 as the base year, coefficients on planned rays are between 0.47 and 0.53. Coefficients of interest are smaller by 0.13 to 0.17 when 1960 is instead the base year. As a result, second stage estimates always end up larger if 1960 is the base year. Furthermore, there may be some concern that the timing of highway construction is endogenous to commuting demand, with the highways with the largest treatment effects built first. Therefore, even though outcomes of interest are measured as of 1960 and 2000, 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.

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national highway system, the "Pershing Map". This plan indicates three priority levels for construction and was put together with less regard for intercity trade than the 1947 plan used to construct the instrument. Unfortunately, instruments derived from the Pershing Map are insufficiently strong to be useful for this analysis.

<sup>8</sup>In Baum-Snow (2007a), I find that about two-thirds of the long run response of urban form to the highway system occurs within 20 years.

<sup>9</sup>Beyond the set of controls included in the table, a broader set was tried including 1960 log SMSA employment and 1940 SMSA industry shares. Results in no cases were appreciably affected and these controls always have insignificant coefficients.

### 3 Empirical Strategy

The primary empirical goal of this paper 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 (2007a), Baum-Snow (2010) and Baum-Snow et al. (2012) 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 employment  $emp_{ki}^{CC}$  or working population  $pop_{ki}^{CC}$  in each industry  $k$  holding the total number of SMSA jobs or working population in that and all other industries constant, where  $i$  indexes SMSA:

$$\begin{aligned}\Delta \ln(emp_{ki}^{CC}) &= \rho_{0k} + \rho_{1k}\Delta(hwy_i) + \rho_{2k}\Delta \ln(emp_{ki}^{SMSA}) + \sum_{j \neq k} \rho_{2k}^j \Delta \ln(emp_{ki}^{SMSA}) + X_i \varrho_k + \epsilon_{ki} \\ \Delta \ln(pop_{ki}^{CC}) &= r_{0k} + r_{1k}\Delta(hwy_i) + r_{2k}\Delta \ln(pop_{ki}^{SMSA}) + \sum_{j \neq k} r_{2k}^j \Delta \ln(pop_{ki}^{SMSA}) + X_i R_k + u_{ki}\end{aligned}\tag{2}$$

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  $\rho_{1k}$  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. A final potential difficulty is that there may be cross-industry effects. That is, the total number of SMSA workers in services may influence where manufacturing firms wish to locate. I provide some indirect evidence below that such cross-industry effects, as captured by  $\rho_{2k}^j$  and  $r_{2k}^j$ , are small.

To get around inclusion of industry-specific SMSA employment as a predictor for identifying parameters of interest  $\rho_{1k}$  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 (2013). 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.

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

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

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

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 people who either work or reside (or both) in SMSA  $i$ . 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 scale 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 differences in coefficients across equations can be attributed only to differences in the outcome variable.

Several 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, this object should respond positively to the number of highways, whether planned or built. On the other hand direct inclusion of  $\Delta \ln(popemp_i^{SMSA})$  may introduce a correlation with

the error term since shocks to one sector of employment mechanically affect aggregate employment in all sectors. In practice, results in the next section indicate that the bias from excluding this control is small since it does not respond much to highways. If highways cause SMSA population growth, it can be shown that excluding this variable leads to transport coefficients that are positively biased, whereas including this variable yields transport coefficients that are negatively biased.<sup>10</sup> Moreover, attempts to instrument for  $\Delta \ln(\text{popemp}_i^{\text{SMSA}})$  using average january temperature and annual precipitation, similar to the strategy in Glaeser & Gyourko (2005), yield estimates of  $\alpha_{1k}$  and  $a_{1k}$  that are within 0.01 of estimates in regressions in which I instrument only for  $\Delta(\text{hwy}_i)$ .<sup>11</sup>

The final issue is to consider which variables belong in additional controls  $X$ . There are two 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  $\alpha_1$ . 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 with 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.

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

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<sup>10</sup>The econometrics of these biases is seen in the following simplified environment. Suppose that the underlying structural equation for SMSA jobs in a given industry is  $\ln(\text{emp}_{ki}^{\text{SMSA}}) = \alpha_{0k} + \alpha_{1k}(\text{hwy}_i) + \alpha_{2k} \ln(\text{popemp}_i^{\text{SMSA}}) + \varepsilon_{ki}$ ,  $\ln(\text{popemp}_i^{\text{SMSA}}) = \ln(\sum_k e^{\ln(\text{emp}_{ki}^{\text{SMSA}})})$ . Here,  $\text{hwy}_i$  is instrumented with  $\text{hwy}_i^{47}$ , which is uncorrelated with  $\varepsilon_{ki}$ . The IV estimate of  $\alpha_{1k}$  excluding  $\ln(\text{popemp}_i^{\text{SMSA}})$  from the regression equals  $\alpha_{1k} + \alpha_{2k} \frac{\text{Cov}(\text{hwy}_i^{47}, \ln(\text{popemp}_i^{\text{SMSA}}))}{\text{Cov}(\text{hwy}_i, \text{hwy}_i^{47})}$  while the IV estimate of  $\alpha_{1k}$  including this variable is  $\alpha_{1k} - \frac{\text{Cov}(\text{hwy}_i^{47}, \ln(\text{popemp}_i^{\text{SMSA}})) \text{Cov}(\ln(\text{popemp}_i^{\text{SMSA}}), \varepsilon_{ik})}{D > 0}$ .

<sup>11</sup>An alternative commonly used instrument for the growth in total metropolitan area employment or population is Bartik (1989) style industry shift-shares. Such instruments are less suitable for this analysis since historical industry shares are mechanically correlated with industry level outcomes of interest. Nevertheless, instrumenting with the vector of 1 digit 1940 SMSA industry shares also yields similar highways coefficients, with a few exceptions.

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  $\alpha_{1k}$  and  $a_{1k}$ .

Armed with estimates of  $a_{1k}$  and  $\alpha_{1k}$ , the next step is to specify equations that allow us to recover the impacts of highways on urban decentralization by industry holding the 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.

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

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

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. The same argument for negative biases of  $\omega_{1k}$  and  $w_{1k}$  when including  $\Delta \ln(popemp_i^{SMSA})$  in the regressions and positive biases of these coefficients when excluding  $\Delta \ln(popemp_i^{SMSA})$  from these regressions hold as for (3) and (4). As with estimation of (3) and (4), use of weather variables as instruments for  $\Delta \ln(popemp_i^{SMSA})$  affects coefficients of interest by less than 0.01 except for military coefficients which change by up to 0.03.

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  $\alpha_{1k}$ ,  $a_{1k}$ ,  $\omega_{1k}$  and  $w_{1k}$  causal effects of highways on decentralization of jobs or working resident population by industry are given by the following

expressions respectively:

$$\rho_{1k} = \omega_{1k} - \frac{\omega_{2k}}{\alpha_{2k}}\alpha_{1k} + \sum_{j \neq k} \left( \frac{\alpha_{1k}}{\alpha_{2k}}\alpha_{2j} - \alpha_{1j} \right) \rho_{2k}^j \quad (7)$$

$$r_{1k} = w_{1k} - \frac{w_{2k}}{a_{2k}}a_{1k} + \sum_{j \neq k} \left( \frac{a_{1k}}{a_{2k}}a_{2j} - a_{1j} \right) r_{2k}^j \quad (8)$$

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 one adjustment for the effect on industry composition, whose size depends on the importance of the industry in the economy, and an additional adjustment for cross-industry effects. Note that while  $\rho_{2k}^j$  and  $r_{2k}^j$  are not identified, we expect them to be between -1 and 1. Therefore, the terms capturing cross-industry effects can be bounded. The following section discusses estimates of these four sets of elements used to build the ultimate parameters of interest. Parameters can be recovered using linear IV or GMM, run separately for each industry  $k$ .

## 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.<sup>12</sup> The remaining columns of Table 5 show that manufacturing is the only industry with a statistically significant response of SMSA employment to new transport infrastructure. Each radial highway is estimated to cause about 10 percent of the manufacturing jobs and working residents to depart an SMSA, either to rural areas or abroad.

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<sup>12</sup>This result is in contrast to evidence in Baum-Snow (2007) and Duranton & Turner (2011b) that metro areas building more highways experienced population increases. There are two reasons for this discrepancy. First, this paper uses more constrained metropolitan area geographies and much of the urban growth caused by highways manifested itself as sprawl in outlying areas. Second, samples in the other two papers included many metropolitan areas that were smaller than 250,000 in 1960, and these smaller metropolitan areas also exhibit positive growth effects of highways using 1960 geographies.

While most rays coefficients in Panel B are not statistically different from those in Panel A, highways are estimated to cause greater declines in SMSA working residents than employment in each industry. Gaps between rays coefficients in Panel A and B range from 0.03 to 0.09 across industries. Each highway is estimated to cause the number of SMSA residents working in manufacturing to significantly decline by 14 percent, residents working in retail or wholesale trade to significantly decline by 5 percent and residents working in public administration to significantly decline by 9 percent. Estimates for other industries are not statistically significant. The consistent discrepancy between highways coefficients in Panels A and B reflects the residential decentralization out of 1960 definition SMSAs caused by new highways. All results in Table 5 are robust, with indicated statistical significance levels and changes of less than 0.01 in magnitudes, to inclusion of 1960 log SMSA employment and 1940 1-digit 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. OLS regressions analogous to those in Table 5 yield very similar results.

## 4.2 Effects of Highways on Decentralization by Industry

Table 6 reports estimated effects of radial highways on central city employment by industry in Panel A and working population by industry in Panel B. Because most highways coefficients in Table 5 are near 0, highways coefficients in Table 6 for all industries except manufacturing are very close to 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, while holding the SMSA industry mix constant.

Before exploring heterogeneity in effects across industries, it is instructive to examine results in the first column, for all workers. Baum-Snow (2007a) estimates highway treatment effects analogous to that reported in column 1, Panel B but for population rather than just workers. 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 analogous Baum-Snow (2007a) estimate of -0.12. It should be noted that this estimate applies to only about half of people used in Baum-Snow (2007a). The effect of each ray on the total number of jobs, reported in column 1 of Panel A, is

much smaller in absolute value at -0.06. This difference of 0.10 is statistically significant and this gap far exceeds that which 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 trade-off between decentralizing (and further lowering input costs) or maintaining some level of clustering to take advantage of agglomeration spillovers that operate at sub-market spatial scales. The fact that the coefficient for all employment in Panel A is less negative than that in Panel B for all working residents reflects this additional force pushing for firm centralization.

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. Equations (7) and (8) indicate the potential importance of adjusting for the endogenous change in the industry mix induced by new highways in interpreting coefficients in Table 6. Table 7 reports such causal effects of each radial highway on central city employment in Column 1 and resident workers by industry in Column 2, holding the SMSA industry composition fixed. These treatment effects are very similar to coefficients in Table 6 because highways had only a small effect on the SMSA industry mix. Entries in Table 7 are constructed by estimating a five equation system for each industry (including a "first stage") by GMM and calculating causal effects of interest using (7) and (8), ignoring any potential cross-industry effects. The delta method is used to calculate standard errors. Since own-industry SMSA employment composition adjustments are negligible for all industries except manufacturing, and are small for manufacturing, any cross industry adjustments to causal effects of interest must be negligible.

BOUNDS ON CROSS-INDUSTRY EFFECTS

As the model developed in the following section demonstrates, the magnitudes of highway responses reported in Table 7 provide information about the strength of localized agglomeration economies. Smaller effects of highways on decentralization of both employment and residences are evidence of stronger agglomeration forces keeping firms in the central city. Results in Table 7 re-



veal a statistically significant positive effect of highways on central city agricultural employment and insignificant slightly positive point estimates for public administration and the military. These three industries exhibit the largest gaps between location responses of workers and firms to new highways, but are also the industries in which the free market probably has the least influence on employment location. Among remaining industries, each radial highway caused central city employment in finance insurance & real estate to decline by about 4 percent and central city employment in retail & wholesale trade to decline by about 14 percent, with others in between at 7-8 percent. This evidence of relatively strong local agglomeration forces in finance insurance & real estate and relatively weak such forces in retail & wholesale trade is quantified more carefully in Section 6 using the structure of the model developed in Section 5 and these estimated treatment effects.

The second column of Table 7 presents causal effects of each highway on central city working residents by industry. These effects exhibit much less variation across industries than do response of employment locations. This is consistent with predictions of the model. Many factors influencing residential location choice do not depend on work location. Other than agriculture, which has a statistically insignificant treatment effect of -0.05, point estimates indicate that each highway caused between 12 and 21 percent of central city workers to suburbanize, depending on industry. The smallest effect is for workers in finance, insurance & real estate, which likely incorporates the relatively small response of firm location as well in this industry. The largest effect is for those working in construction and and wholesale & retail trade, also consistent with this industry's small localized agglomeration spillovers. Gaps between effects of highways on employment and residential locations, reported in the third column of Table 7, are positive for each industry.

Consistent with prior research on similar questions, IV estimates of rays coefficients reported in Table 6 are larger in absolute value than OLS coefficients, which are reported in Table A2. It does remain true that OLS estimated effects of highways on residential decentralization are consistently larger in absolute value than OLS estimated effects of highways on employment decentralization, though these gaps are smaller in most industries than analogous IV estimates. As is discussed in Baum-Snow (2007a) and Duranton & Turner (2012), the OLS-IV discrepancy occurs for several reasons. First, highways that were proscribed by the plan were likely to have been built first

and caused a large amount of decentralization before more recently built endogenous highways were constructed.<sup>13</sup> Second, many highways built in addition to the plan were vehicles by which the federal government channeled assistance to economically struggling metropolitan areas. Such metropolitan areas may have experienced less rapid changes of all sorts, including decentralization.

#### EVIDENCE ON OLS-IV GAPS

### 4.3 Commuting Mechanisms

To understand the mechanisms through which reductions in transport costs have caused worker and firm decentralization, I next explore how highways caused 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 8, indicate that highways were very important in shaping the changing commuting patterns in U.S. metropolitan areas reported in Table 3. Highways had statistically significant effects on 3 of the 8 commuting flows considered. Each highway caused an estimated 15 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.<sup>14</sup>

### 4.4 Robustness to Specification and Central City Definition

To this point, I have necessarily defined central cities to correspond to their 1960 census geographies. However, when examining effects of highways on residential location, it is possible to redefine each SMSA's central city as being within a fixed radius of the SMSA's central business district in tracted SMSAs. While the limited availability of census tract data in 1960 reduces sample sizes to between 78 and 93, depending on CBD distance, use of these alternative central city geographies indicates that central city geographic definition is not driving the results. Figure 4 Panel A graphs coefficients

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<sup>13</sup> Attempts to estimate nonlinear effects of highways are unsuccessful due to large standard errors.

<sup>14</sup> 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.

in radial highways in regressions similar to those reported in Table 6 Panel B Column 1, in which log total central city working population is the outcome, as functions of imposed central city radius. If the central city radius is between 2 and 9 km from the CBD, each radial highway is estimated to cause decentralization of about 20 percent of central city resident workers. Beyond a radius of 9 km, the addition of each km in central city radius reduces the estimated effect of each highway by about 0.01. No coefficient on true 1960 central city radius is statistically significant in these regressions. Also evident in Figure 4 is how similar coefficients are when total SMSA working population is excluded (top, blue line) versus included (bottom, red line) in the regression. Under reasonable assumptions discussed in Section 4, true causal effects of highways are bounded by these two lines.

Figure 4 Panel B presents similar coefficient estimates but when central city radius is determined separately for each SMSA such that 10, 20, 30, 40 or 50 percent of SMSA employment is within the given radii, as calculated separately for each SMSA. This normalization indicates that the drift upwards in coefficient as a function of central city size begins at radii below which 10 percent of the year 2000 employment is in the central city, for which each radial highway causes about 25 percent of central city working residents to move to the suburbs. The highways coefficient levels off at -0.16 for radii containing 40-50 percent of year 2000 employment, which is the same estimate reported in Table 6 Panel B. Figure A3 shows similar results using data from the larger sample of 154 SMSAs of over 100,000 in population in 1960 for which some 1960 census tract data exist. Unfortunately, an analogous exercise for job location is not possible because of data limitations in 1960. Attempts to use data only from 2000 were unsuccessful and highlight the importance of first differencing in order to control for unobserved fixed factors that influenced the location of planned highways.

## 5 Model

This section provides a framework for evaluating how the treatment effects of transport improvements on employment decentralization and population decentralization presented in the previous section can be used to recover information about the spatial scope of local agglomeration economies and welfare gains from new highways. The model is sufficiently stylized such that comparative

statics involving transport costs have clear interpretations and the model can be calibrated with available information. Treatment effects reported in the previous section are, along with calibrated cost and expenditure share parameters, sufficient statistics (Chetty, 2009) for carrying out this evaluation. Unlike many other land use models with endogenous firm location, this model is also simple enough such that it has a unique equilibrium given transport cost and agglomeration forces.

This is a "closed city" absentee landlord model with two metropolitan regions: the city and the suburbs. The model is in the spirit of Rosen (1979) and Roback (1982) but considers only two locations: the central city and the suburbs. 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 residents not to equal the number of jobs. Second, there are agglomeration spillovers between workers in the two regions which themselves may also depend on the transportation cost. The model is optimized to theoretically represent the spatial nature of the data used to recover the treatment effects discussed in the prior section of the paper. Indeed, this model can be interpreted as a spatially aggregated version of the more spatially continuous land use models developed by Lucas & Rossi-Hansberg (2002) and Ahlfeldt et al. (2012). While this model has no worker or firm heterogeneity, Fu and Ross (2013) provide compelling empirical evidence that worker heterogeneity does not drive productivity differences across space within metropolitan areas.

## 5.1 Setup

There is an exogenous amount of central city land  $L_c$ , for which workers and firms compete, 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  $N$ , measure  $N_c$  works in the city and  $N_s$  work in the suburbs.  $Q_c$  is the total residential population of the city and  $N - Q_c$  is the suburban residential population.

### 5.1.1 The Tradeable Sector

Tradeable sector firms produce a good of price 1 using a constant returns to scale technology with land, labor and capital. Their total factor productivity incorporates a Hicks neutral agglomeration force  $A_r(N_c, t)$  that is increasing in the number of workers in the region  $r$  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  $t$ .<sup>15</sup> Because of the constant returns to scale technology, we can conceptualize each firm as operating on one unit of space. I denote  $n_c$  as workers per unit space in the city and  $n_s$  as workers per unit space in the suburbs.  $k_c$  and  $k_s$  are capital per unit space in each region respectively. Labor, capital and location are firms' only choice variables. Profit functions for city and suburban firms respectively are thus:

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

In these expressions,  $w_c$  and  $w_s$  are wages while  $v$  is the capital rental rate, which does not differ by location. Because firms are fully mobile, they must earn the same profit in each location. Total differentiation of the indirect profit function given input costs yields the following equilibrium relationship between productivity, wages and rents between the city and suburbs. This equation is a within-city version of one central Rosen (1979) and Roback (1982) equilibrium condition, in which  $\phi_N$  is the cost share of labor and  $\phi_L$  is the cost share of land.

$$d \ln A = \phi_N d \ln w + \phi_L d \ln r \tag{9}$$

This equation indicates that the higher wage and rent location (the city) must also have higher total factor productivity in order for firms to be willing to locate there simultaneously as in the lower cost suburbs. Because capital has the same cost in both locations, it drops out of this equation.

Optimization over the labor and capital inputs while imposing 0 profits pins down the number

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<sup>15</sup>The time cost  $t$  is specified such that it is 0 if it is costless to travel everywhere and 1 if it takes a worker's full time endowment to travel between home and work within the central city.

of workers hired at each firm and the equilibrium wage. For these calculations, I employ the Cobb-Douglas production technology  $f(n, k) = n^\gamma k^\mu$ . The central city wage as a function of rent is

$$w_c = \frac{A_c^{\frac{1}{\gamma}} v^{-\frac{\mu}{\gamma}} \mu^{\frac{\mu}{\gamma}} \gamma (1 - \gamma - \mu)^{\frac{1-\gamma-\mu}{\gamma}}}{r^{\frac{1-\gamma-\mu}{\gamma}}}.$$

The resulting mass of workers hired by each central city firm is

$$n_c = \frac{r^{\frac{1-\mu}{\gamma}}}{A_c^{\frac{1}{\gamma}} \left[\frac{\mu}{v}\right]^{\frac{\mu}{\gamma}} (1 - \gamma - \mu)^{\frac{1-\mu}{\gamma}}}.$$

This factor demand function is increasing in central city land rent  $r$  since higher rents induce firms to substitute toward labor and away from land. Because each firm operates on one unit of space, the implied amount of central city space devoted to production is the same as the number of firms and is given by  $\frac{N_c}{n_c}$ . This aggregate factor demand function is downward sloping in land rent  $r$  and shifts out with increases in total factor productivity.

### 5.1.2 The Housing Sector

Housing is produced with a different constant returns to scale technology over the same three inputs to production. As with tradeable goods, because of the CRS nature of the production technology, total differentiation of indirect profit functions yields an equation that relates the difference in housing prices  $p$  between a central city and surrounding suburban area with differences in land rents and wages.

$$d \ln p = \theta_L d \ln r + \theta_N d \ln w \quad (10)$$

Key to this equation is the assumption that firm productivities in the housing sector do not differ across space. Therefore, any differences in rents and wages must be reflected in housing price differences.<sup>16</sup>

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<sup>16</sup>Rather than assume they are zero, it would be possible to recover housing sector productivity differences between cities and suburbs with home price data. Unfortunately, quality adjusted home value information for sub-metropolitan area regions is difficult to construct in 1960.

### 5.1.3 Consumers

Each person in each metropolitan region is identical and has preferences over a traded consumption good  $z$  of price 1, housing  $H$  and a local amenity  $q$ . Each individual is endowed with one unit of time that is allocated toward working 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 or between the suburbs and the city at time cost  $c_{sc} t$ , where  $c_{sc} > c_s > 1$ . 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:

$$\begin{aligned} V_c &= \max_{z, H} [U(z, H, q_c) + \lambda_c(w_c(1 - t) - z - p_c H)] = V(p_c, w_c(1 - t), q_c) \\ V_s &= \max_{z, H} [U(z, H, q_s) + \lambda_s(w_s(1 - c_s t) - z - p_s H)] = V(p_s, w_s(1 - c_s t), q_s) \\ V_{sc} &= \max_{z, H} [U(z, H, q_s) + \lambda_{sc}(w_c(1 - c_{sc} t) - z - p_s H)] = V(p_s, w_c(1 - c_{sc} t), q_s) \end{aligned} \quad (11)$$

I ignore the possibility of reverse commuters as reverse commuting has a small market share and would be difficult to rationalize at the same time as suburb to city commutes in a simple model. The utility function is concave in all three of its arguments.

Notice that since all suburban residents face the same prices and have the same utility, they must consume the same bundle  $(z_s, H_s)$  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, we can approximate the city-suburban log wage difference as the difference in commuting times for suburban residents:

$$\ln(w_c) - \ln(w_s) \approx (c_{sc} - c_s)t \quad (12)$$

Given equal utility for city and suburban residents, without even considering the production

side of the model it is clear that there are three potential reasons why cities have higher home prices than the suburbs. Wages are higher, commuting costs may be lower and amenities may be higher. If home prices were not higher to compensate, everyone would choose to live in the city. This observation about relative home prices can be formalized by imposing the  $V_c = V_{sc}$  or  $V_c = V_s$ . Differentiating either of these equilibrium conditions yields an equation which states that the percent difference across locations in home prices, normalized by the expenditure share on housing, has to equal the percent difference across locations in wages net of commuting costs plus an adjustment for amenity differences. Substituting in for  $d \ln p$  from (10) yields an equation that pins down equilibrium rent differences between the city and the suburbs. This identity is discussed more generally in Albouy (2012). Using this equality implies an expression for city rents, where  $\sigma_H$  is the housing expenditure share and  $\sigma_q$  is a constant that does not depend on  $t$ . I will sometimes use  $\ln \tilde{r}$  below, which includes both suburban rents and the adjusted amenity difference. If  $\frac{\partial \ln U / \partial \ln q}{d \ln U / d \ln [w(1-t)]}$  is a constant,  $\ln \tilde{r}$  does not depend on  $t$ , allowing it to drop out in comparative statics with respect to  $t$ .<sup>17</sup>

$$\ln r \approx \ln \underline{r} + \frac{1 - \sigma_H \theta_N}{\sigma_H \theta_L} (c_{sc} - c_s) t + \frac{1}{\theta_L \sigma_H} \frac{\partial \ln U / \partial \ln q}{d \ln U / d \ln [w(1-t)]} (\ln q_c - \ln q_s) \equiv \ln \tilde{r} + \frac{1 - \sigma_H \theta_N}{\sigma_H \theta_L} (c_{sc} - c_s) t \quad (13)$$

In considering the firm side of the market below, the equilibrium conditions on relative wages and rents will prove useful.

Following the literature, of which Mayo (1981) provides a review updated by Davis & Ortalo-Magné (2008), I assume that housing demand is constant elasticity in prices and income. Substituting the equilibrium condition from the housing sector (10) into this constant elasticity demand function derives the consumer demand function for central city land. In this expression,  $R$  is a constant,  $\varepsilon$  is the price elasticity of demand for housing and  $\eta$  is its income elasticity of demand.

$$\ln l^d(r, w_c) = R + \eta \ln [w_c(1-t)] + \varepsilon (\theta_L \ln r + \theta_N \ln w_c) - (\theta_K + \theta_N) \ln r + \theta_N \ln w_c \quad (14)$$

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<sup>17</sup>The utility function  $U = qz^\alpha H^\beta$ , as used by Ahlfeldt et al. (2012) is consistent with  $\ln \tilde{r}$  being constant.



The constant incorporates the cost of capital. The second term captures the influence of consumers' income net of commuting costs. The third term captures the fact that land costs and wages contribute to housing costs, which influences demand for space via its price elasticity. The remaining terms capture the general equilibrium effects that as land costs rise, homebuilders substitute toward capital and labor and away from land and as wages rise homebuilders substitute away from labor and toward land.

## 5.2 Model Solution

### 5.2.1 Equilibrium

The previous sub-section developed Equations (9), (12) and (13), which are combined into the first equilibrium equation of this model.

$$\ln A_c(N_c, t) - \ln A_s(N_c, t) = [\phi_N + \phi_L \frac{1 - \sigma_H \theta_N}{\sigma_H \theta_L}] (c_{sc} - c_s) t + \phi_L \frac{\sigma_q}{\sigma_s} d \ln q \quad (15)$$

One remarkable feature of this expression is that it provides an implicit solution for total city employment  $N_c$ , but does not depend on the level of suburban rents or the amount of space available in the city.<sup>18</sup> The following subsection will work with this expression to evaluate how it relates to estimates of the response of the number of central city workers to urban highway infrastructure.

Imposing market clearing for space in the city allows us to determine the number of residents in the city. This equation represents the equilibrium relationship between the number of jobs and residents in the central city, given respectively by  $N_c$  and  $Q_c$ .

$$N_c \left[ \frac{1 - \gamma - \mu}{r} \right]^{\frac{1-\mu}{\gamma}} A_c(N_c, t)^{\frac{1}{\gamma}} \left[ \frac{\mu}{v} \right]^{\frac{\mu}{\gamma}} + Q_c l^d(r, w_c) = L_c \quad (16)$$

The first term in this expression describes the amount of city land used in production. Unlike the

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<sup>18</sup>To keep the model simple and tractable, I impose that all metropolitan area residents work in the tradeable sector. Housing sector labor can be thought of as coming from reducing the exogenous metro area population  $N$  by a small amount. Though this amount is technically endogenous to  $t$ , because it is a small fraction of  $N$ , incorporating it explicitly in the model will not affect results much. The construction industry employed an average of 6 percent of urban workers in sample metropolitan areas in both 1960 and 2000. Alternatively, one could respecify preferences to be over land rather than housing. This adjustment leads to very similar results, though with a less rich interpretation.

total amount of central city employment  $N_c$ , the amount of central city space used by firms does depend on the level of suburban rent. Higher city land rents  $r = \tilde{r} e^{\frac{1-\theta_N}{\sigma_H \theta_L} (c_{sc} - c_s)t}$  lead firms to economize on space and hire more workers per unit area. The second term is the product of the number of city residents and consumer demand for land. In working with this expression below, I substitute in for the central city rents  $r$  and wages  $w_c$  with objects derived above.

### 5.2.2 Specifying the Agglomeration Function

With equilibrium values of  $N_c$  and  $Q_c$  determined from (15) and (16), we are in a position to derive analytical expressions for responses of these quantities of central city residents and workers to changes in transportation costs  $t$ . Comparing these theoretical changes to actual changes measured in the data will allow us to recover elements of interest that capture agglomeration spillovers and are contained in the functions  $A_c(N_c, t)$  and  $A_s(N_c, t)$ .

I use the following generalized constant elasticity functional forms for the agglomeration functions.

$$A_c(N_c, t) = \alpha_c h(t) g_c(N_c), \quad A_s(N_c, t) = \alpha_s h(t) g_s(N_c)$$

$\alpha_c$  and  $\alpha_s$  capture natural productivity advantages of cities and suburbs respectively. The function  $h(t)$ ,  $h' < 0$  captures the potential for transportation cost reductions to improve contact between all firms in a metropolitan area, thereby enhancing agglomeration spillovers.

The element of primary interest in the TFP functions are the  $g_c$  and  $g_s$  functions. As is shown below, recovery of  $\frac{d \ln g_c}{d \ln N_c}$  and  $\frac{d \ln g_s}{d \ln N_c}$  is possible through combining treatment effect estimates and calibrated parameters. One simple specification of such functions is constant elasticity in  $N_c$  and  $N_s$ :

$$g_c(N_c) = N_c^{\beta_c} (N - N_c)^{\rho_c}, \quad g_s(N_c) = (N - N_c)^{\beta_s} N_c^{\rho_s}$$

Given this specification, we can recover the parameter combinations  $\beta_c - \frac{N_c}{N_s} \rho_c > 0$  and  $\rho_s - \frac{N_c}{N_s} \beta_s < 0$ , which capture the relative strength of agglomeration forces within versus across regions. Indicated signs assume that within region agglomeration spillovers exceed across region agglomeration spillovers.

More standard specifications of the agglomeration spillover functions, used for example in Ahlfeldt et al. (2012) are:

$$g_c(N_c) = [N_c + \rho_c(N - N_c)]^{\beta_c}, g_s(N_c) = [N - N_c + \rho_s N_c]^{\beta_s}$$

For these specifications,  $\frac{d \ln g_c}{d \ln N_c} = \frac{\beta_c N_c (1 - \rho_c)}{N_c + \rho_c N_s} > 0$  and  $\frac{d \ln g_s}{d \ln N_c} = \frac{\beta_s N_c (\rho_s - 1)}{N_s + \rho_s N_c} < 0$ . If  $\beta_c = \beta_s$  and  $\rho_c = \rho_s$ , both parameters are just identified by the calibration procedure employed below.

Whatever the specific forms of  $g_c(N_c)$  and  $g_s(N_c)$  that are chosen, calibration of the model allows for recovery of the relative sizes of agglomeration spillovers in the city versus the suburbs and vice-versa on local firms. The empirical setup makes this possible by holding the total number of workers and residents  $N$  in the metropolitan area constant and by isolating the sizes of shocks to central city versus suburban employment induced by reductions in commuting costs. While estimates are reported in terms of responses of the generalized  $g_c(\cdot)$  and  $g_s(\cdot)$  functions, they can be interpreted as capturing parameter combinations from either of the two specifications indicated above.

### 5.2.3 Comparative Statics

Differentiating (15) yields the following equation, which is the partial elasticity of central city employment with respect to travel time.

$$\frac{d \ln N_c}{dt} = \frac{[\phi_N + \phi_L \frac{1 - \sigma_H \theta_N}{\sigma_H \theta_L}](c_{sc} - c_s)}{\frac{d \ln g_c}{d \ln N_c} - \frac{d \ln g_s}{d \ln N_c}} \quad (17)$$

The intuition behind this expression is as follows. Transport cost increases drive up central city wages and rents relative to suburban wages and rents. This means that in order for firms to continue to exist in both the central city and suburbs, the relative size of agglomeration spillovers must also increase to compensate. This increase in relative agglomeration forces is facilitated by increasing central city employment as long as the agglomeration spillovers within the city exceeds those between the city and suburbs. Using calibrated values for elements of the numerator, empirical

estimates of  $\frac{d \ln N_c}{d[hwy]}$  and calibrated values of  $\frac{d[hwy]}{dt}$ , we can therefore recover a value for  $\frac{d \ln g_c}{d \ln N_c} - \frac{d \ln g_s}{d \ln N_c}$ . Because total metropolitan area employment is fixed, this difference can be thought of as the total sum of agglomeration forces in the own region relative to that in the other region of the metro area, with an adjustment for regions' relative size. In mathematical terms,  $\frac{d \ln g_c}{d \ln N_c} - \frac{d \ln g_s}{d \ln N_c} = \left[ \frac{\partial \ln g_c}{\partial \ln N_c} - \frac{N_c}{N_s} \frac{\partial \ln g_c}{\partial \ln N_s} \right] + \left[ \frac{N_c}{N_s} \frac{\partial \ln g_s}{\partial \ln N_s} - \frac{\partial \ln g_s}{\partial \ln N_c} \right]$ . Because  $c_{sc} > c_s$ , the derivative  $\frac{d \ln N_c}{dt}$  is positive if agglomeration economies are stronger locally than between cities and suburbs. Because this object only depends on a few parameters, model simulations presented below can quantify the extent to which agglomeration spillovers operate at sub-metropolitan area scales with reasonably tight bounds. Moreover, because (17) is not derived from any conditions using the allocation of quantities between cities and suburbs, it can be directly applied separately for each industry.

Differentiating (16) yields an expression for the partial elasticity of central city (working) population with respect to commuting time. The resulting expression depends crucially on comparative statics of log central city rents and wages with respect to commuting costs:

$$\begin{aligned} \frac{d \ln r}{dt} &= \frac{1 - \sigma_H \theta_N}{\sigma_H \theta_L} (c_{sc} - c_s) > 0 \\ \frac{d \ln w_c}{dt} &= \frac{1}{\gamma} \frac{d \ln h}{dt} + \frac{1}{\gamma} \frac{d \ln g_c}{d \ln N_c} \frac{d \ln N_c}{dt} - \frac{1 - \gamma - \mu}{\gamma} \frac{d \ln r}{dt} < 0 \end{aligned}$$

As transport costs increase, central city land rents increase because there is more competition for central city space to avoid the higher commuting cost from the suburbs. The wage response has three components. First, transportation costs have a direct negative effect on agglomeration spillovers and worker productivity. Calibrating this element will require choosing  $\frac{d \ln h}{dt}$ , which I initially set to  $-1$ . Second, agglomeration spillovers increase as employment location centralizes. Third, the amount of land per worker decreases as the price of central city space increases, making workers less productive.

Given these central city wage and rent responses, the following expression breaks out  $\frac{d \ln Q_c}{dt}$  into a number of components. In this expression,  $X_c$  represents the central city land area devoted to

production and  $L_c - X_c$  is the central city land area devoted to residences.

$$\begin{aligned}
\frac{d \ln Q_c}{dt} = & \eta & \text{A. standard income effect (+)} \\
& -\varepsilon \theta_L \frac{d \ln r}{dt} & \text{B. rent changes and price effect (+)} \\
& -\eta \frac{d \ln w_c}{dt} & \text{C. wage changes and income effect (+)} \\
& -\varepsilon \theta_N \frac{d \ln w_c}{dt} & \text{D. wage changes and price effect (-)} \\
& -\theta_N \frac{d \ln w_c}{dt} & \text{E. wage changes and housing factor reallocation (+)} \\
& + [1 - \theta_L] \frac{d \ln r}{dt} & \text{F. rent changes and housing factor reallocation (+)} \\
& + \frac{X_c}{L_c - X_c} \left[ \frac{1 - \mu}{\gamma} \frac{d \ln r}{dt} \right] & \text{G. firm land use change because of rents (+)} \\
& - \frac{X_c}{L_c - X_c} \frac{d \ln N_c}{dt} & \text{H. firm land use change because of employment (-)} \\
& - \frac{X_c}{L_c - X_c} \left( \frac{1}{\gamma} \frac{d \ln g_c}{d \ln N_c} \frac{d \ln N_c}{dt} + \frac{1}{\gamma} \frac{d \ln h}{dt} \right) & \text{I. firm land use change b/c of agglom(?) }
\end{aligned}$$

A brief summary of each mechanism is indicated next to each term with the sign of the effect assuming that  $\frac{d \ln w_c}{dt} < 0$ . Components A and B reflect standard income and price effects of an increase in transport costs. Higher  $t$  increases commuting costs and reduces real income, causing space per-capita to fall and central city population to rise. The city-suburban rent gap also increases, thereby inducing central city residents to economize on space, mediated by the share of land in housing production. Component C captures the direct impact the change in the wage has on income. Unless agglomeration spillovers are very strong, commuting cost increases cause central city wages to fall, leading individuals to economize on housing and space. Component D captures how central city wage declines pass through to lower housing costs, causing consumers to consume more housing and space. Component E captures how land intensity in housing production decreases as wages fall. Component F captures the substitution away from land in housing production that occurs with rent increases. Finally, Components G, H and I reflect that commuting cost increases lead firms to economize on space per worker, freeing up more space for residents, but also influence worker productivity through the potential reorientation of employment into the central city and

direct changes captured in the  $h(t)$  function. Magnitudes of these final three components are mediated by the fraction of central city land in production.

As the strength of localized agglomeration economies approaches 0, the sign of  $\frac{d \ln Q_c}{dt}$  is unambiguously positive, since the force keeping workers and firms in the central city disappears. Indeed, greater estimates of both  $\frac{d \ln Q_c}{dt}$  and  $\frac{d \ln N_c}{dt}$  are evidence of weaker local agglomeration forces, as they reflect a less strong force keeping firms and workers in central cities in the face of commuting cost reductions. As  $\frac{d \ln N_c}{dt}$  approaches 0, the percent difference in within versus cross-region agglomeration forces approaches infinity.

## 6 Model Calibration

### 6.1 Baseline Parameters

Substituting for  $\frac{d \ln N_c}{dt}$  from (17) into (18) yields  $\frac{d \ln Q_c}{dt}$  as a function solely of exogenous elements and parameters. Given a value for  $\frac{d \ln h}{dt}$ , this system of equations can then be solved for parameter combinations that describe relative agglomeration forces.

Regression estimates reported in Section 4 indicate that for all industries combined,  $\frac{\Delta \ln N_c}{\Delta hwy} \approx 0.06$ . To relate this derivative to the empirical results, we can write  $\frac{d \ln N_c}{dt} \approx \frac{\Delta \ln N_c}{\Delta hwy} \frac{\Delta hwy}{\Delta t}$ . Determining a value to use for  $\frac{\Delta hwy}{\Delta t}$  requires a more complete specification of urban spatial structure than exists in this model. In a continuous space monocentric city, like that studied in Baum-Snow (2007b), each highway roughly doubles commuting speed for those who live and work on it, reducing the fraction of time spent commuting by 0.03 on average from a base of 0.06, or 18 minutes in a 10 hour day. However, each radial highway with such a speed ratio to surface streets only serves any part of commutes for about one-fifth of the population in a circular city. Therefore,  $\frac{\Delta t}{\Delta hwy}$  is about 0.005 when averaged across all central city commuters. I present results over the range of values 0.005 to 0.015.<sup>19</sup> Additional parameters that must be calibrated are  $\eta, \varepsilon$  and  $\sigma_H$  from consumer preferences,  $\theta_L$  and  $\theta_N$  from housing production, and  $\phi_L$  and  $\phi_N$  from traded goods production. As

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<sup>19</sup>Duranton & Turner (2013) estimate the elasticity of speed with respect to lane km of roads to be about 0.10. Taking  $t = 0.06$ , this is consistent with  $\frac{\Delta t}{\Delta hwy} = -0.006$  for a city that goes from 1 to 2 radial highways. The typical central city received about 2.5 new radial highways between 1950 and 2000.

a starting point, I use the same cost share parameters as Albouy (2012), though I carefully study the sensitivity of results to labor's share in traded goods production. For the income elasticity of demand for housing,  $\eta$ , I start with 0.7 as a compromise between Glaeser, Kahn & Rappaport (2008) and Davis & Ortalo-Magné (2011), though I study sensitivity of results to this parameter. Also following Davis & Ortalo-Magné (2011), I calibrate the price elasticity of housing demand  $\varepsilon$  to  $-1$ .<sup>20</sup> Based on data in the consumer expenditure survey, I calibrate  $\sigma_H$ , the share of income spent on housing services, to 0.17.<sup>21</sup>

Remaining parameters  $X_c$  and  $L_c - X_c$ , which capture fractions of central city space devoted to production and housing respectively, and commuting costs  $t$ ,  $c_{sc}$  and  $c_s$ , I calculate separately for each SMSA using census data. To calculate  $X_c$  I begin with information on the number of working residents and jobs in each microgeographic unit (TAZ, tract or block group) in each central city from the 2000 census. Using this information, I estimate  $\beta_1$  and  $\beta_2$  in the following regression equation:

$$L_{ij} = \alpha_{0i} + \alpha_{1i} dis_{ij}^{CBD} + \alpha_{2i} (dis_{ij}^{CBD})^2 + \beta_1 res_{ij} + \beta_2 emp_{ij} + \varepsilon_{ij}$$

In this equation,  $i$  indexes SMSA and  $j$  indexes TAZ, tract or block group. The parameters  $\beta_1$  and  $\beta_2$  capture the average amount of space occupied by each working resident and each employee nationwide, controlling for SMSA and location relative to the CBD.<sup>22</sup> Applying these estimates of per-capita space consumption to 1960 central city employment and working residents yields the following expression for the relative intensity of central city land used in production versus consumption:

$$\left[ \frac{X_c}{L_c - X_c} \right]_i = \frac{\beta_2 emp_i^{CC60}}{\beta_1 res_i^{CC60}}$$

This of course is not the ideal measure of the relative land use of firms and residents because  $\beta_1$  and  $\beta_2$  reflect post-transport infrastructure land use. However, without microgeographic information about the location of employment in 1960, this is a viable measure. Moreover, results are insensitive

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<sup>20</sup>Most results are insensitive to using  $\varepsilon = -0.5$  instead.

<sup>21</sup>This number crucially excludes utilities and financing costs, which do not make up part of housing production in the model.

<sup>22</sup>While the model does analytically deliver the amount of central city space used by firms, the requisite  $\alpha_c$  parameter is not easily calibrated. Attempts to index  $\beta_1$  and  $\beta_2$  by SMSA produce coefficients that differ too widely across city to be credible.

to reasonable choices of  $\frac{X_c}{L_c - X_c}$ . I also calculate relative commuting cost parameters  $c_{sc}$  and  $c_s$  using data from 2000 separately for each metropolitan area. For the purpose of these calculations, I combine regions outside of SMSAs to or from which commutes involving the SMSA take place with suburbs. Averages across the 100 largest SMSAs of all calibrated parameters are reported in Table 9. Therefore, results reported below apply for an average large metropolitan area.

## 6.2 Recovering Agglomeration Parameters

Using (17) plus empirical estimates reported in Table 7, it is straightforward to recover estimates of  $\frac{d \ln g_c(N_c)}{d \ln N_c} - \frac{d \ln g_s(N_c)}{d \ln N_c}$  for each industry. This object captures the sum of the relative strength of within versus cross-region agglomeration spillovers. Thus, if no region-specific spillovers existed for suburban firms, it would fully capture the extent to which spillovers to central city firms come from the central city versus the suburbs. However, if the agglomeration function for central city and suburban firms is the same, with only the arguments reversed, it captures about double the relative size of agglomeration spillovers within a firm's metropolitan region versus across regions.<sup>23</sup> Table 10 reports these calibrated estimates for each industry as functions of the effect of labor's share of production  $\phi_N = \gamma$ , the response of average central city commute times to each additional highway and the income elasticity of demand for housing. These are the three model parameters to which the results are most sensitive.

Estimates of  $\frac{d \ln g_c(N_c)}{d \ln N_c} - \frac{d \ln g_s(N_c)}{d \ln N_c}$  based on the calibrated model for all industries, reported in the fourth column of Table 10, range from 0.04 to 0.13. Magnitudes are well in line with results discussed in Combes et al.'s (2010) review of the empirical literature on agglomeration economies, which reports consensus estimates in the literature of the metropolitan area level elasticity of productivity with respect to population to be in the 0.05 to 0.15 range. Because agglomeration functions that are symmetric across regions imply that the results in Table 10 are double the magnitude of local spillovers, this is strong evidence that agglomeration spillovers within sub-metropolitan regions represent a large fraction of the aggregate agglomeration economies in metropolitan areas.

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<sup>23</sup>If these two functions are identical or  $\tilde{g}_c(N_1, N_2) = \tilde{g}_s(N_1, N_2) = \tilde{g}(N_1, N_2)$ , where  $N_1$  is total employment in the closer region and  $N_2$  is total employment in the further region, then  $\frac{d \ln g_c}{d \ln N_c} - \frac{d \ln g_s}{d \ln N_c} = 2 \frac{d \ln g}{d \ln N_1} - 2 \frac{d \ln g}{d \ln N_2} \frac{N_c}{N_s}$ .



The model structure reinforces the intuition coming from relatively small estimated response of firm location choices to reductions in transportation costs that being spatially clustered below the metropolitan area scale is an important source of firm’s total factor productivity.

Estimates in Table 10 are most sensitive to  $\frac{\Delta t}{\Delta hwy}$ . For each increment of  $\frac{\Delta t}{\Delta hwy}$  by -0.005, the implied magnitude of localized agglomeration spillovers in a metropolitan area increases by 0.03-0.05 for all other parameter values examined. As additional highways cause commuting times to fall more quickly (and  $\frac{\Delta t}{\Delta hwy}$  rises in absolute value), we infer a smaller change in central city employment for a given change in  $t$ . The model interprets this smaller change as evidence of stronger agglomeration forces keeping firms in the central city.

### 6.3 Results by Industry

Because the logic used to derive (17) holds for each industry separately, treatment effects of highways on employment location by industry reported in Table 7 are used to derive measures of the localization of agglomeration economies by industry. Of course there may be coagglomeration incentives that generate complicated cross-industry linkages in agglomeration spillovers (Helsley & Strange, 2012). As with almost all of the existing empirical literature on localized agglomeration spillovers, such potential linkages are not considered. Indeed, they are not separately identified from within-industry linkages.

The remaining columns of Table 10 report the localization of agglomeration spillovers for each industry for the sets of parameters examined for all workers collectively. Regardless of parameter values, the relative magnitudes across industries of the extent of localization of agglomeration spillovers are remarkably stable. Allocations in public administration, the military and agriculture are not likely to be determined by market forces so I do not consider them carefully. Among remaining industries, for all combinations of parameter values studied, finance, insurance and real estate has the largest local agglomeration spillovers at 0.06 to 0.20 while wholesale & retail trade has the smallest at 0.02 to 0.06. Construction, services, transportation, communications and public utilities and manufacturing are in between, listed in order of most to least localized. Magnitudes of effects reported in Table 7 match up with these conclusions.

## 6.4 Why Did Highways Cause Suburbanization?

By making use of (18) jointly with (17), it is in principle possible to recover separate estimates for  $\frac{d \ln q_c}{d \ln N_c}$  and  $\frac{d \ln q_s}{d \ln N_c}$ . Carrying out this exercise yields implied values for  $\frac{d \ln q_c}{d \ln N_c}$  that are negative unless  $\frac{\Delta t}{\Delta hwy}$  is at least -0.02, which seems too large to be plausible, or  $\frac{d \ln h}{dt}$  is far greater than 1, which is also probably implausible. Moreover, implied estimates of  $\frac{d \ln q_c}{d \ln N_c}$  are extremely sensitive to small changes in  $\frac{\Delta t}{\Delta hwy}$ . More likely, the model does not incorporate all of the reasons for which highways have caused people to decentralize. The fact that each highway caused 16 percent of the central city working population to decentralize is simply too much of a response to be driven by the forces laid out in this standard model. For example, one likely additional important mechanism which is outside the model is that new highways interacted with relative higher local amenity value of suburbs to promote decentralization. Any such interaction may have exacerbated amenity differences between central cities and suburbs through a Tiebout (1956) sorting mechanism. Introducing consumer heterogeneity, thereby allowing local amenities  $q_c$  and  $q_s$  to endogenously depend on  $t$  may be a fruitful avenue for future work in order to understand mechanisms through which highways have caused suburbanization that are residual to this analysis.

To provide an upper bound on the magnitudes of each of the mechanisms driving population decentralization, or  $\frac{d \ln Q_c}{d hwy}$ , specified in (18), I calibrate each one assuming that  $\frac{d \ln q_c}{d \ln N_c} = 0$  and  $\frac{d \ln h}{dt} = 0$ . Given a value for  $\frac{d \ln N_c}{dt}$ , the more localized are agglomeration spillovers for central city firms, the smaller the population response to new highways. This is mostly because as  $\frac{d \ln q_c}{d \ln N_c}$  increases, wages increase less with new highways, limiting the expansion of central city space consumption and consequent population decentralization. Therefore, by imposing  $\frac{d \ln q_c}{d \ln N_c} = 0$  I provide an upper bound on the magnitudes of each of the components in (18). I also separate out the potential impact of  $\frac{d \ln h}{dt}$  because I have no guidance from data or theory on its magnitude.

Table 11 quantifies each of the components of  $\frac{d \ln Q_c}{d hwy}$  listed in Equation (18). Factor reallocation away from land in housing production (Component F) is the largest negative component at between -0.033 and -0.098, or up to almost two-thirds of the estimated treatment effect of -0.16. Firm adjustments to space per worker (Component G) adds -0.021 to -0.064 to this, but this is somewhat

counteracted by the crowd-in effect of firms moving operations to the suburbs (Component H) of 0.029. Price & income effect mechanisms and factor reallocation in housing production because of wage changes sum to no more than -0.05, mostly because of components A and B. Choosing  $\frac{d \ln h}{dt} = -1$  generates up to an additional -0.032. Even with generous assumptions about the magnitudes of  $\frac{d \ln g_c}{d \ln N_c}$  and  $\frac{d \ln h}{dt}$ , the components in (18) do not add up to the empirical treatment effect estimate of  $\frac{d \ln Q_c}{d \ln N_c} = -0.16$  for most combinations of parameter values. Localized agglomeration forces  $\frac{d \ln g_c}{d \ln N_c}$ , that are calibrated to one-half of  $\left[ \frac{d \ln g_c}{d \ln N_c} - \frac{d \ln g_s}{d \ln N_c} \right]$  reported in Table 10, add back no more than 0.008 to calibrated values of  $\frac{d \ln Q_c}{d \ln N_c}$ .

Given this model, it is tempting to try to draw conclusions about the welfare consequences of new highways. However, central to any such calculation is to know how much the central city wage changes with each new highway. While this is a response that the model does deliver endogenously, because the model's implications about magnitudes and signs of  $\frac{d \ln g_c}{d \ln N_c}$  are implausible and the model provides no guidance about  $\frac{d \ln h}{dt}$ , implications about  $\frac{d \ln w_c}{d \ln N_c}$  are also implausible. Though Sanchis-Guarner (2012) provides evidence that highway access did increase wages in the United Kingdom, attempts to empirically isolate causal effects of highways on central city wages holding total metropolitan area employment constant in the empirical context of this paper, in order to directly measure  $\frac{d \ln w_c}{d \ln N_c}$ , yield inconclusive results. The main difficulty is in accurately controlling for the large shifts in quantities of relative skill across metropolitan areas over time.

## 7 Conclusions

This paper demonstrates 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 and smaller for finance, insurance and real estate. Viewed in the context of a calibrated urban model, these results provide evidence that local spillovers remain an important incentive for firms to cluster spatially, even in the face of transportation cost reductions. Moreover, spillovers

across firms within central cities represent a large fraction of metropolitan area wide agglomeration economies.

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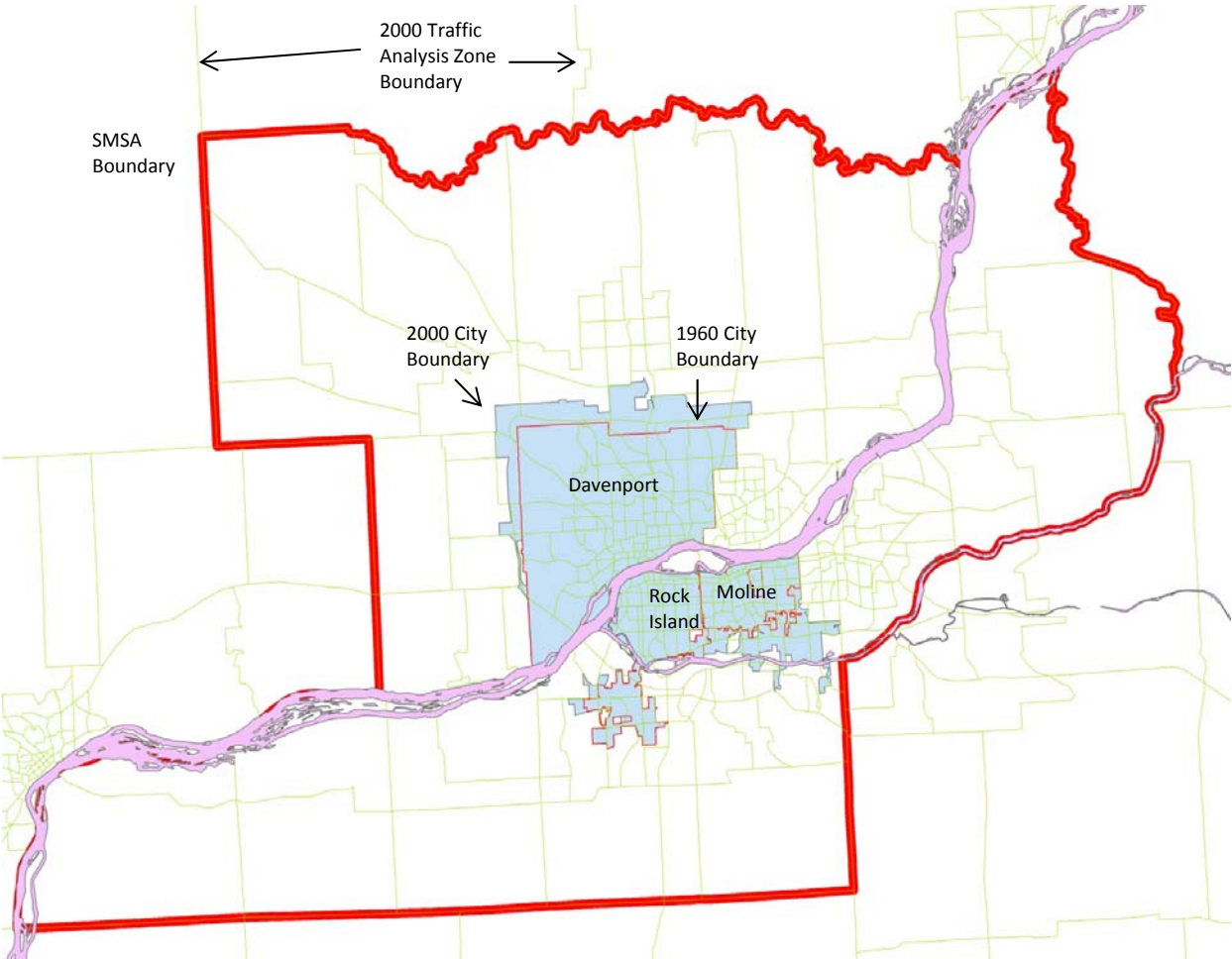
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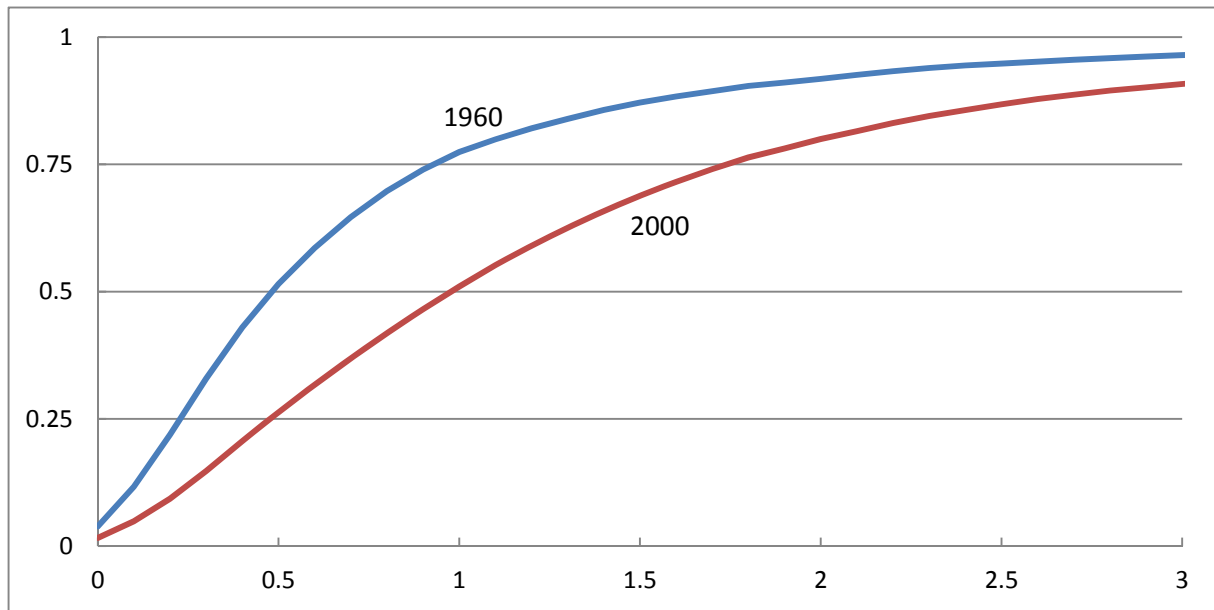
Figure 1: Davenport SMSA



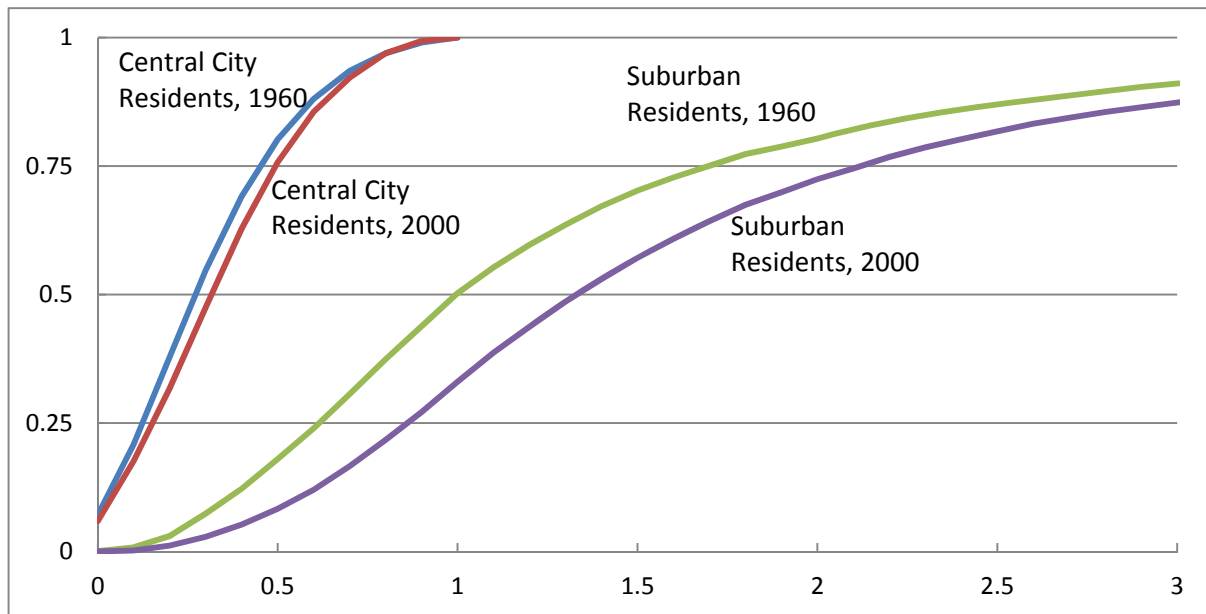


**Figure 2: CDFs of Residential Population  
by Residential Location (0=CBD, 1=Central City Edge)**

**Panel A: All Locations Pooled**



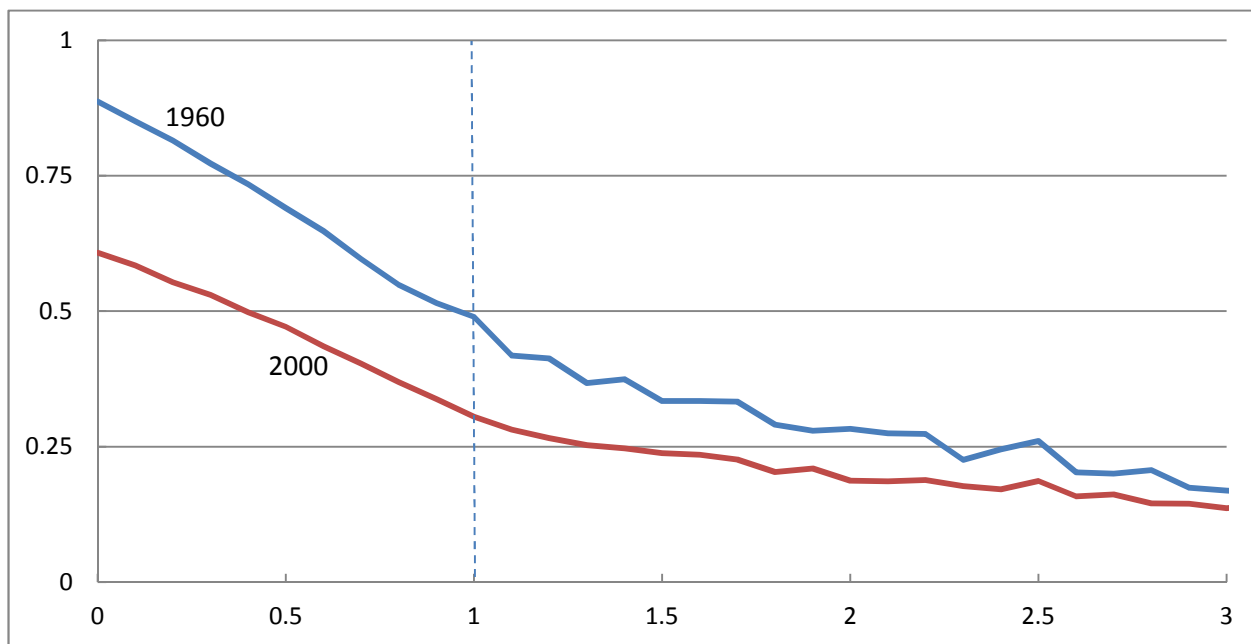
**Panel B: Central City and Suburban Residents Broken Out**



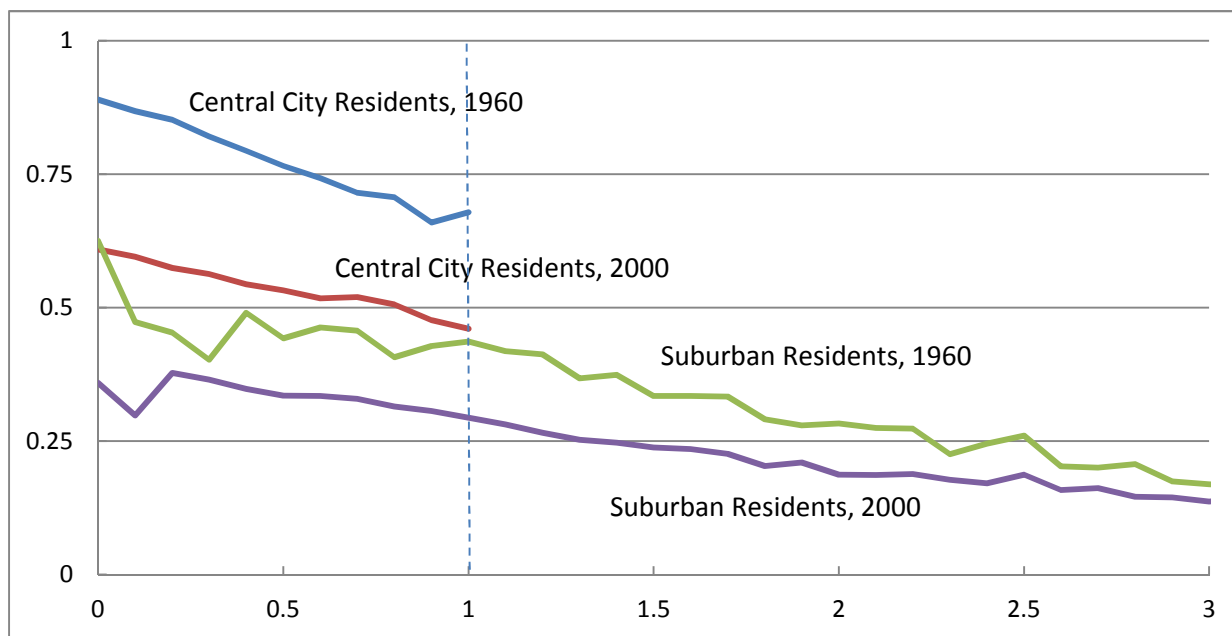
Notes: Plots show the cumulative distribution functions of SMSA residents in 1960 and 2000. The distance index on the horizontal axis is 0 at the CBD and 1 at the central city edge. 78 of the 100 SMSAs with at least 250,000 residents in 1960 contribute to the plots. The remaining 22 are not included because of missing or incomplete 1960 census tract information.

**Figure 3: Average Fraction Commuting to Primary Central City  
by Residential Location (1=Central City Edge)**

**Panel A: All Locations Pooled**



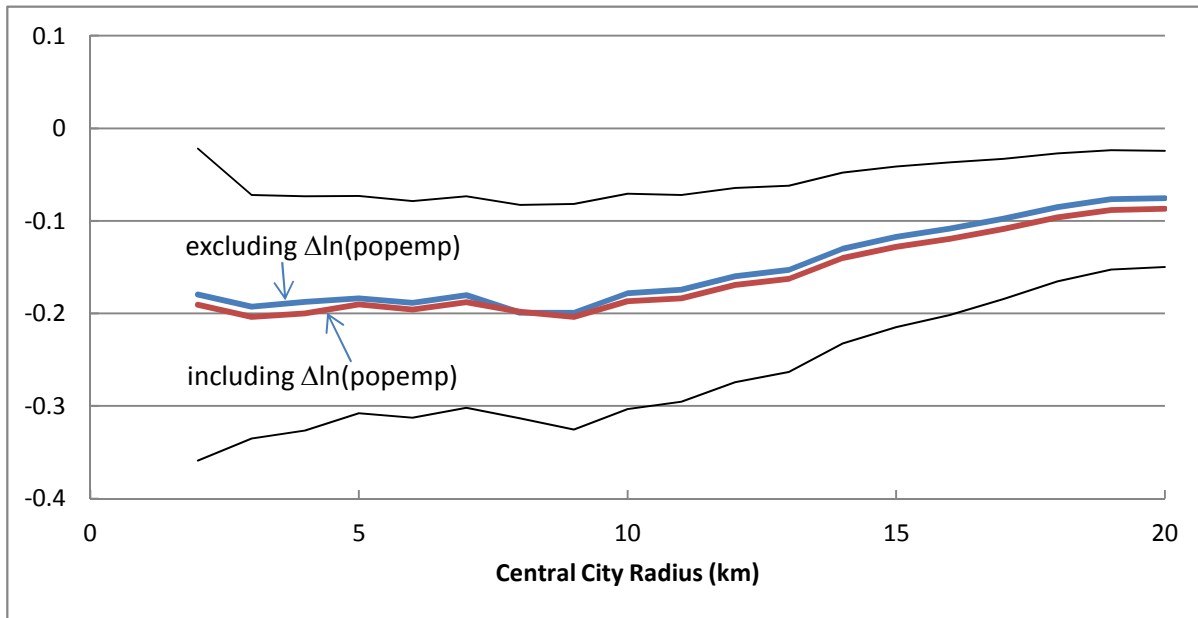
**Panel B: Central City and Suburban Residents Broken Out**



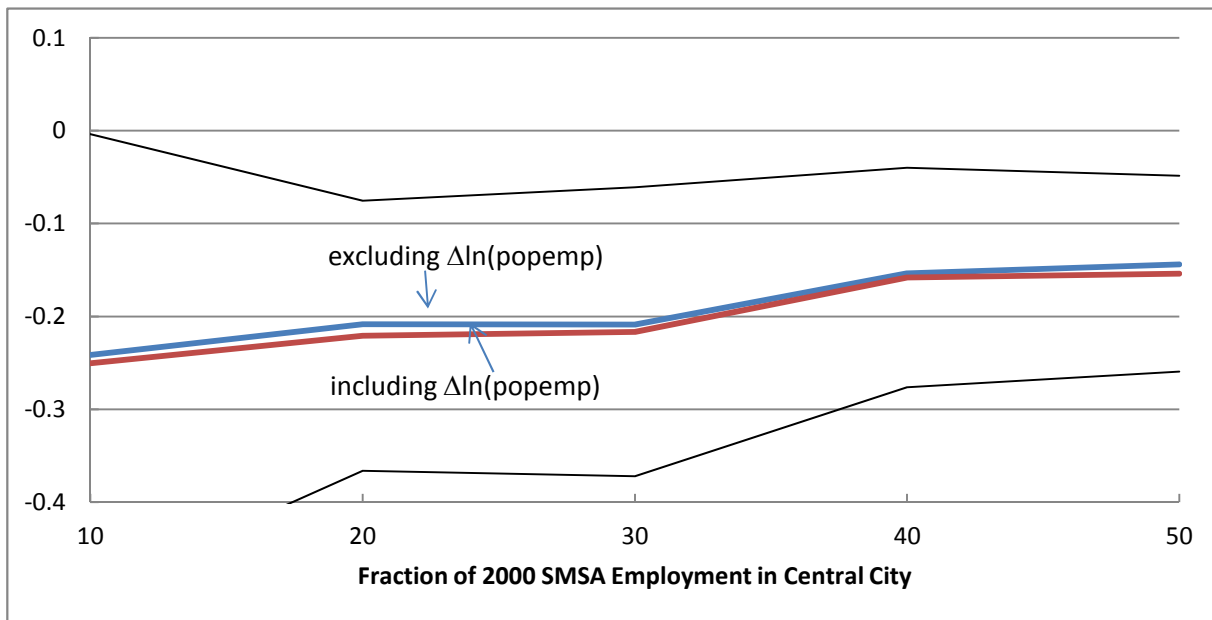
Notes: Plots show the fraction of workers in 1960 and 2000 commuting to a primary central city averaged across SMSAs. The distance index on the horizontal axis is 0 at the CBD and 1 at the central city edge.

**Figure 4: Estimated Effects of Highways on Central City Working Residents**  
**Alternative Central City Definitions**

**Panel A: Central City Defined as Within Set Distances (km)**

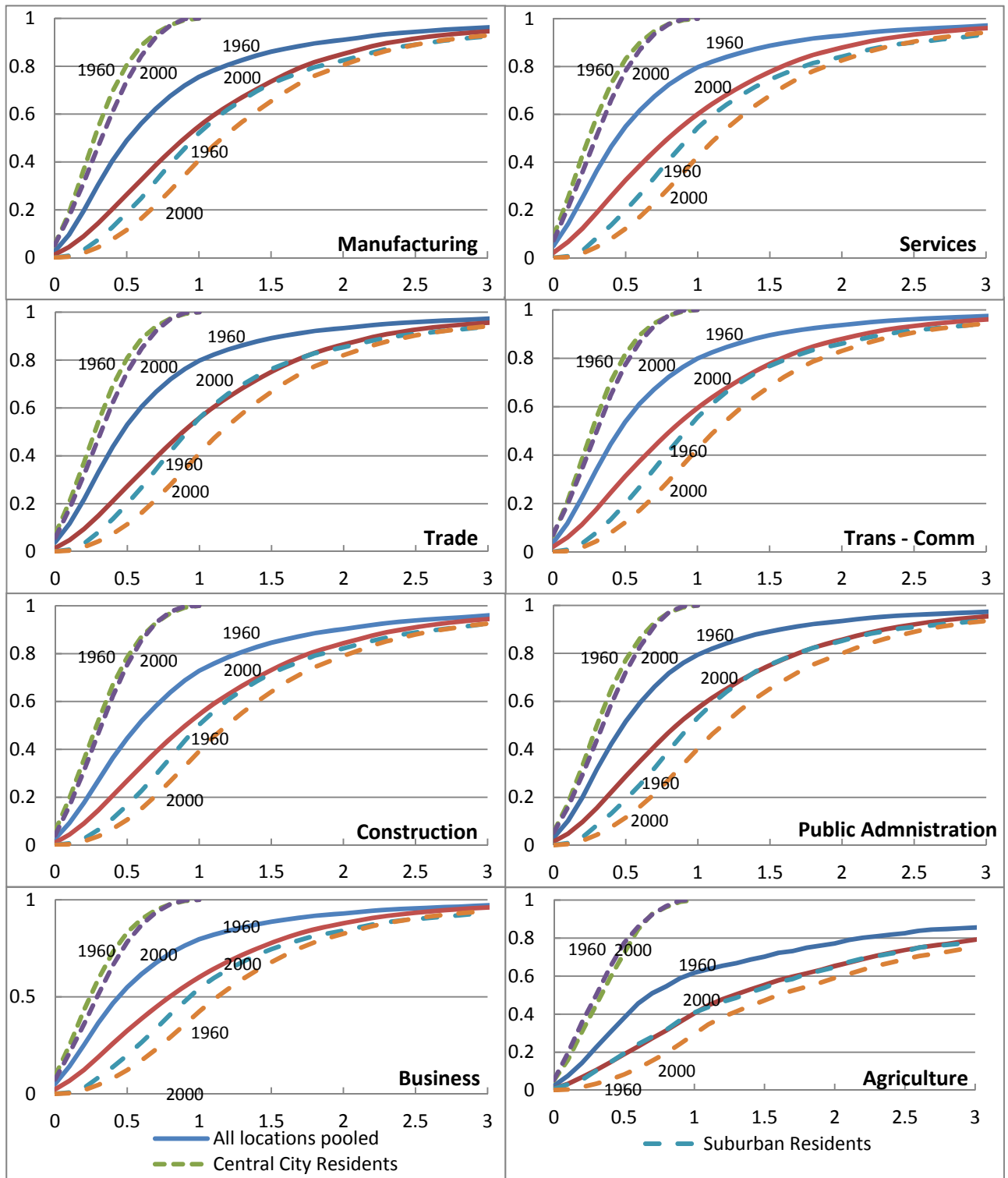


**Panel B: Central City Defined as Containing Set Percentages of 2000 Employment**



Notes: Each panel shows highway coefficients and 95 percent confidence intervals from regressions analogous to those in Table 6 Panel B Column 1 including (red lines) and excluding (blue lines) the control for change in log SMSA employment and residents. In Panel A, central cities are defined as being within the number of km of the CBD listed on the horizontal axis. In Panel B, central cities are defined as being within the radius at which the fraction of SMSA employment given on the horizontal axis was in 2000. Sample size ranges from 78 to 93, depending on 1960 census tract availability within the given CBD radius.

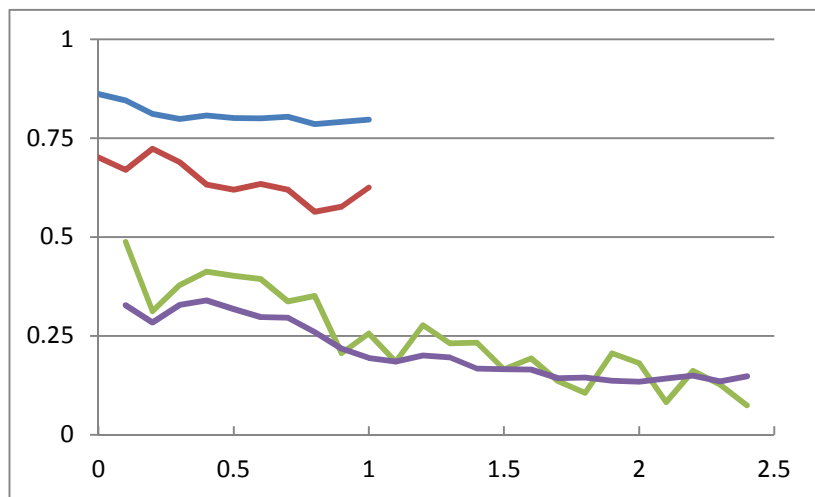
**Figure A1: CDF of Residential Population  
by Residential Location and Industry (1=Central City Edge)**



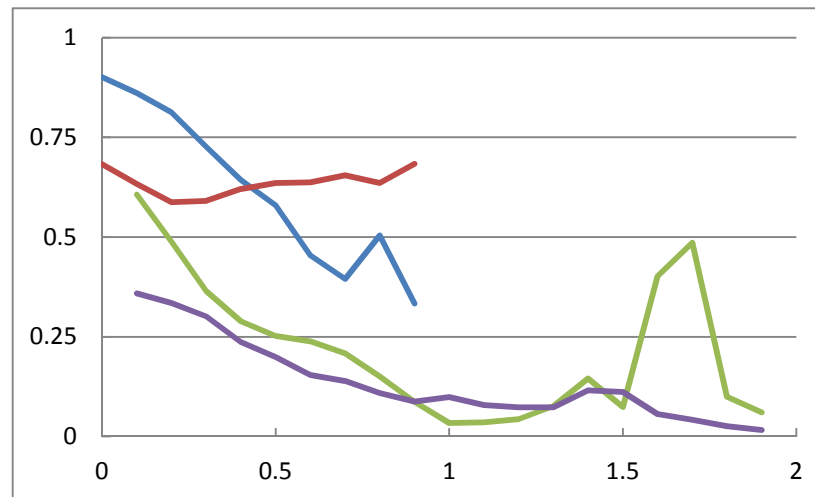
Notes: Plots are analogous to those in Figure 2 except they are broken out by industry of resident workers.

Figure A2: Fraction Commuting to Primary Central City: Example Cities

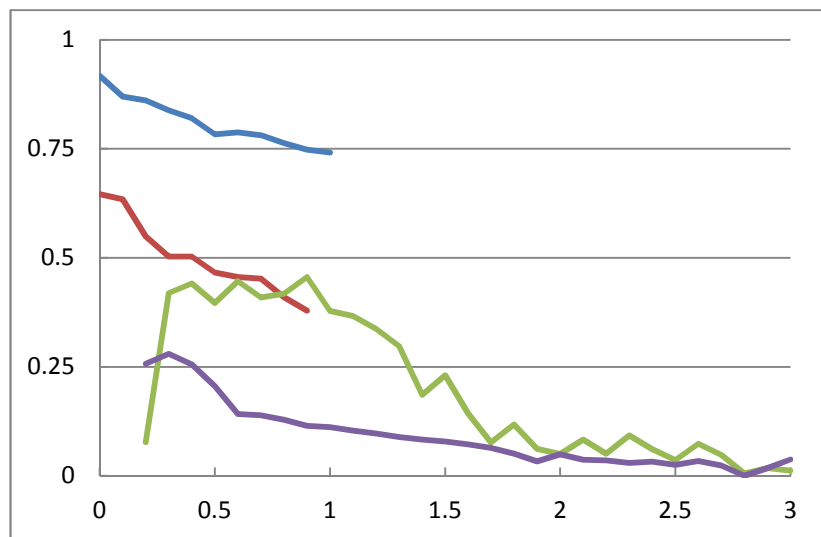
Boston



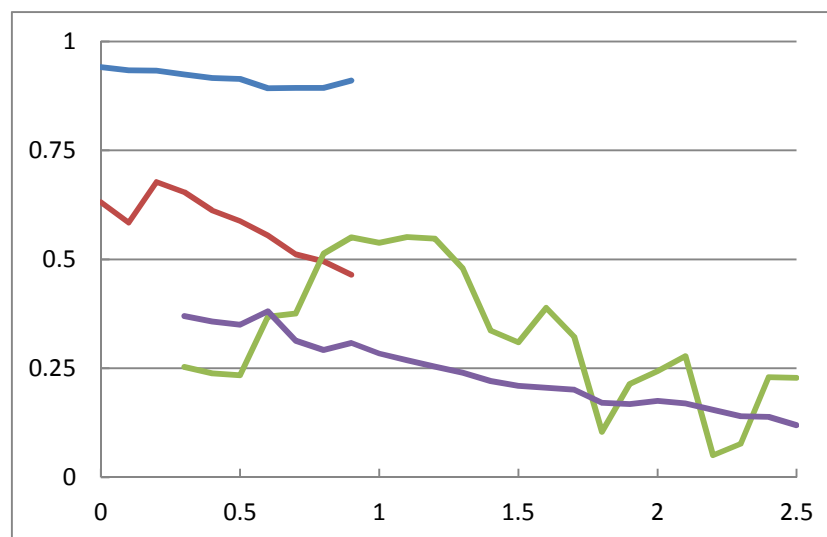
Los Angeles



Detroit

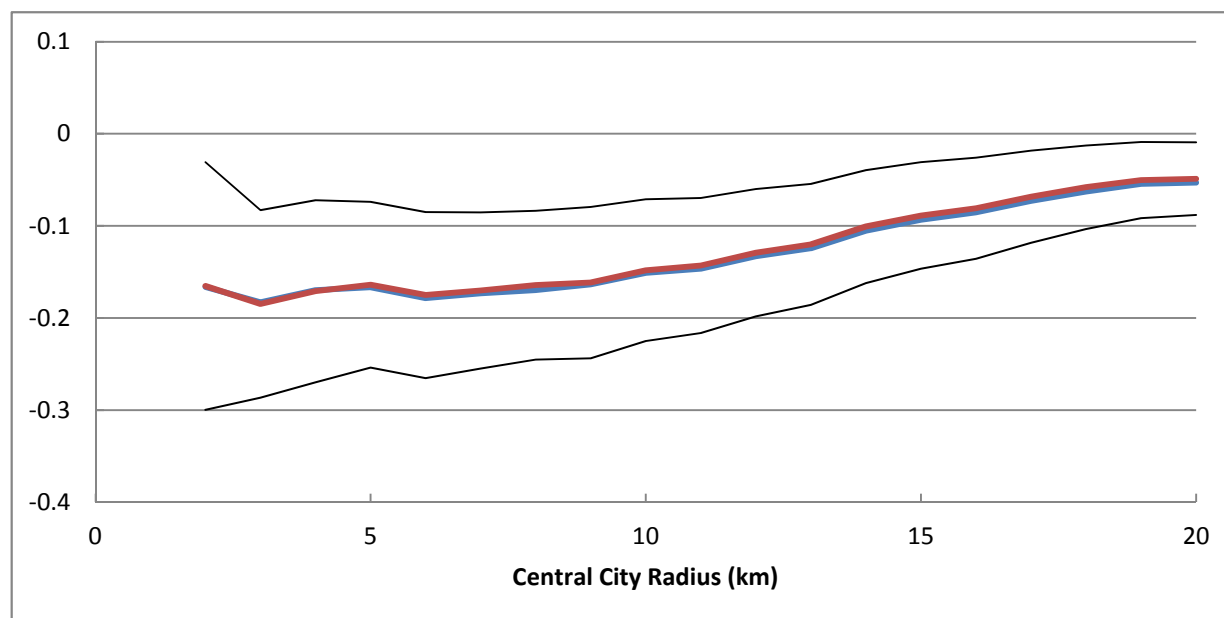


St. Louis

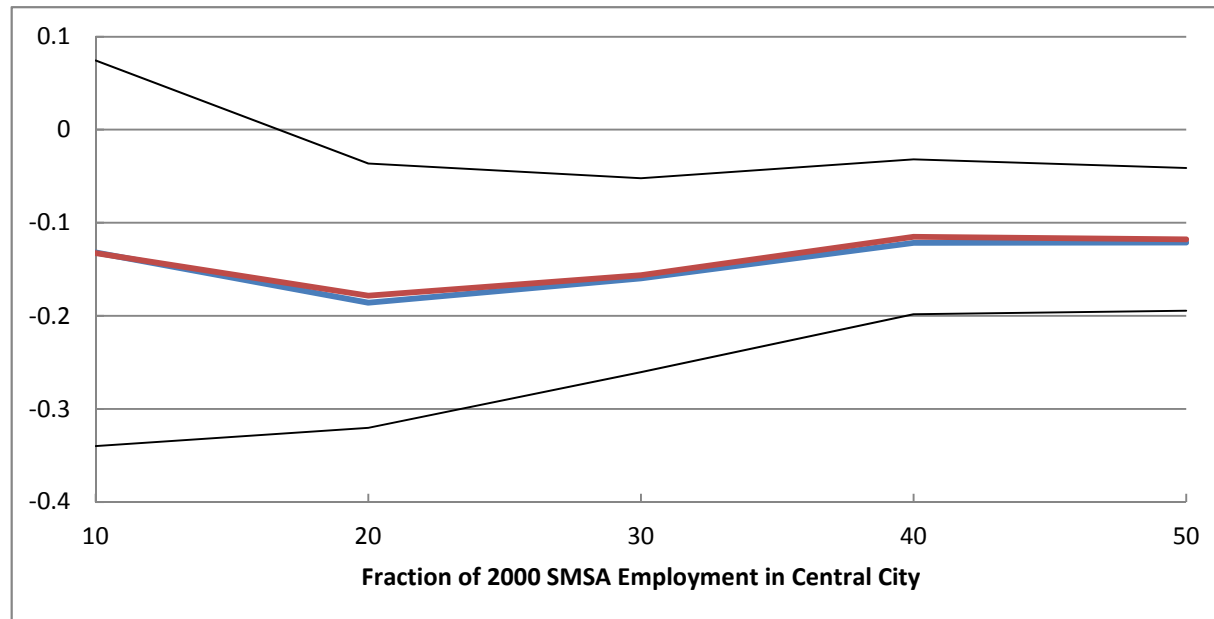


**Figure A3: Estimated Effects of Highways on Central City Working Residents**  
**Alternative Central City Definitions - Complete Sample**

**Panel A: Central City Defined as Within Set Distances (km)**



**Panel B: Central City Defined as Containing Set Percentages of 2000 Employment**



Notes: Graphs are analogous to those in Figure 4, except they use a more complete sample of SMSAs. Depending on availability of 1960 tract data at different CBD distances, the sample size ranges from 125 to 154.

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

	1960	2000	Percent Change	Change in Fraction
Live in Central City	18.7	18.4	-0.01	-0.25
(fraction of total)	(0.49)	(0.24)		
Work in Central City	23.3	26.2	0.12	-0.28
(fraction of total)	(0.61)	(0.34)		
Live in SMSA	36.3	66.8	0.84	-0.10
(fraction of total)	(0.95)	(0.86)		
Work in SMSA	36.8	71.1	0.93	-0.05
(fraction of total)	(0.96)	(0.91)		
Live or Work in SMSA	38.1	78.1	1.05	

Notes: Counts are aggregates from the 100 metropolitan areas with 1960 populations over 250,000, expressed 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 and those contributing to worker counts may live anywhere. Data from 1960 incorporate the author's imputations for nonreported work locations and the 2000 data incorporate 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	-0.25	-0.25	-0.30	-0.26	-0.20	-0.28	-0.30	-0.18	-0.04
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	-0.27	-0.33	-0.24	-0.39	-0.32	-0.24	-0.16	-0.37	-0.09	0.00
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	-0.18	0.21	-0.04	0.01	0.01	-0.01	0.03	-0.01	-0.01

Notes: Counts used to construct entries are aggregated over all primary sample SMSAs. See the notes to Table 1 for an explanation of the 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 SMSAs are not available.



**Table 3: Changes in Commuting Patterns, 1960-2000**

					Avg. 2000 Commute Time	
		1960	2000	Change	Weighted	Unweighted
Live in CC	Work in CC	16.5	12.0	-27%	27	19
		(0.43)	(0.16)	-0.28	1	1
Live in CC	Work in Ring	1.8	5.0	177%	30	26
		(0.05)	(0.06)	0.02	1.13	1.38
Live in CC	Work Outside SMSA	0.4	1.0	127%	46	46
		(0.01)	(0.01)	0.00	1.73	2.46
Live in Ring	Work in CC	5.9	10.7	82%	33	27
		(0.15)	(0.14)	-0.01	1.25	1.46
Live in Ring	Work in Ring	10.8	32.4	200%	22	20
		(0.28)	(0.42)	0.14	0.85	1.07
Live in Ring	Work Outside SMSA	0.9	4.4	384%	41	40
		(0.02)	(0.06)	0.03	1.53	2.14
Live Outside SMSA	Work in CC	1.0	3.9	294%	54	47
		(0.03)	(0.05)	0.02	2.02	2.52
Live Outside SMSA	Work in Ring	0.9	7.4	735%	43	41
		(0.02)	(0.10)	0.07	1.63	2.19
Total		38.1	76.7	101%		

Notes: Each entry in the first two columns is the number of people with the indicated type of commute in the indicated year, expressed in millions. The fraction of total commutes in the indicated year is in parentheses. The 2000 total does not match the total in Table 1 because the Census Bureau omits some difficult to impute flows in its Census Transportation Planning Package tables. Those working at home are counted as commuting within their regions of residence. Column 4 shows one-way commute times averaged across all workers in sampled SMSAs and ratios relative to the average within central city commute time. Column 5 shows mean SMSA one-way commute times averaged across sampled SMSAs and ratios relative to this measure of within central city commute time. Commuting times are not available in 1960.

**Table 4: First Stage Results****Panel A: 1950 Base Year**

Planned Rays	0.53*** (0.10)	0.47*** -0.11 (0.11)	0.47*** (0.11)
1960 Central City Radius		0.11 -0.08 (0.08)	0.10 (0.08)
Change in Log SMSA Employment +Workers, 1960-2000			0.32 (0.38)
Constant	1.13*** (0.32)	0.80** (0.39)	0.62 (0.45)
R-Squared	0.23	0.24	0.25

**Panel B: 1960 Base Year**

Planned Rays	0.36*** (0.10)	0.34*** (0.11)	0.33*** (0.11)
1960 Central City Radius		0.04 (0.08)	0.03 (0.08)
Change in Log SMSA Employment +Workers, 1960-2000			0.29 (0.39)
Constant	0.94*** (0.33)	0.81** (0.41)	0.65 (0.46)
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 for the 100 SMSAs in the primary sample. Regressions using the number of radial highways in 2000 instead are statistically indistinguishable from those in Panel A. Coefficients on planned rays in analogous regressions using a more complete sample of 164 SMSAs are statistically significant at 0.42 and 0.28 in Columns 2 or 3 of Panels A and B respectively.

**Table 5: Effects of Highways on SMSA Employment and Working Residents by Industry**  
IV Estimates

	All	Manuf- acturing	Services	Trade	TCPU	Const- ruction	Public Admin.	FIRE	Military	Agric- ulture
<b>Panel A: SMSA Employment</b>										
Change in Rays	0.03	-0.11**	-0.00	-0.01	0.01	0.03	-0.06	0.04	0.05	-0.01
1950 to 2000	(0.06)	(0.05)	(0.02)	(0.02)	(0.03)	(0.03)	(0.05)	(0.03)	(0.14)	(0.06)
1960 Central City Radius	0.04*	0.05**	0.00	-0.01	0.00	0.01	-0.02	-0.03***	-0.11**	0.03
	(0.03)	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)	(0.02)	(0.01)	(0.06)	(0.02)
Change in Log SMSA Employment +Workers, 1960-2000		1.40***	0.82***	0.94***	1.15***	0.80***	0.83***	0.89***	0.51**	0.39***
		(0.08)	(0.03)	(0.03)	(0.05)	(0.04)	(0.08)	(0.05)	(0.24)	(0.10)
Constant	0.43***	-1.03***	0.74***	-0.18***	-0.07	0.01	0.21**	0.52***	-0.41	-1.18***
	(0.14)	(0.11)	(0.04)	(0.04)	(0.07)	(0.06)	(0.10)	(0.07)	(0.32)	(0.13)
R-Squared	0.07	0.75	0.91	0.93	0.84	0.80	0.54	0.77	0.06	0.17
<b>Panel B: SMSA Working Residents</b>										
Change in Rays	0.00	-0.14***	-0.03	-0.05**	-0.02	-0.01	-0.09**	-0.00	-0.04	-0.05
1960 to 2000	(0.06)	(0.05)	(0.02)	(0.02)	(0.03)	(0.03)	(0.05)	(0.03)	(0.14)	(0.06)
1960 Central City Radius	0.05*	0.05**	0.01	-0.00	0.00	0.01	-0.01	-0.02*	-0.08	0.03
	(0.02)	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)	(0.02)	(0.01)	(0.06)	(0.02)
Change in Log SMSA Employment +Workers, 1960-2000		1.38***	0.81***	0.94***	1.12***	0.80***	0.81***	0.90***	0.52**	0.43***
		(0.09)	(0.04)	(0.04)	(0.05)	(0.05)	(0.08)	(0.05)	(0.24)	(0.10)
Constant	0.44***	-0.99***	0.74***	-0.17***	-0.07	0.01	0.21**	0.52***	-0.40	-1.18***
	(0.13)	(0.12)	(0.05)	(0.05)	(0.07)	(0.07)	(0.10)	(0.07)	(0.31)	(0.13)
R-Squared	0.05	0.71	0.85	0.87	0.83	0.75	0.51	0.78	0.07	0.12

Notes: Regressions are of the change in the log of outcomes listed in column headers on variables listed at left. These are Equations (3) and (4) in the text. The sample includes the same 100 SMSAs used for Tables 1 through 4. The change in the number of rays is instrumented with rays in the 1947 national plan. The estimated effect of highways on total SMSA employment plus resident workers is identical to that for all employment in Panel A. Excluding the change in log SMSA employment+workers yields no significant change in any highways coefficient. The first-stage F statistic for all industry level regressions is 19.55.

**Table 6: Effects of Highways on Central City Employment and Working Residents by Industry**  
**IV Estimates**

	All	Manuf- acturing	Services	Trade	TCPU	Const- ruction	Public Admin.	FIRE	Military	Agric- ulture
<b>Panel A: Central City Employment</b>										
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)	(0.05)	(0.16)	(0.09)
1960 Central City Radius	0.05***	0.11***	0.05***	0.10***	0.07***	0.06***	-0.04**	0.05**	-0.11*	-0.01
	(0.02)	(0.03)	(0.01)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.07)	(0.03)
Change in Log Total	0.81***	1.01***	0.58***	0.77***	0.87***	0.58***	0.78***	0.59***	0.48*	0.37**
Employment+Residents	-0.06	-0.13	-0.06	-0.10	-0.07	-0.07	-0.08	-0.09	-0.28	-0.15
Constant	-0.56***	-1.71***	0.37***	-1.14***	-0.58***	-0.43***	0.06	-0.20	-0.70*	-1.44***
	(0.08)	(0.17)	(0.08)	(0.13)	(0.10)	(0.10)	(0.11)	(0.12)	(0.37)	(0.20)
R-Squared	0.66	0.43	0.50	0.44	0.63	0.46	0.50	0.36	0.04	0.13
<b>Panel B: Central City Working Residents</b>										
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)
1960 Central City Radius	0.09***	0.11***	0.09***	0.08***	0.09***	0.11***	0.05**	0.07***	0.00	-0.04
	(0.02)	(0.03)	(0.02)	(0.02)	(0.02)	(0.03)	(0.02)	(0.02)	(0.07)	(0.03)
Change in Log Total	0.62***	1.02***	0.41***	0.52***	0.65***	0.61***	0.27***	0.42***	-0.50*	0.14
Employment+Residents	(0.08)	(0.14)	(0.09)	(0.10)	(0.09)	(0.11)	(0.10)	(0.08)	(0.30)	(0.15)
Constant	-0.51***	-1.50***	0.30***	-0.65***	-0.57***	-0.45***	-0.29**	-0.12	-0.46	-0.66***
	(0.10)	(0.18)	(0.11)	(0.14)	(0.12)	(0.15)	(0.13)	(0.11)	(0.40)	(0.19)
R-Squared	0.32	0.22	0.06	-0.04	0.32	0.04	-0.04	0.21	0.01	-0.02

Notes: Regressions are the same as those in Table 5 except with different outcomes. These are Equations (5) and (6) in the text. Excluding the change in log SMSA employment+residents yields no significant change in any highways coefficient. The first stage F statistics for all industry level regressions is 19.12. Each regression has 100 observations except that for the military in Panel A, which is missing Canton, OH because it had 0 reported central city military jobs in 2000.

**Table 7: Implied Effects of Each Highway on Urban Decentralization  
by Industry**

	Employment	Working Residents	Difference
All	-0.06* (0.04)	-0.16** (0.07)	0.10** (0.04)
Manufacturing	-0.08 (0.05)	-0.15*** (0.05)	0.07 (0.06)
Services	-0.07** (0.03)	-0.15*** (0.05)	0.08** (0.03)
Retail and Wholesale Trade	-0.14** (0.05)	-0.19*** (0.05)	0.05 (0.04)
TCPU	-0.07* (0.04)	-0.13*** (0.05)	0.06 (0.05)
Construction	-0.08** (0.04)	-0.21*** (0.06)	0.14*** (0.05)
Public Administration	0.01 (0.03)	-0.13*** (0.05)	0.14** (0.06)
FIRE	-0.04 (0.05)	-0.12*** (0.05)	0.07 (0.05)
Military	0.01 (0.15)	-0.14 (0.27)	0.16 (0.33)
Agriculture	0.16** (0.07)	-0.05 (0.07)	0.21** (0.09)

Notes: Entries give estimated effects of one radial highway on the log of central city employment or working residents in the indicated industry holding the composition of SMSA industries constant. Equations (3), (4), (5) and (6) in the text plus a first stage equation that are jointly estimated by GMM are used along with (7) and (8) to generate reported coefficients and standard errors.

**Table 8: Estimated Effects of Highways on Aggregate Commuting Flows**

	Work in Central City	Work in Ring	Work Outside SMSA
<b>Panel A: Central City Residents</b>			
Change in Rays	-0.15***	-0.04	-0.06
1950 to 2000	(0.05)	(0.06)	(0.09)
1960 Central City Radius	0.14***	0.07***	0.06*
	(0.02)	(0.02)	(0.03)
Change in Log Total	0.51***	0.79***	0.17
Employment+Residents	(0.09)	(0.10)	(0.15)
Constant	-1.12***	0.21	0.50**
	(0.12)	(0.13)	(0.19)
R-Squared	0.38	0.48	0.00
<b>Panel B: Suburban Residents</b>			
Change in Rays	-0.07	0.10*	0.06
1950 to 2000	(0.09)	(0.06)	(0.07)
1960 Central City Radius	0.10***	0.02	0.03
	(0.04)	(0.02)	(0.03)
Change in Log Total	1.11***	1.26***	0.92***
Employment+Residents	(0.15)	(0.10)	(0.13)
Constant	-0.37*	-0.15	0.79***
	(0.20)	(0.13)	(0.17)
R-Squared	0.45	0.70	0.42
<b>Panel C: Residents Outside SMSA Who Work in SMSA</b>			
Change in Rays	-0.09	0.22**	
1950 to 2000	(0.06)	(0.08)	
1960 Central City Radius	0.13***	0.02	
	(0.02)	(0.03)	
Change in Log Total	0.88***	1.32***	
Employment+Residents	(0.11)	(0.14)	
Constant	0.36***	0.52***	
	(0.14)	(0.19)	
R-Squared	0.55	0.52	

Notes: Each column in each panel shows regression results of the change in the log number of indicated commuters between 1960 and 2000 on variables listed at left. Radial highways in the 1947 national plan instruments for the change in the number of rays 1950 to 2000. The first-stage F-statistic for each regression is 19.55.

**Table 9: Base Parameter Values**

Parameter	Description	Value
$\Delta t/\Delta \text{hwy}$	Change in central city commuting time for each additional highway	-0.01
$\eta$	Income elasticity of demand for housing	0.7
$\varepsilon$	Price elasticity of demand for housing	-1
$\sigma_H$	Share of income spent on housing	0.17
$\theta_L$	Land share in production of housing	0.233
$\theta_K$	Capital Share in the production of housing	0.15
$\theta_N$	Labor share in the production of housing	0.617
$\phi_L$	Land share in production of tradeables	0.025
$\phi_K, \mu$	Capital Share in the production of tradeables	0.15
$\phi_N, \gamma$	Labor share in the production of tradeables	0.825
$X_c/(L_c - X_c)$	Fraction of CC space taken up by production	0.48
$t$	Fraction of time spent commuting for within central city commuters	0.06
$c_{sc}$	Ratio of commuting time suburb-city versus city-city	1.75
$c_s$	Ratio of commuting time suburb-suburb versus city-city	1.36
$d\ln h_{dt}$	The direct elasticity of TFP with respect to commuting time	-1

Notes: Parameters' base calibration values are based on estimates in the literature, as explained in the text. Commuting cost parameters are calibrated using 2000 commuting data for primary sample SMSAs.

**Table 10: Agglomeration Parameters by Industry**

Parameters			$d\ln g_c/d\ln N_c - d\ln g_s/d\ln N_c$									
$\phi_N, \gamma$	$\Delta t/\Delta hwy$	$\eta$	All	Manufacturing	Services	Trade	TCPU	Construction	Public Admin.	FIRE	Military	Agriculture
0.6	-0.01	0.7	0.073	0.055	0.063	0.031	0.063	0.055	-0.439	0.110	-0.439	-0.027
0.65	-0.01	0.7	0.076	0.057	0.065	0.033	0.065	0.057	-0.458	0.114	-0.458	-0.029
0.7	-0.01	0.7	0.079	0.060	0.068	0.034	0.068	0.060	-0.477	0.119	-0.477	-0.030
0.75	-0.01	0.7	0.083	0.062	0.071	0.035	0.071	0.062	-0.496	0.124	-0.496	-0.031
0.8	-0.01	0.7	0.086	0.064	0.073	0.037	0.073	0.064	-0.514	0.129	-0.514	-0.032
0.85	-0.01	0.7	0.089	0.067	0.076	0.038	0.076	0.067	-0.533	0.133	-0.533	-0.033
0.825	-0.005	0.7	0.044	0.033	0.037	0.019	0.037	0.033	-0.262	0.065	-0.262	-0.016
0.825	-0.01	0.7	0.087	0.065	0.075	0.037	0.075	0.065	-0.524	0.131	-0.524	-0.033
0.825	-0.015	0.7	0.131	0.098	0.112	0.056	0.112	0.098	-0.786	0.196	-0.786	-0.049
0.7	-0.005	0.7	0.040	0.030	0.034	0.017	0.034	0.030	-0.238	0.060	-0.238	-0.015
0.7	-0.01	0.7	0.079	0.060	0.068	0.034	0.068	0.060	-0.477	0.119	-0.477	-0.030
0.7	-0.015	0.7	0.119	0.089	0.102	0.051	0.102	0.089	-0.715	0.179	-0.715	-0.045
0.6	-0.01	1	0.073	0.055	0.063	0.031	0.063	0.055	-0.439	0.110	-0.439	-0.027
0.65	-0.01	1	0.076	0.057	0.065	0.033	0.065	0.057	-0.458	0.114	-0.458	-0.029
0.7	-0.01	1	0.079	0.060	0.068	0.034	0.068	0.060	-0.477	0.119	-0.477	-0.030
0.75	-0.01	1	0.083	0.062	0.071	0.035	0.071	0.062	-0.496	0.124	-0.496	-0.031
0.8	-0.01	1	0.086	0.064	0.073	0.037	0.073	0.064	-0.514	0.129	-0.514	-0.032
0.85	-0.01	1	0.089	0.067	0.076	0.038	0.076	0.067	-0.533	0.133	-0.533	-0.033
0.825	-0.005	1	0.044	0.033	0.037	0.019	0.037	0.033	-0.262	0.065	-0.262	-0.016
0.825	-0.01	1	0.087	0.065	0.075	0.037	0.075	0.065	-0.524	0.131	-0.524	-0.033
0.825	-0.015	1	0.131	0.098	0.112	0.056	0.112	0.098	-0.786	0.196	-0.786	-0.049
0.7	-0.005	1	0.040	0.030	0.034	0.017	0.034	0.030	-0.238	0.060	-0.238	-0.015
0.7	-0.01	1	0.079	0.060	0.068	0.034	0.068	0.060	-0.477	0.119	-0.477	-0.030
0.7	-0.015	1	0.119	0.089	0.102	0.051	0.102	0.089	-0.715	0.179	-0.715	-0.045

Notes: Entries give the combination of agglomeration parameters described in the text. Calibrated parameter values are in Table 9.



**Table 11: Mechanisms Through Which Highways Cause Decentralization**

			Components of $d\ln Q_c/dhwy$ if $d\ln g_c/dt=0$ & $d\ln h/dt=0$								Additional	Remainder	Additional
$\phi_N, \gamma$	Parameters	$\eta$	Price & Income Effects				Housing Factor Realloc.		Firm GE Effects		Given	of	With
	$\Delta t/\Delta hwy$		A	B	C	D	E	F	G	H	$d\ln h/dt=1$	$d\ln Q_c/dhwy$	$d\ln g_c/dt$
0.6	-0.01	0.7	-0.007	-0.020	-0.002	0.002	-0.002	-0.065	-0.043	0.029	-0.020	-0.032	0.004
0.65	-0.01	0.7	-0.007	-0.020	-0.002	0.002	-0.002	-0.065	-0.043	0.029	-0.018	-0.034	0.004
0.7	-0.01	0.7	-0.007	-0.020	-0.002	0.002	-0.002	-0.065	-0.043	0.029	-0.017	-0.035	0.004
0.75	-0.01	0.7	-0.007	-0.020	-0.002	0.002	-0.002	-0.065	-0.043	0.029	-0.016	-0.036	0.004
0.8	-0.01	0.7	-0.007	-0.020	-0.002	0.002	-0.002	-0.065	-0.042	0.029	-0.015	-0.038	0.004
0.85	-0.01	0.7	-0.007	-0.020	-0.002	0.002	-0.002	-0.065	-0.042	0.029	-0.014	-0.039	0.004
0.825	-0.005	0.7	-0.004	-0.010	-0.001	0.001	-0.001	-0.033	-0.021	0.029	-0.007	-0.114	0.002
0.825	-0.01	0.7	-0.007	-0.020	-0.002	0.002	-0.002	-0.065	-0.042	0.029	-0.014	-0.038	0.004
0.825	-0.015	0.7	-0.011	-0.030	-0.003	0.002	-0.002	-0.098	-0.064	0.029	-0.022	0.037	0.006
0.7	-0.005	0.7	-0.004	-0.010	-0.001	0.001	-0.001	-0.033	-0.021	0.029	-0.008	-0.112	0.002
0.7	-0.01	0.7	-0.007	-0.020	-0.002	0.002	-0.002	-0.065	-0.043	0.029	-0.017	-0.035	0.004
0.7	-0.015	0.7	-0.011	-0.030	-0.003	0.003	-0.003	-0.098	-0.064	0.029	-0.025	0.042	0.006
0.6	-0.01	1	-0.010	-0.020	-0.004	0.002	-0.002	-0.065	-0.043	0.029	-0.025	-0.023	0.005
0.65	-0.01	1	-0.010	-0.020	-0.003	0.002	-0.002	-0.065	-0.043	0.029	-0.023	-0.025	0.005
0.7	-0.01	1	-0.010	-0.020	-0.003	0.002	-0.002	-0.065	-0.043	0.029	-0.021	-0.027	0.005
0.75	-0.01	1	-0.010	-0.020	-0.003	0.002	-0.002	-0.065	-0.043	0.029	-0.020	-0.029	0.005
0.8	-0.01	1	-0.010	-0.020	-0.003	0.002	-0.002	-0.065	-0.042	0.029	-0.019	-0.030	0.005
0.85	-0.01	1	-0.010	-0.020	-0.003	0.002	-0.002	-0.065	-0.042	0.029	-0.017	-0.031	0.005
0.825	-0.005	1	-0.005	-0.010	-0.001	0.001	-0.001	-0.033	-0.021	0.029	-0.009	-0.110	0.002
0.825	-0.01	1	-0.010	-0.020	-0.003	0.002	-0.002	-0.065	-0.042	0.029	-0.018	-0.031	0.005
0.825	-0.015	1	-0.015	-0.030	-0.004	0.002	-0.002	-0.098	-0.064	0.029	-0.027	0.048	0.007
0.7	-0.005	1	-0.005	-0.010	-0.002	0.001	-0.001	-0.033	-0.021	0.029	-0.011	-0.108	0.003
0.7	-0.01	1	-0.010	-0.020	-0.003	0.002	-0.002	-0.065	-0.043	0.029	-0.021	-0.027	0.005
0.7	-0.015	1	-0.015	-0.030	-0.005	0.003	-0.003	-0.098	-0.064	0.029	-0.032	0.054	0.008

Notes: Entries in the final column assume that  $d\ln g_c/d\ln N_c$  is one-half of the numbers reported in Table 10.

**Table A1: Summary Statistics**

<b>Variable</b>	<b>Industry</b>	<b>Mean</b>	<b>Sd</b>	<b>p25</b>	<b>p50</b>	<b>p75</b>
Planned Rays	All	2.9	1.5	2	3	4
1960 Central City Radius	All	4.4	2.1	2.9	4.1	5.2
Change in log Total Employment+Residents	All	0.73	0.41	0.44	0.65	0.96
Change in Rays 1950 to 2000	All	2.7	1.7	2	2	4
Change in Rays 1960 to 2000	All	2.0	1.6	0.5	2	3
Change in log SMSA Employment	All	0.68	0.42	0.37	0.60	0.91
	Manufacturing	-0.07	0.63	-0.53	-0.15	0.39
	Services	1.36	0.35	1.13	1.28	1.53
	Trade	0.46	0.39	0.16	0.39	0.69
	TCPU	0.81	0.51	0.49	0.78	1.07
	Construction	0.72	0.37	0.45	0.70	0.88
	Public Admin.	0.57	0.44	0.30	0.55	0.82
	FIRE	1.15	0.41	0.85	1.08	1.40
	Military	-0.39	0.97	-1.00	-0.26	0.25
	Agriculture	-0.76	0.43	-1.03	-0.80	-0.52
Change in log SMSA Residents	All	0.63	0.41	0.33	0.52	0.85
	Manufacturing	-0.11	0.62	-0.56	-0.28	0.34
	Services	1.31	0.35	1.05	1.23	1.50
	Trade	0.41	0.39	0.14	0.30	0.65
	TCPU	0.74	0.50	0.41	0.67	0.99
	Construction	0.64	0.38	0.39	0.61	0.82
	Public Admin.	0.51	0.43	0.24	0.49	0.76
	FIRE	1.10	0.41	0.79	1.02	1.36
	Military	-0.47	0.94	-1.21	-0.28	0.16
	Agriculture	-0.85	0.42	-1.08	-0.89	-0.64
Change in log Central City Employment	All	0.11	0.42	-0.17	0.04	0.39
	Manufacturing	-0.88	0.64	-1.38	-0.91	-0.46
	Services	0.84	0.33	0.61	0.80	1.01
	Trade	-0.51	0.50	-0.89	-0.55	-0.15
	TCPU	0.20	0.47	-0.12	0.10	0.48
	Construction	0.11	0.38	-0.17	0.08	0.38
	Public Admin.	0.34	0.44	0.05	0.30	0.60
	FIRE	0.41	0.45	0.09	0.43	0.70
	Military	-0.65	1.10	-1.14	-0.45	0.07
	Agriculture	-0.81	0.61	-1.13	-0.80	-0.39
Change in log Central City Resident Workers	All	-0.09	0.36	-0.35	-0.14	0.11
	Manufacturing	-0.91	0.59	-1.32	-0.99	-0.57
	Services	0.58	0.34	0.34	0.54	0.80
	Trade	-0.46	0.39	-0.75	-0.51	-0.21
	TCPU	-0.06	0.44	-0.32	-0.12	0.21
	Construction	-0.09	0.44	-0.42	-0.09	0.17
	Public Admin.	-0.29	0.38	-0.53	-0.26	-0.07
	FIRE	0.19	0.36	-0.08	0.20	0.40
	Military	-1.18	1.17	-1.73	-1.15	-0.31
	Agriculture	-0.89	0.56	-1.26	-0.91	-0.54

**Table A2: Effects of Highways on Central City Workers and Residents by Industry**  
OLS Estimates

	All	Manuf- acturing	Services	Trade	TCPU	Const- ruction	Public Admin.	FIRE	Military	Agric- ulture
<b>Panel A: Central City Workers in Listed Industry</b>										
Change in Rays	-0.02	-0.06*	-0.02	-0.06***	-0.01	-0.03	-0.03	-0.01	0.00	0.09**
1950 to 2000	(0.02)	(0.03)	(0.01)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.07)	(0.04)
1960 Central City Radius	0.04***	0.09***	0.04***	0.08***	0.05***	0.05***	-0.05***	0.05**	-0.09*	0.00
	(0.01)	(0.02)	(0.01)	(0.02)	(0.01)	(0.01)	(0.02)	(0.02)	(0.06)	(0.03)
Change in Log Total	0.79***	0.97***	0.56***	0.74***	0.85***	0.57***	0.78***	0.59***	0.51*	0.40***
Employment+Residents	(0.06)	(0.12)	(0.06)	(0.09)	(0.07)	(0.07)	(0.08)	(0.09)	(0.28)	(0.15)
Constant	-0.61***	-1.85***	0.30***	-1.25***	-0.64***	-0.47***	0.04	-0.20*	-0.61*	-1.36***
	(0.07)	(0.13)	(0.06)	(0.10)	(0.08)	(0.08)	(0.09)	(0.11)	(0.32)	(0.17)
R-Squared	0.68	0.50	0.58	0.52	0.66	0.47	0.50	0.36	0.05	0.15
<b>Panel B: Central City Residents Working in Listed Industry</b>										
Change in Rays	-0.05***	-0.06**	-0.04**	-0.06***	-0.04*	-0.06***	-0.06***	-0.05**	0.01	0.01
1960 to 2000	(0.02)	(0.03)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.07)	(0.03)
1960 Central City Radius	0.06***	0.07***	0.06***	0.05***	0.07***	0.07***	0.03	0.05***	-0.03	-0.05*
	(0.01)	(0.02)	(0.01)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.06)	(0.03)
Change in Log Total	0.58***	0.94***	0.36***	0.46***	0.61***	0.54***	0.23**	0.39***	-0.55*	0.11
Employment+Residents	(0.06)	(0.11)	(0.07)	(0.08)	(0.08)	(0.09)	(0.09)	(0.08)	(0.30)	(0.14)
Constant	-0.66***	-1.76***	0.14*	-0.85***	-0.70***	-0.66***	-0.43***	-0.21**	-0.64*	-0.76***
	(0.07)	(0.12)	(0.08)	(0.09)	(0.10)	(0.10)	(0.10)	(0.09)	(0.34)	(0.16)
R-Squared	0.59	0.51	0.37	0.34	0.45	0.42	0.14	0.31	0.04	0.04

Notes: Regression models are identical to those estimated in Table 6 except in this table the change in rays 1960 to 2000 is not instrumented.