# Agglomeration and Congestion Spillovers: Evidence from Base Realignment and Closure*

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## Abstract

I quantify agglomeration and congestion spillovers using variation from a natural experiment by instrumenting for changes in local employment with proposed changes to civilian employment at military installations through the Base Realignment and Closure (BRAC) process. I find an agglomeration spillover elasticity consistent with the existing literature. However, my estimate of the congestion spillover elasticity is smaller in magnitude than common parameterizations of quantitative economic geography models. All else equal, with a weaker congestion spillover elasticity, more of the distribution of economic activity across space is due to natural advantages and disadvantages. This result implies smaller gains from implementing the optimal spatial policy.

*Keywords:* Economic geography, Spillovers, Base Realignment and Closure (BRAC), Optimal spatial policy, Defense spending
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# 1 Introduction

The distribution of economic activity within the United States is far from uniform. To illustrate, in 2007 Cook County, Illinois, had an employment density of 2,530 workers per square mile. In contrast, Cherry County, Nebraska, had an employment density of only 0.28 workers per square mile. Further, per capita income is higher in locations with a greater density of employment: Cook County's per capita income was $54,283 in 2007, compared to only $19,001 for Cherry County. Even between neighboring locations, differences in economic activity can be meaningful. Both location fundamentals and externalities from the concentration of employment contribute to these differences, but what are the relative contributions of each? Additionally, what is the implication of the strength of these local externalities on policies that target spatial inequities? To answer these questions, it is necessary to structurally estimate the parameters that govern local employment externalities in a general equilibrium framework.

In this paper, I estimate the strength of agglomeration and congestion spillover elasticities by exploiting variation in local employment of civilians at military installations. Agglomeration and congestion spillovers capture the externalities from the concentration of employment on local productivity and local amenities, respectively. These externalities are central forces in determining the spatial equilibrium in quantitative economic geography models. Specifically, I develop a model that extends Allen and Arkolakis (2014) with a government that can implement location-specific income taxes and subsidies. In this model, workers are perfectly mobile and pick their location taking prices, wages, and local amenities as given. Products are differentiated by location and, taking wages as given, produced using labor as an input. It follows that prices and wages are a function of local productivity. Trade between locations is subject to bilateral iceberg trade costs. In equilibrium, the welfare of workers equalizes across space.

To estimate the impact of employment density on local productivity and amenities, I first invert the the model to recover these measures for each location from data on the observed equilibrium distribution of wages and employment. However, agglomeration and congestion spillover elasticities cannot be separately identified with data on local employment density and wages alone; workers' location choices are a function of location fundamentals, so the direct effect of employment density is confounded. For this reason, shocks to local employment that are exogenous to changes in location fundamentals are required to determine the relative contribution of externalities and fundamentals to the spatial equilibrium. To address this identification challenge, I use variation in local military employment, instrumented by proposed changes to local military employment through the Base Realignment and Closure (BRAC) process. The BRAC process allows the Department of Defense (DoD) to reorganize the distribution of defense activity by closing military installations and is designed to insulate base closure decisions from political interference. Therefore, the key identifying assumption is that the proposed changes by the DoD to civilian employment at military installations were chosen based on changes in the installation's value to military objectives and not on shocks to location fundamentals conditional on state-by-year fixed effects.

The resulting estimate of the agglomeration spillover elasticity is 0.057, which implies that a doubling of the employment density in a county results in a 5.7% increase in local productivity. This estimate is broadly in line with the existing literature on agglomeration economies (Rosenthal and Strange 2004; Melo, Graham, and Noland 2009). However, more recent estimates that also use natural experiments and structural measures of productivity produce a wider range of agglomeration spillover elasticities (Kline and Moretti 2014; Ahlfeldt et al. 2015; Giannone 2017; Farrokhi and Jinkins 2019). Specifically, my result is most similar to estimates from the literature that are smaller in magnitude, such as the agglomeration spillover elasticity in Ahlfeldt et al. (2015). The estimated congestion spillover elasticity is -0.078, which implies that a doubling of the employment density in a county results in a 7.8% decrease in local amenities. This result is smaller in magnitude than common parameterizations of quantitative economic geography models (Allen and Arkolakis 2014; Diamond 2016).

A weaker congestion elasticity implies that variation in local amenities is explained less by differences in the concentration of economic activity and more by differences in location fundamentals. Further, with weaker externalities relative to location fundamentals, the solution to the social planner's problem (a set of location-specific income taxes and subsidies that accounts for the externalities caused by workers' location decisions) calls for less income redistribution across space. As a result, the welfare gain from implementing this optimal spatial policy is smaller. I also find that the welfare loss associated with the implied spatial redistribution (compared to the competitive equilibrium) due to the observed distribution of defense employment is larger with weaker congestion spillovers.

Unlike earlier research on agglomeration economies that uses wages as a proxy for productivity (Rosenthal and Strange 2004; Melo, Graham, and Noland 2009), I use a quantitative model of economic geography to structurally estimate the direct effect. By combining structural measures of productivity with variation from a natural experiment to instrument for employment density, my estimation method is similar to Kline and Moretti (2014) and Greenstone, Hornbeck, and Moretti (2010). However, I not only estimate the agglomeration spillover elasticity, but also structurally estimate the congestion spillover elasticity. Two notable papers also estimate both parameters to quantify the strength of spillovers within cities. Ahlfeldt et al. (2015) use variation in neighborhood market access due to the division and reunification of Berlin to estimate spillover elasticities that capture the strength of within-block externalities. Brinkman (2016) similarly quantifies the strength of spillovers within American cities. However, by focusing on the internal arrangement of cities, these papers do not estimate a single net congestion spillover elasticity; they instead decompose congestion forces into multiple sources such as commuting, amenity, and residential externalities. Consequently, these estimates are not easily incorporated into many quantitative economic geography models. For example, Allen and Arkolakis (2014) remain agnostic about the magnitude of the congestion spillover elasticity by providing results for a range of values, and for their baseline results they use the share of consumer expenditures spent on housing. In addition, Fajgelbaum and Gaubert (2020) use the structure of their model to recover congestion spillover elasticities by inverting the state-level labor demand elasticities from Diamond (2016). In this paper, I report estimates of the net agglomeration and congestion spillover elasticities at the county level for the U.S. that differ from these previous parameterizations. Specifically, I find a net congestion elasticity that is smaller in magnitude and explore the impact this has on the optimal spatial policy, which contributes to the growing literature on the scope of optimal spatial policies (Fajgelbaum and Gaubert 2020; Fajgelbaum and Schaal 2020; Blouri and Ehrlich 2020).

Defense activity, the source of variation exploited in this paper, has been used to quantify various features of the economy including business cycles (Blanchard et al. 1992) and fiscal spending multipliers (Nakamura and Steinsson 2014). In particular, Nakamura and Steinsson (2014) employ a similar identification strategy as I use in this paper: instrumenting for potentially endogenous local defense activity with shocks to this activity due to changing aggregate defense objectives that create differential impacts by location. However, given their focus on fiscal multipliers, the defense activity in Nakamura and Steinsson (2014) is defense spending through procurement contracts instead of civilian employment by the DoD. One unique feature of the distribution of defense employment is that major changes must go through the BRAC process. While the effects of BRAC have been studied directly (Krizan et al. 1998; Poppert and Herzog Jr 2003; Hultquist and Petras 2012), the shocks due to BRAC have not been applied in many contexts. Further, in this literature, the identification strategy is most often based on the explicit assumption that observed changes in military employment are not correlated with local economic characteristics. One notable exception is Zou (2018), who uses a shift-share instrument constructed from changes in defense employment over the first four BRAC rounds to study the impact of base closures on local labor markets. In this paper, I instrument for changes in civilian employment at military bases with BRAC proposals by the DoD, which are not always implemented as recommended. My novel approach addresses this potential endogeneity introduced by the BRAC commission and this aligns more closely with Nakamura and Steinsson (2014).

This paper proceeds as follows: Section 2 characterizes the quantitative model of economic geography and highlights the channels through which the agglomeration and congestion spillover elasticities determine both the competitive equilibrium and the optimal spatial policy. Section 3 details the data used in the analysis and how, in combination with the structure of the model, measures of local productivity and amenities can be recovered. Section 4 outlines the identification strategy for estimating the agglomeration and congestion spillover elasticities, including background on the institutional features of the BRAC process. Section 5 reports the structural estimates. Section 6 presents applications of the estimates, including analyzing the general equilibrium and conducting counterfactuals that quantify how the magnitude of the congestion spillover elasticity impacts the welfare gains from implementing the optimal spatial policy. Section 7 concludes.

# 2 Model

In this section, I develop a model of the spatial economy that extends Allen and Arkolakis (2014) with an additional sector: a government that can implement location-specific income taxes and subsidies. I compare the spatial equilibrium under two government policies by first deriving the allocative equilibrium with an arbitrary set of transfers and then analyzing the competitive equilibrium (the case with no government transfers). In addition, I characterize the solution to the social planner's problem, i.e., the welfare-maximizing set of transfers, as a function of the agglomeration and congestion spillover elasticities.

## 2.1 Setup

The economy consists of a set of locations $s \in S$ and $\overline{L}$ freely mobile workers. Products are differentiated by location of origin. Trade between locations is costly and takes an iceberg form such that $\tau_{is}$ units need to be sent from $i$ to $s$ for a single unit to arrive in $s$. However, local trade costs, i.e., $\tau_{ii}$, are normalized to equal one for all locations. Let the set of trade costs to each location $s$ from location $i$ for all $s \in S$ be defined as the geographic location of $i$. Workers in $i$, $L_i$, have constant elasticity of substitution (CES) preferences over the differentiated varieties they consume and additionally receive a benefit from the composite amenity value, $u_i$, in the location they choose. Welfare, $W_i$, in location $i$ is defined as:

$$W_i = \left[ \sum_{s=1}^{n} q_{si}^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}} u_i, \tag{1}$$

where $q_{si}$ is the quantity of goods from $s$ consumed in $i$ and $\sigma$ is the CES parameter.

Workers in location $i$ inelastically supply their labor and receive a wage $w_i$ in return. Production is linear in labor, so the price at the source for the variety produced in $i$ is $p_i = \frac{w_i}{a_i}$, where $a_i$ represents the composite productivity of each worker in location $i$. Thus, the price of the variety from another location, $s$, in $i$ is $p_{si} = \frac{\tau_{si} w_s}{a_s}$.

Define the local composite productivity, $a_i$, as a general function of local employment:

$$a_i = \overline{a_i} L_i^{\alpha}, \tag{2}$$

where $\alpha$ is the agglomeration spillover elasticity, and $\overline{a_i}$ is the natural productivity value in $i$. Correspondingly, define local composite amenities as a general function of local employment:

$$u_i = \overline{u_i} L_i^{\beta}, \tag{3}$$

where $\beta$ is the congestion spillover elasticity, and $\overline{u_i}$ is the natural amenity level in $i$. The benefit of this form for agglomeration and congestion spillovers is that it ensures an isomorphism to multiple prominent models of economic geography (Allen and Arkolakis 2014).[1]

With consumption per capita in $i$ defined as $x_i$, the standard gravity equation follows from the model:

$$X_{si} = \left(\frac{p_{si}}{\mathcal{P}_i}\right)^{1-\sigma} x_i L_i, \tag{4}$$

where $X_{si}$ is the value of goods sent from $s$ to $i$ and $\mathcal{P}_i = \left(\sum_{s=1}^{n} p_{si}^{1-\sigma}\right)^{\frac{1}{1-\sigma}}$ is the price index in location $i$. Using Equations (1) and (4), the per capita indirect utility of workers who locate in $i$ can be expressed in terms of expenditures and prices:

$$W_i = u_i \frac{x_i}{\mathcal{P}_i}. \tag{5}$$

In the equilibrium, because labor is freely mobile, workers will locate so that welfare equalizes across space. This implication of workers' location choices, when combined with the definition of $\mathcal{P}_i$, $p_{si}$, and Equation (5), yields the first equilibrium condition,

$$w_i^{\sigma} L_i = a_i^{\sigma-1} \overline{W}^{1-\sigma} \sum_{s \in S} \tau_{is}^{1-\sigma} u_s^{\sigma-1} \; x_s^{\sigma} L_s. \tag{6}$$

Similarly, using Equation (5) and the equilibrium condition that total labor income in $i$, $w_i L_i$ must be equal to the value of exports from $i$, $\sum_{s=1}^{n} X_{is}$, results in the second equilibrium

[1] As in Allen and Arkolakis (2014), $\overline{a_i}$, $\overline{u_i}$, and the geographic location of $i$ represent the geographic component of the model.

condition,

$$x_i^{1-\sigma} u_i^{1-\sigma} = \overline{W}^{1-\sigma} \sum_{s=1}^{n} \tau_{si}^{1-\sigma} w_s^{1-\sigma} a_s^{\sigma-1}. \tag{7}$$

Together, the two equilibrium conditions represent labor supply and demand. To complete the model, a description of the relationship between the value of local consumption, $x_s L_s$, to local production, $w_s L_s$, is required. The following subsections present three distinct formulations of this connection and formalize the relationship between the agglomeration and congestion spillover elasticities and spatial policy.

## 2.2 Competitive Equilibrium

The simplest connection between expenditures and the value of production in location $i$ is to assume they are the same. This scenario, where there is no redistribution, is equivalent to imposing balanced trade. With $x_i = w_i$, the equilibrium conditions reduce to

$$w_i^{\sigma} L_i = a_i^{\sigma-1} \overline{W}^{1-\sigma} \sum_{s \in S} \tau_{is}^{1-\sigma} u_s^{\sigma-1} w_s^{\sigma} L_s, \tag{8}$$

and

$$w_i^{1-\sigma} u_i^{1-\sigma} = \overline{W}^{1-\sigma} \sum_{s \in S} \tau_{si}^{1-\sigma} w_s^{1-\sigma} a_s^{\sigma-1}. \tag{9}$$

This model, which is a special case of the more generalized model with transfers, is the same as the model developed in Allen and Arkolakis (2014). Given symmetric trade costs, Equations (8) and (9) can be consolidated into a single set of equilibrium equations,

$$L_i^{\tilde{\sigma}\gamma_1} = \overline{u}_i^{(1-\tilde{\sigma})(\sigma-1)} \overline{a}_i^{\tilde{\sigma}(\sigma-1)} \overline{W}^{1-\sigma} \sum_{s \in S} \tau_{is}^{1-\sigma} \overline{u}_s^{\tilde{\sigma}(\sigma-1)} \overline{a}_s^{(1-\tilde{\sigma})(\sigma-1)} \left( L_s^{\tilde{\sigma}\gamma_1} \right)^{\frac{\gamma_2}{\gamma_1}}, \tag{10}$$

that express the equilibrium employment in each location as a function of the underlying geography as well as the distribution of employment.

## 2.3 Allocative Equilibrium

A more general specification of the model allows for a government that can make transfers between locations such that the value of local consumption need not equal the value of local production. With location-specific income taxes and subsidies, it is possible for overall welfare improvements through redistribution because agglomeration and congestion spillovers create externalities from workers' location decisions. Further, government transfers add an additional mechanism that creates variation in the location decisions of workers that need not be a function of local economic characteristics. Specifically, assume expenditures and output per worker are connected by a local transfer, $t_i$, and a universal lump-sum transfer, $\bar{t}$, such that

$$x_i = w_i + t_i + \bar{t}. \tag{11}$$

The specific transfer represents any distributional policies and the universal lump-sum transfer is applied to balance the government budget, i.e.,

$$\bar{t} = \frac{1}{\bar{L}} \sum_{i \in S} t_i L_i. \tag{12}$$

## 2.4 Social Planner Equilibrium

Equations (11) and (12) define a general set of transfers across locations. An application of the framework in Fajgelbaum and Gaubert (2020), implies that there exists a specific schedule of transfers that maximizes the welfare of workers and is thus the solution to the social planner's problem. Specifically, optimal transfers will take the form,

$$t_i = \left(\frac{\alpha + \beta}{1 - \beta}\right) \left(w_i - \overline{\omega}\right), \tag{13}$$

where $\overline{\omega}$ is the average value of production per capita in the economy, $\overline{\omega} = \frac{\sum_{i=1}^{N} w_i L_i}{\bar{L}}$, and the lump-sum transfer equals $\bar{t} = \left(-\frac{\alpha+\beta}{1-\beta}\right)\overline{\omega}$. Under the standard assumption that $\alpha > 0$ and $\beta < 0$, the optimal spatial policy will take the form of an income tax and lump sum transfer that accounts for the agglomeration and congestion externalities that workers do not consider when choosing their location.

The solution to the social planner's problem is a direct function of the spillover elasticities that govern the agglomeration and congestion externalities. For example, in the case that local productivities and amenities are not functions of local employment (i.e., $\alpha = 0$ and $\beta = 0$) the optimal spatial policy is no transfers at all and the competitive equilibrium is the solution to the social planner's problem. This follows from the fact that the agglomeration and congestion spillover elasticities are the determinant of how much of the observed distribution of economic activity (i.e., wages and employment) is due to natural productivities and amenities that do not respond to the level of employment (i.e., $\overline{a_i}$ and $\overline{u_i}$) and spillover effects from employment, that combine to form the composite productivities and amenities defined by Equations (2) and (3). When $\alpha = 0$ and $\beta = 0$, only natural advantages determine the distribution of economic activity and thus there are no externalities to a worker's location choice. The specific non-zero estimates of $\alpha$ and $\beta$ chosen to calibrate the model directly determine the strength of externalities and thus the scope of the channels that the social planner's solution offsets.

# 3 Recovering geography

To estimate local spillover elasticities, it is necessary to utilize the structure of the model to recover composite productivities and amenities. Equations (6) and (7) represent a set of equilibrium conditions that define a solution for the distribution of labor in terms of geographic variables: local productivities, amenities, and trade costs. However, in the data, it is the equilibrium distribution of economic activity, i.e., local employment and wages, that is observed and not the underlying geography. It follows that the equilibrium conditions must be inverted to represent a solution for the geography in terms of the distribution of economic activity.

## 3.1 Model inversion

The first step to invert the model is to collapse the equilibrium conditions into a single set of equations. With symmetric trade costs, equating Equations (6) and (7) yields,

$$w_i^{\sigma} L_i a_i^{1-\sigma} = \phi w_i^{1-\sigma} u_i^{1-\sigma}, \tag{14}$$

where $\phi$ is a constant. Plugging Equation (14) back into the equilibrium condition (Equation (6)) and dividing by a reference location $j \in S$ results in a set of equilibrium conditions that can be solved through an iterative procedure to recover local amenities up to scale given a distribution of wages, employment, and trade costs:

$$\frac{u_i}{u_j} = \left(\frac{x_i}{x_j}\right)^{-1} \frac{\left[\sum_{s \in S} \tau_{si}^{1-\sigma} x_s^{\sigma-1} u_s^{\sigma-1} w_s L_s\right]^{\frac{1}{1-\sigma}}}{\left[\sum_{s \in S} \tau_{sj}^{1-\sigma} x_s^{\sigma-1} u_s^{\sigma-1} w_s L_s\right]^{\frac{1}{1-\sigma}}}. \tag{15}$$

The recovered amenities from Equation (15) can be used with a normalized version of Equation (14) to recover local productivities (also up to scale):

$$\frac{a_i}{a_j} = \left(\frac{w_i}{w_j}\right)^{\frac{\sigma}{\sigma-1}} \left(\frac{L_i}{L_j}\right)^{\frac{1}{\sigma-1}} \left(\frac{x_i}{x_j}\right) \left(\frac{u_i}{u_j}\right). \tag{16}$$

## 3.2 Data

As outlined in Equations (15) and (16), composite amenities and productivities that rationalize the observed equilibrium can be recovered with data on local wages, employment, expenditures and trade costs.

The source of data on county-level wages and employment for the private sector is the Quarterly Census of Employment and Wages (QCEW).[2] These data are combined to construct the measure of labor income used in the quantitative implementation. Further, total employment in each county is the combination of the private sector employment from the QCEW and data on military base employment of civilians from the annual reports on the Dis-

[2] Here, private sector is defined as all non-government (federal, state, and local) employers.

tribution of Personnel by State and Selected Locations from the DoD.[3] In order to combine military personnel data by installation with county-level economic data, each installation is mapped to a county using military data on the location of installations and mapping software. In addition, due to changes in county boundaries over the sample period, some counties in the quantitative analysis represent the aggregation of jurisdictions so that the definitions are consistent across the sample period.[4] Expenditures at the county level are constructed by combining data on labor income with government transfers due to civilian employment at military installations. The panel period is between 1983 and 2009.[5] The resulting employment density and wages by county are presented in Figure 1.

The final input required for model inversion is a set of bilateral symmetric trade costs. Trade costs are determined by combining data on the transportation network of the U.S. with data on intranational trade by mode following the methodology in Farrokhi and Jinkins (2019) which incorporates the use of the Fast Marching Method (FMM) as in Allen and Arkolakis (2014). Data on intranational trade by mode is collected from the 2007 U.S. Commodity Flow Survey (CFS). This is the same data used in Farrokhi and Jinkins (2019) and includes data on trade between CFS areas by mode of transportation.[6] Trade costs are recovered by constructing maps of the U.S. transportation infrastructure (see Appendix B) and using them to determine relative physical distances between locations for each mode of transportation. With relative weights within a mode (e.g. a "speed" for interstates versus other roads) from Allen and Arkolakis (2014) and maps of the mode-specific networks, the FMM can be applied to determine the least-cost distance between any two locations by mode. The railroad network was sourced from the Department of Homeland Security (DHS) and

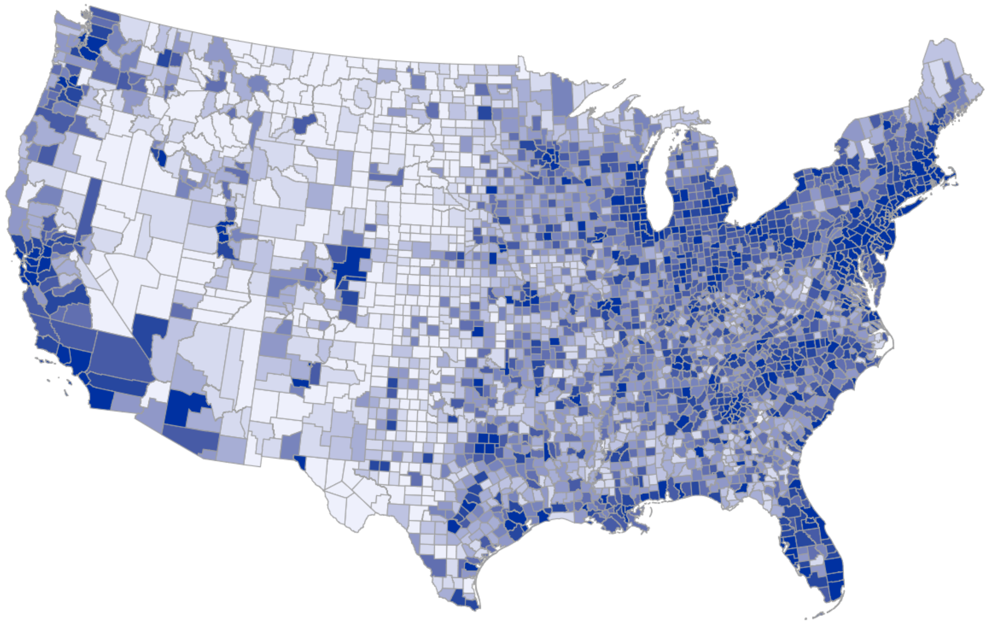
[3] Documentation suggests that installations with limited manpower, such as recruitment centers, are not included in these reports. Given this, to ensure consistent installations across the panel, only counties with military base employment that is non-zero for more than one year and has a maximum value over the sample period of at least two-hundred combined civilian and active duty personnel are included in the panel.

[4] The largest impact of this aggregation follows from the creation of Broomfield County in Colorado from a number of existing counties in the metropolitan Denver area.

[5] Since the first round of BRAC was implemented in 1988 and it is necessary to have 5-years of pre-policy data to construct the instrumental variable, the initial year of the panel is 1983. In terms of the final year, 2009, this is the last year for which the military census data is available. As a result, the final year of the 2005 BRAC round implementation window is not included in the panel.

[6] In general CFS areas are equivalent to metropolitan statistical areas (MSAs), but are all contained within one state and additionally include an area for any portion of a state not included in an MSA. It follows that the estimation of trade cost parameters use CFS areas as the geographic unit.

(a) Log(Employment Density)



(b) Annual Per Capita Earnings

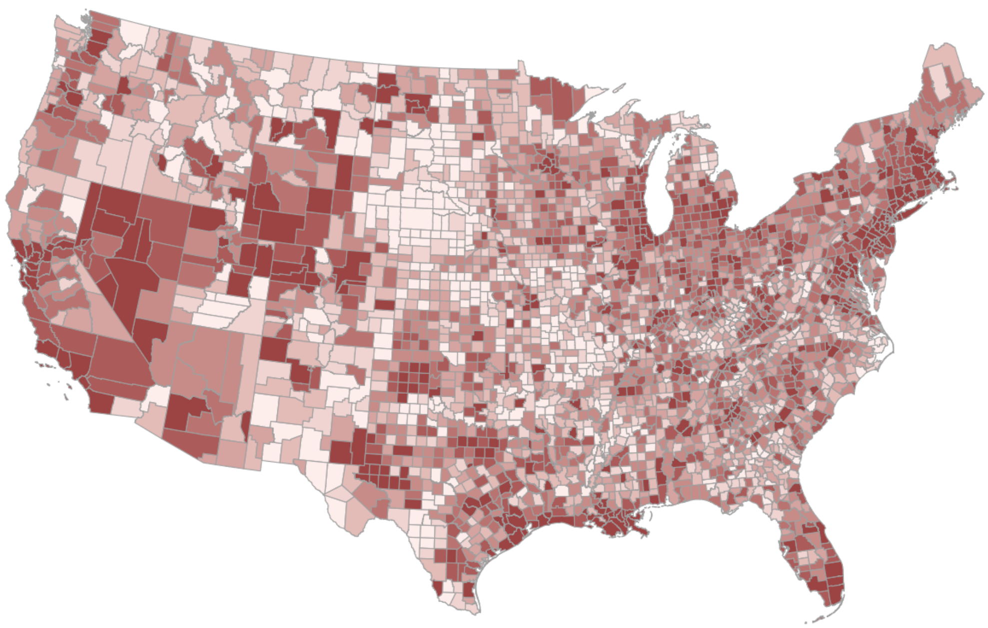


Figure 1: Economic Variables by County (2007)

*Note*: Each figure presents counties by decile of the respective variable (with the darkest color representing the highest decile and the lightest color the lowest decile).

the road and commercially navigable waterway networks were sourced from the Department of Transportation (DOT).

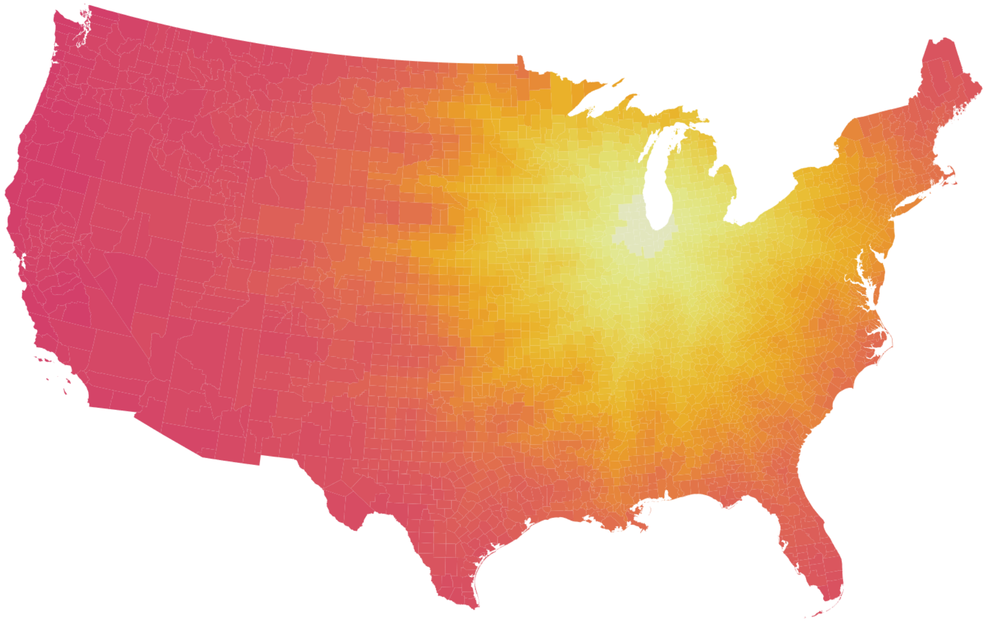


Figure 2: Bilateral Trade Costs (Cook County, IL)

*Notes*: This figure presents the bilateral trade costs for Cook County, IL. Lighter colors reflect lower bilateral trade costs and darker colors reflect higher bilateral trade costs.

To estimate mode-specific variable and fixed trade costs, the distances are combined with observed trade shares in a discrete choice framework as in Allen and Arkolakis (2014). Mode-specific trade costs are combined to form total trade costs and estimation of the model-implied gravity equation produces a shape parameter that scales trade costs based on the observed value of trade flows. This results in a single trade cost value for each bilateral link.[7] Finally, since CFS areas are more aggregated than counties, the estimates from the CFS-area-based estimation are applied to the least-cost distances derived with the FMM for each county pair.[8] Figure 2 presents the resulting bilateral trade costs for Cook County, IL using this methodology and illustrates the significance of the U.S. transportation

[7]Small differences between estimated trade costs from $i$ to $j$ and $j$ to $i$ are removed by taking the average between both directions. This ensures that the trade costs used in the estimation and counterfactuals are symmetric and follows the methodology in Farrokhi and Jinkins (2019).

[8]The resulting trade costs are similar to an alternative approach that assumes the same trade costs for all locations within a CFS area. The primary difference is an expected small increase in within-CFS-area variation.

network for determining intranational trade costs. One parameter necessary to execute this methodology to recover trade costs is the value of the CES parameter, $\sigma$. In the quantitative implementation, I assume $\sigma = 5$, which is consistent with both Head and Mayer (2014) and Fajgelbaum and Gaubert (2020).

## 3.3 Geography

The result of the application of Equations (15) and (16) to the observed economic data as described in Section 3.2 is a set of composite amenities and productivities that are presented in Figure 3.

In the model, composite amenities represent compensating differentials for wage differences between otherwise similar locations. Specifically, in the competitive equilibrium, if two counties have the same location in space (set of trade costs to other locations), then they have the same cost of living and their relative amenities are equal to

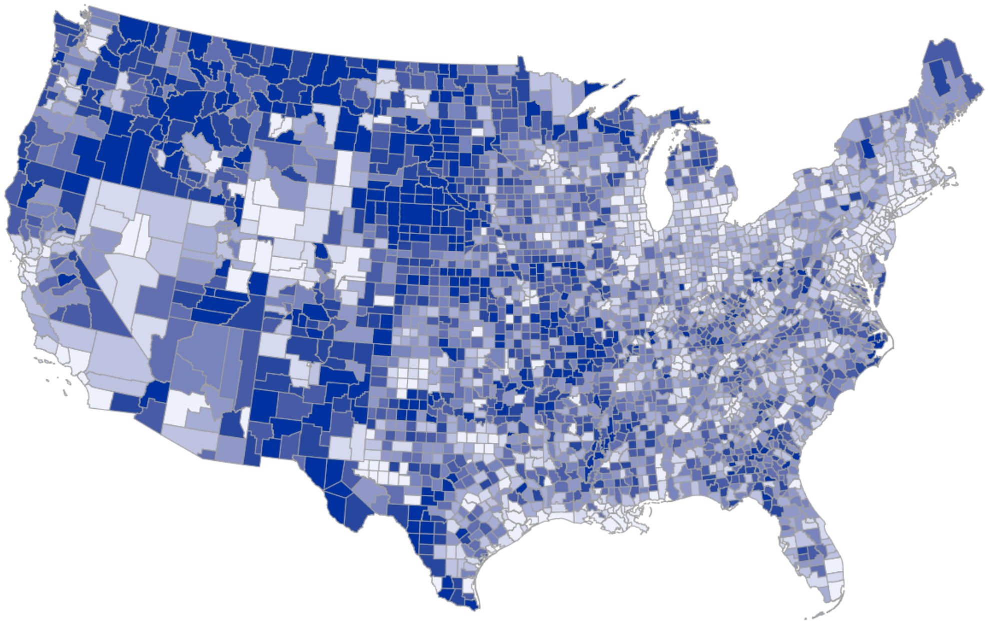
$$\frac{u_i}{u_j} = \left(\frac{w_i}{w_j}\right)^{-1}, \tag{17}$$

and their relative productivities are equal to,

$$\frac{a_i}{a_j} = \left(\frac{w_i}{w_j}\right)\left(\frac{w_i L_i}{w_j L_j}\right)^{\frac{1}{\sigma-1}}. \tag{18}$$

For locations that are not similar, i.e., differ in their cost of living (here the price index captures remoteness conditional on the distribution of economic activity), amenities compensate for real wage differentials. Due to this, composite amenities that capture both natural amenities and congestion do not necessarily align with the commonplace definition of amenities. While characteristics of a location such as the weather fall under natural amenities, the additional component of composite amenities, spillover effects that are dependent on the level of employment, is a net effect. Thus composite amenities include both the positive and negative attributes that arise from living in a location with a more people, such as positive effects like more diverse housing, dining, and entertainment options and negative effects like housing and traffic congestion. This distinction is illustrated in Figure 3a by

(a) Composite Amenities



(b) Composite Productivities

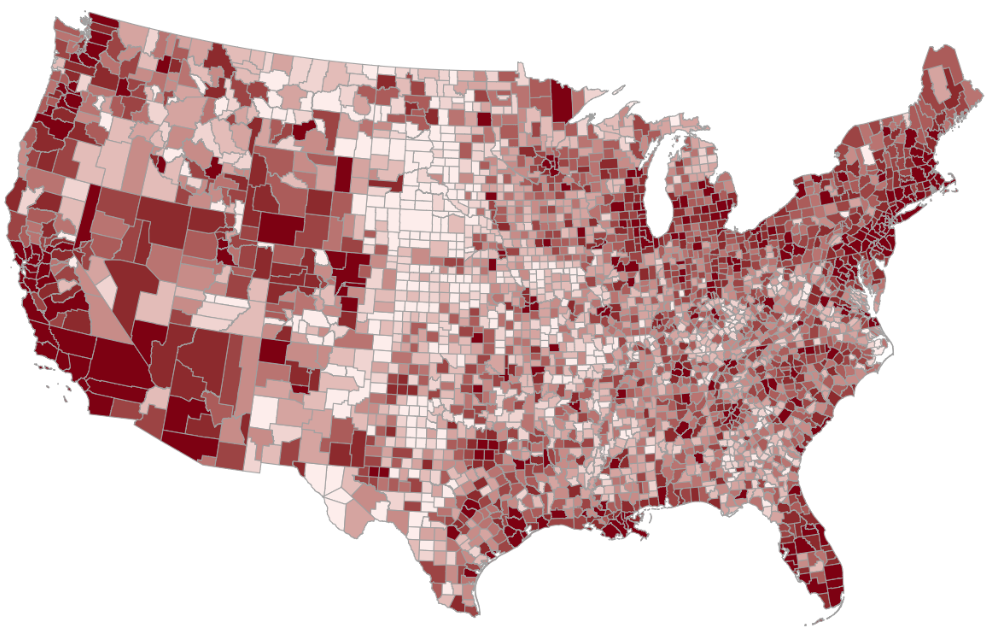


Figure 3: Composite Geographic Variables by County (2007)

*Notes*: Each figure presents counties by decile of the respective variable (with the darkest color representing the highest decile and the lightest color the lowest decile).

the composite amenity values in South Florida. Intuition suggests that natural amenities in South Florida are high and that it should even benefit from many of the positive amenity spillovers associated with greater employment density. Nonetheless, the composite amenities derived from the observed distribution of economic activity for Miami-Dade and Palm Beach counties are in the second lowest decile. On net, the balance between the positive and negative impacts of population density on amenities has an important implication for the uniqueness of the equilibrium distribution of economic activity. If the net effect of congestion is negative and sufficiently large to counteract the positive effects of agglomeration, then the model results in a unique equilibrium (Allen and Arkolakis (2014)).[9] If this is not the case, then there is exists the possibility of multiple equilibria. Thus, estimating the agglomeration and congestion spillover elasticities not only allows for a decomposition of amenities and productivities into their natural and spillover components, but also determines the ability of the quantitative model to sufficiently describe the observed economic equilibrium. As a result, well-identified estimates of the agglomeration and congestion spillover elasticities are critical to understanding the economic channels that form the spatial equilibrium and the extent to which it is efficient.

## 3.4 Estimating Equations

With local composite amenities and productivities for each location, Equations (2) and (3) constitute a set of estimating equations for the congestion and agglomeration elasticities, respectively. In log form the estimating equations can be expressed as

$$log\left(a_i\right) = \mathcal{C}^a + \alpha \log\left(L_i\right) + \epsilon_i^a \tag{19}$$

and

$$log\left(u_i\right) = \mathcal{C}^u + \beta \log\left(L_i\right) + \epsilon_i^u. \tag{20}$$

In Equations (19) and (20), $\mathcal{C}^u$ and $\mathcal{C}^a$ capture the normalization of composite amenities and productivities, and $\epsilon_i^u$ and $\epsilon_i^a$ capture the relative natural amenities and productivities,

[9]Specifically, with $\alpha \in [0, 1]$ and $\beta \in [-1, 0]$, the model has a unique equilibrium if and only if $\alpha + \beta \leq 0$.

respectively. However, ordinary least squares (OLS) estimates of $\alpha$ and $\beta$ using these estimating equations will be biased because the labor supply (see Equation (10)) is itself a function of the natural amenities and productivity of a location, i.e., $\epsilon_i^u$ and $\epsilon_i^a$. In terms of the agglomeration elasticity, with $\alpha \in [0,1]$, $\beta \in [-1,0]$, $\alpha+\beta<0$, and $\sigma>1$, since a higher natural productivity encourages more workers to choose a location, the model suggests that the OLS estimate of $\alpha$ will be biased upwards (further from zero). Equation (21) illustrates the specific connection between a shock to natural productivities and workers' location decisions:

$$\frac{\partial {}^{L_i}/_{\overline{L}}}{\partial \overline{a_i}} \frac{\overline{a_i}}{{}^{L_i}/_{\overline{L}}} = \frac{\sigma - 1}{1-\alpha(\sigma-1)-\beta\sigma} > 0. \tag{21}$$

Similarly, with $\alpha \in [0,1]$, $\beta \in [-1,0]$, $\alpha+\beta<0$, and $\sigma>1$, since workers choose locations with high natural amenities, but additional workers reduce amenities through congestion, the model suggests that the congestion elasticity will also be biased upwards (but here, closer to zero with $\beta<0$). Equation (22) illustrates the specific connection between a shock to natural amenities and workers' location decisions:

$$\frac{\partial {}^{L_i}/_{\overline{L}}}{\partial \overline{u_i}} \frac{\overline{u_i}}{{}^{L_i}/_{\overline{L}}} = \frac{\sigma}{1-\alpha(\sigma-1)-\beta\sigma} > 0. \tag{22}$$

However, since composite amenities and productivities are a function of the distribution of employment and wages there may be additional bias introduced through measurement error. Given the structural and statistical expectation of bias in the OLS estimates, additional sources of variation are necessary to identify the agglomeration and congestion spillover elasticities.

# 4 Identification Strategy

In order to estimate $\alpha$ and $\beta$, I leverage an additional source of variation in local employment density that is independent of location fundamentals. Within the model, a source of this kind of variation is changes in relative government transfers. Specifically, the ideal form would be a government program that creates heterogenous shocks in local transfers that leads to movement across space and is uncorrelated with location fundamentals.

Many real programs meet the first condition of an ideal source of variation: heterogenous shocks to local transfers. Examples include place-based policies such as Empowerment Zones (Busso, Gregory, and Kline 2013), regional transfers in the European Union (Blouri and Ehrlich 2020), and state-level subsidies for firm relocation (Ossa 2015). However, since the purpose of place-based policies is to address economically lagging locations by targeting them for investments and subsidies, the selection into such programs does not meet the second condition of an ideal source of variation, i.e., being uncorrelated with natural amenities and productivity. Given these constraints, one method that has been used is to source variation in local shocks from natural experiments (e.g. Black, McKinnish, and Sanders (2005), Greenstone, Hornbeck, and Moretti (2010), and Ahlfeldt et al. (2015)).

In this paper, I employ a similar strategy to recover unbiased estimates of the agglomeration and congestion elasticities. In the remainder of this section, I present the institutional features of Base Realignment and Closure (BRAC), a government policy to rationalize the domestic organization of the military, and how to incorporate it as a source of variation to aid in the estimation of the strength of spillovers.

## 4.1 BRAC

The current BRAC process was formalized at the end of the Cold War. In 1988, the Secretary of Defense was given authority by Congress to create recommendations to cut spending on excess capacity and decrease the size of the armed forces. This process was formalized in the Base Realignment and Closure Act of 1990 which was utilized to conduct four additional BRAC rounds in 1991, 1993, 1995 and 2005. Under the 1990 act, the BRAC process is initiated by Congress authorizing a new round. The DoD responds by conducting an analysis of their installation capacity, current, and projected military needs. These analyses are translated by the DoD into a list of recommendations according to a predetermined list of criteria where "military value is the primary consideration" that are forwarded to the BRAC commission, an independent body appointed by the President (BRAC Commission 2005). The BRAC commission then reviews the recommendations in light of the predetermined criteria (which are still primarily related to military value, but also require subordinate assessments of savings, environmental, and economic effects). Any recommendations that the commission decides are not aligned with the selection criteria are dropped from the final list of closures and realignments. In the most recent round the commission was also enabled to suggest additional bases for closure or to adjust realignment schedules through a process that involved an additional review by the DoD. The final list is presented to the President by the commission. The BRAC round only moves forward if the President decides to send the proposal to Congress. Finally, Congress has the opportunity to enact a resolution of disapproval that, if passed, stops the proposal. The President then has the normal veto powers with respect to the resolution of disapproval. If it is forwarded to Congress by the President and Congress does not enact a resolution of disapproval within 45 days, then the proposal comes into effect and the DoD is tasked with executing the BRAC round within a five-year implementation window.

This process is designed to remove direct input from Congress on decisions about any specific installation when redistributing defense activity. This resolves the issue that individual members of Congress are compelled by local interests to lobby against any base closures in their district. These features make BRAC an ideal tool for economic analysis as the original recommendation list by the DoD is mandated by law to be based on defense needs and the BRAC commission is compelled to consider the military efficiency gain and cost savings of closing an installation before any local impacts such as economic or environmental concerns. In my analysis, I will utilize the DoD recommendations directly as an instrument for observed changes in local military employment. This differs from the existing literature on BRAC, which most commonly makes the explicit assumption that observed changes in military employment are not correlated with local economic characteristics.

In Table 1, summary statistics for local employment density, annual payroll per capita, amenities, and productivity are presented for all counties, non-military base counties, military base counties, and the subset of military base counties targeted by one or more round of BRAC. In general, military base counties have both higher wages and more employment density. It follows that they also have higher composite productivity and lower composite amenities. Some portion of the higher employment density (which influences each of the other variables) is mechanically driven by the presence of the military installation. However, it is possible that some of the features that make a location suitable for a military installation

Table 1: Summary Statistics by Type of County (1987)

| | All | Non-Mil. | Mil. | BRAC |
|---|---|---|---|---|
| *Annual Pay Per Capita* | | | | |
| Mean | 15463 | 15113 | 18042 | 18438 |
| Min | 9427 | 9427 | 11113 | 11113 |
| Max | 26713 | 26713 | 26713 | 26713 |
| Median | 14912 | 14566 | 17642 | 18305 |
| *Employment Density* | | | | |
| Mean | 87.3 | 54.3 | 330.2 | 412.7 |
| Min | 0.0 | 0.0 | 0.4 | 0.5 |
| Max | 84516.6 | 84516.6 | 10259.0 | 10259.0 |
| Median | 7.8 | 6.3 | 68.4 | 94.2 |
| *Civilian Employment* | | | | |
| Mean | 300 | 0 | 2511 | 3445 |
| Min | 0 | 0 | 0 | 0 |
| Max | 32691 | 0 | 32691 | 32691 |
| Median | 0 | 0 | 660 | 1445 |
| *Amenities* | | | | |
| Mean | 1.35 | 1.37 | 1.16 | 1.13 |
| Min | 0.67 | 0.67 | 0.69 | 0.69 |
| Max | 2.51 | 2.51 | 2.05 | 2.05 |
| Median | 1.32 | 1.35 | 1.13 | 1.10 |
| *Productivity* | | | | |
| Mean | 0.76 | 0.74 | 0.95 | 0.97 |
| Min | 0.19 | 0.35 | 0.19 | 0.19 |
| Max | 2.07 | 1.79 | 2.07 | 2.07 |
| Median | 0.72 | 0.70 | 0.92 | 0.96 |
| *N* | 3061 | 2695 | 366 | 260 |

*Note*: This table reports summary statistics by county in 1987 (pre-BRAC) for annual payroll per capita, employment density, level of civilian employment by the DoD, composite amenities, and composite productivities. The first column presents the values for all counties in the panel. The second and third columns split counties into two groups: those with a military installation and those without. Finally, the fourth column presents the subset of counties that were subsequently targeted by at least one BRAC proposal.

(such as a natural harbor for ships) are correlated with locations that have more concentrated economic activity. As a result, non-military base counties are likely not an effective comparison group for military base counties. On the other hand, military base counties targeted by BRAC proposals are similar to military base counties not targeted by BRAC proposals, especially in terms of the two most critical variables: local composite amenities and productivities.[10]

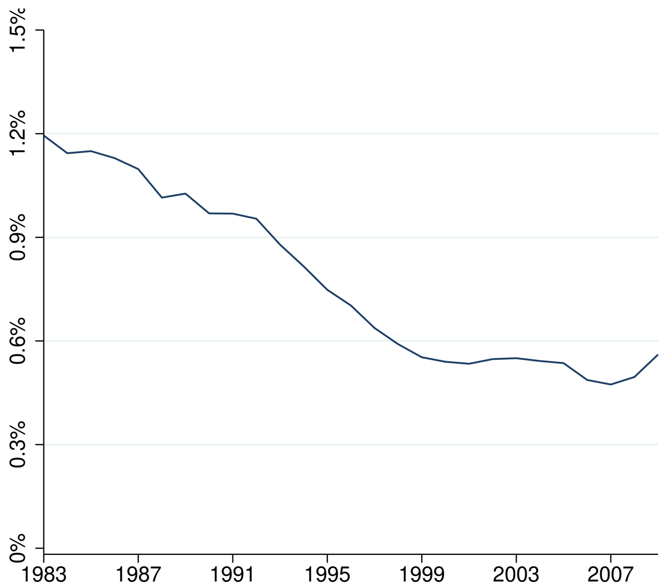



Figure 4: DoD Share of Civilian Employment

In total, the five rounds of BRAC have significantly reduced defense employment, which has fallen from 1.2% of the civilian workforce in 1988 to a low of 0.47% of the civilian workforce in 2007 (see Figure 4). This national drawdown in civilian employment by the DoD was not achieved by across the board reductions of similar magnitudes. Not only do the baseline shares of civilian employment by the DoD vary greatly across space, but the changes due to base closures and realignments were heterogenous shocks. In Figure 5, the difference between the national trend and local trends is illustrated for a set of counties with different military employment trajectories over the sample period. It is specifically this heterogeneity that makes local defense employment a suitable source of variation even when aggregate military activity in the U.S. is not a useful source of variation (Hall 2009). Nakamura and Steinsson (2014) make use of the differential impact of changes in the national trend of defense spending to instrument for state-level defense spending to estimate fiscal multipliers. Unlike military procurement contracts, the institutional features of the BRAC process allows for a more direct approach when using defense employment instead of spending.

[10]In addition, in the pre-BRAC period captured in the data (1983-1987), trends in local civilian employment by the DoD are similar for counties with military installations that were subsequently included in BRAC rounds and those that were not.

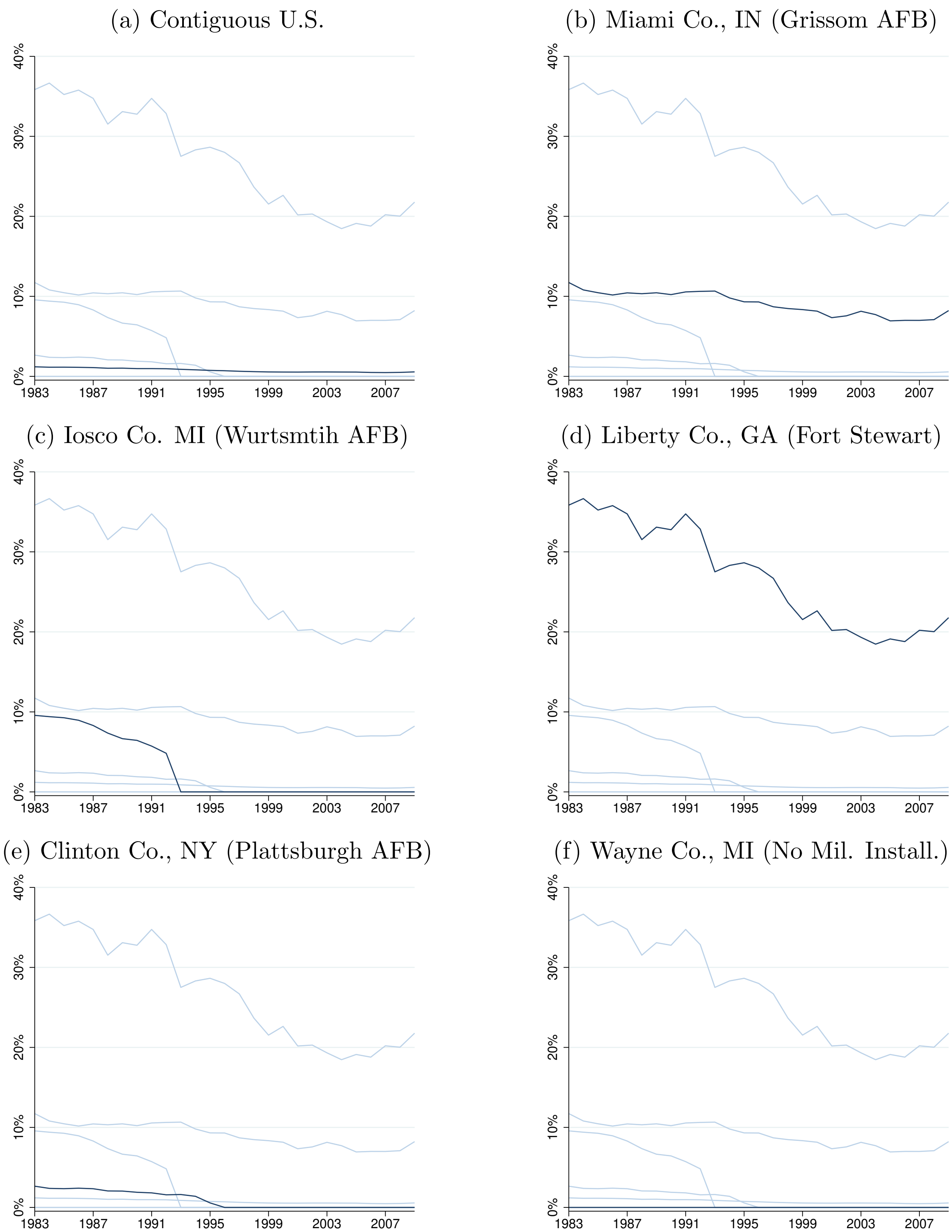



Figure 5: DoD Share of Civilian Employment by County

## 4.2 Changes versus proposals

As discussed in Section 4.1, the BRAC process is designed to limit political interference to ensure that changes to the distribution of military capacity is focused on defense objectives. However, the process features a non-military intermediary, the BRAC commission, that assesses the DoD's recommendations and has the ability to change them. Overall, the proposed changes and the implemented changes are highly correlated (as shown in Figure 6). However, there have been changes proposed that would greatly affect individual locations that were not implemented based on the BRAC commission's review.

Differences between the DoD recommendations and the observed changes in local military employment that reflect interference by the BRAC Commission suggest that the initial proposals are more suitable for use as an instrumental variable (IV) than the actual changes that were implemented. However, most previous studies on the impact of local military employment do not account for this potential correlation between implemented changes and local economic characteristics (Krizan et al. 1998; Poppert and Herzog Jr 2003; Hultquist and Petras 2012). In contrast, Zou (2018) uses a shift-share design that is constructed with initial shares of defense employment in 1988 and observed changes in total defense employment between 1988 and 2000 as well as synthetic controls. This primary identification strategy is a direct parallel of Nakamura and Steinsson (2014) in that it assumes that the national trend in defense employment is determined based on military objectives that are uncorrelated with local economic characteristics. The drawback of this approach is that it does not make full use of the amount of policy-induced variation available. In the following analysis, instead of using the national trend as a source of military-objective based variation, I use the proposed changes directly from the DoD to instrument for observed changes in local civilian employment at military installations.

## 4.3 Proposed base employment

Translating the proposed changes to employment at military installations into an IV that can be used to estimate the agglomeration and congestion spillover elasticities with Equations (19) and (20) requires relating the proposed employment shocks to the employment density.

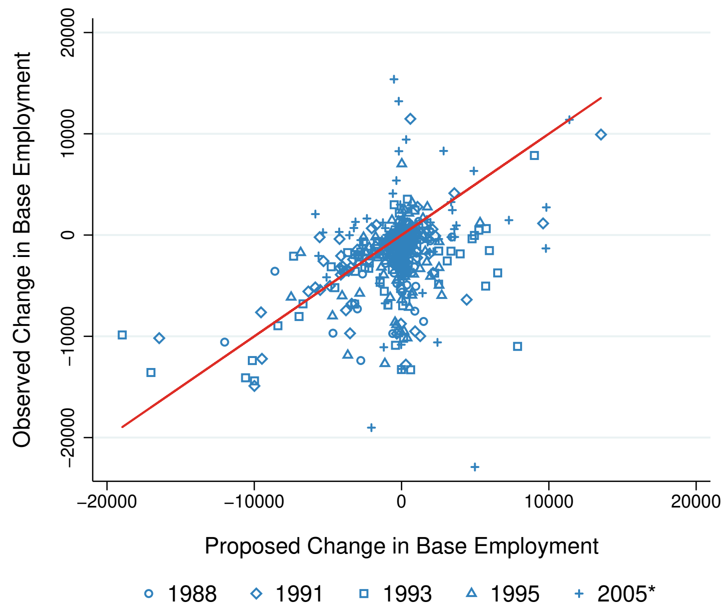



Figure 6: Proposed vs. Observed Changes in Base Employment

*Note*: This figure presents the relationship between proposed changes in base employment compared with the actual changes that were observed in the military census of employment by the round of BRAC. The sample period (1983-2009) only allows for observation of four of the five year implementation window for the 2005 round of BRAC.

As noted in Section 4.1, the implementation window for a proposed change is five years. I construct an instrument, proposed base employment, by combining a lagged value of civilian base employment with proposed changes. Both features of the IV design are supported by the fact that the only mechanism available to the DoD for making significant changes to employment at a military installation is through the BRAC process. For bases with no proposed changes, the assumption is that the current employment levels will be maintained.[11] For installations with a proposed change, the new proposed level of employment is assumed to be the goal of the DoD for the subsequent five-years, unless an additional BRAC proposal is made during the implementation window of the original proposal, in which case the second proposal is assumed to supersede the original. Four examples that each capture a distinct possibility for how proposed base employment relates to actual base employment are presented in Figure 7.

[11]This institutional feature aligns with the assumptions for the best-case use scenario of a lagged variable instrument as outlined in Wang and Bellemare (2019).

In each figure, actual civilian base employment and implied civilian base employment are plotted against one another and gray shading reflects implementation windows if a base was recommended for a change in employment by the DoD. In the first panel, an example of a military installation that was not impacted by BRAC is presented. In the five rounds of BRAC, the DoD never proposed changes in civilian employment at Fort Stewart in Liberty County, GA and it was similarly never slated for changes in the final decisions of the BRAC commission. The second panel presents an example of a straightforward BRAC implementation. In the first round of BRAC in 1988, the DoD recommended that Wurtsmith Air Force Base be closed. This proposal was unaltered by the BRAC commission and was implemented in the following years. In both cases, implied civilian base employment is highly correlated with the potentially endogenous observed civilian base employment. The third panel contains an example of a DoD proposal that was never implemented. In 1991, the DoD recommend that Grissom Air Force Base be closed and all civilian employment at the installation to cease but this was reversed by the BRAC commission and civilian employment at the installation was maintained. Finally, the fourth panel illustrates an example of a DoD proposal that was not only reversed, but completely changed by the BRAC commission. In 1993, the DoD recommendations included a large increase in civilian employment at Plattsburgh Air Force Base in Clinton County, NY. However, the BRAC commission slated the installation for closure and this was ultimately implemented. In both cases, implied civilian base employment is independent of the changes to the implementation of the DoD's recommendations directed by the BRAC commission.

When combined, the structure of the model and the institutional features of the BRAC process support the claim that proposed base employment is both relevant and meets the exclusion restriction as an instrument for local defense employment. In terms of the exclusion restriction, both the model and the BRAC process suggest that the only influence of proposed changes to base employment on local productivity and amenities is through the changes that are actually implemented. Further, two features of the BRAC process support the independence of proposed base employment and local economic characteristics. First, the DoD is only capable of making significant changes to the distribution of defense employment through the BRAC process, which implies that in the absence of a proposed change, lagged base employment is a measure for future base employment that is not correlated with local economic characteristics. Second, because the process itself simultaneously insulates the DoD from local political lobbying and calls on the DoD to make its proposals based on military objectives, the proposed changes reflect decisions based on large-scale military objectives rather than on local economic characteristics.[12]

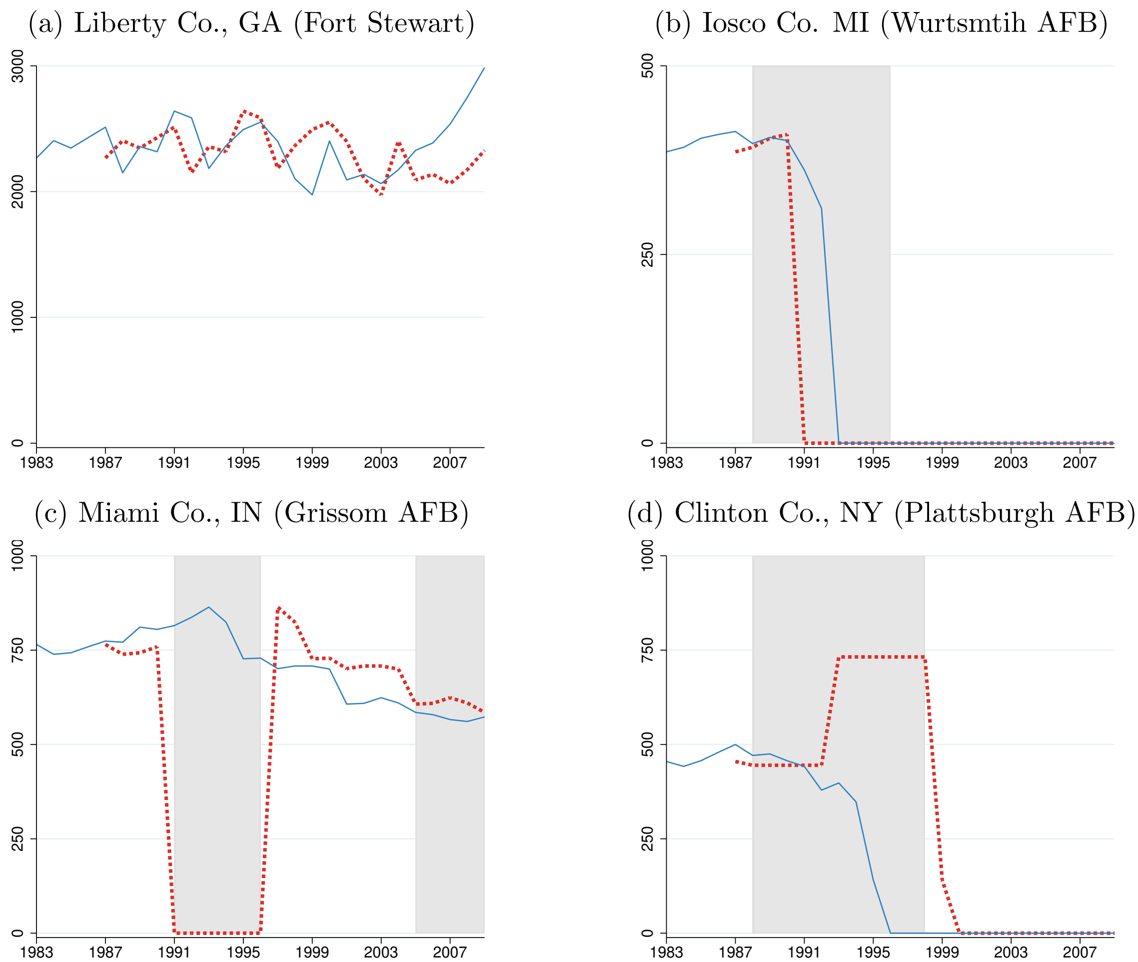



Figure 7: Proposed Base Employment Instrument and Observed Base Employment

*Note*: Each plot presents the actual civilian employment (solid blue line) and the constructed BRAC-implied employment IV (dashed red line) over the panel period within a county. The four specific counties were chosen to illustrate the possible relationships between BRAC proposals and actual implementation: (a) no proposal and no implementation, (b) a BRAC proposal and straightforward followthrough, (c) a proposal but no action taken, and (d) no proposal for closure but a closure action. The gray shading in each figure represents the implementation window for the associated BRAC proposal.

[12]For example, the dissolution of the Soviet Union meant that the U.S. required less air defense in the northern reaches of the country. This resulted in DoD recommendations to close many Air Force bases in northern states.

# 5 Results

This section is divided into two subsections. The first reports estimates of the agglomeration elasticity, $\alpha$, and the congestion elasticity, $\beta$. Separate results are reported for estimation by OLS and using the proposed base employment instrument. The second subsection presents the resulting location fundamentals when the estimates of $\alpha$ and $\beta$ from the preferred specification and the measures of local composite productivities, $a_i$, and amenities, $u_i$, are combined as in Equations (2) and (3).

## 5.1 Spillover elasticities

In Table 2, the estimates of $\alpha$ and $\beta$ and their standard errors using the estimating Equations (19) and (20) are reported. In each specification, state-by-year fixed effects are included. In particular, the year portion of the state-by-year fixed effects controls for any differences in the normalization of the productivities and amenities between years. In addition, due to the panel structure of the data, reported standard errors are clustered by county. The IV estimates are the preferred specification, with an estimate of $\alpha$ equal to 0.0570 and an estimate of $\beta$ equal to -0.0781. These estimates imply that a doubling of the employment density in a county will increase local productivity by 5.7% and decrease local amenities by 7.8%. Comparing these estimates to those in the existing literature reveals differences. In particular, the IV estimate of $\beta$ is smaller than the values generally used to parameterize economic geography models. Allen and Arkolakis (2014) use a $\beta$ of -0.3 based on a mapping of average consumer expenditure on housing into the model and Fajgelbaum and Gaubert (2020) invert labor demand elasticity estimates from Diamond (2016) to recover a $\beta$ of -0.19 for their most comparable specification. The estimate of $\alpha$ is in the middle of the range found by Rosenthal and Strange (2004) in their survey of the agglomeration economics literature. Further, it is very similar to the estimate from Ciccone and Hall (1996) that is used in Fajgelbaum and Gaubert (2020) ($\alpha = 0.06$). However, the value is lower than the parameterization in Allen and Arkolakis (2014).

Table 2: Agglomeration and Congestion Spillovers

| | OLS | | IV | |
|---|---|---|---|---|
| | Log(Productivity) | Log(Amenity) | Log(Productivity) | Log(Amenity) |
| Log(Total Employment Density) | 0.1456*** | -0.0996*** | 0.0570** | -0.0781*** |
| | (0.006) | (0.005) | (0.020) | (0.009) |
| (Year)x(State) Fixed Effects | Yes | Yes | Yes | Yes |
| N | 8418 | 8418 | 7333 | 7333 |
| Kleibergen-Paap rk Wald F-stat | | | 94.224 | 94.224 |

*Note*: This table reports the estimated values of $\alpha$ and $\beta$ from regressions of composite productivities and amenities on total employment density, respectively. The log-log form of the estimating equations is from Equations (19) and (20). The first two columns present the results of OLS estimation and the last two columns present the results of IV estimation using implied base employment density as an instrument for total employment density. Standard errors are in parentheses and clustered at the county-level ( $^{*}$ $p < 0.05$, $^{**}$ $p < 0.01$, $^{***}$ $p < 0.001$).

In terms of the model, the IV estimates of $\alpha$ and $\beta$ align with the conditions for a unique equilibrium to exist ($\alpha \in [0, 1]$, $\beta \in [-1, 0]$, $\alpha + \beta < 0$). One difference between the estimate of $\alpha$ and the existing literature on agglomeration economies is that the results are based on a structural measure of productivity. The range for $\alpha$ from Rosenthal and Strange (2004), 0.03-0.08, is based on estimation that takes wages to be a proxy for productivity. In Table 3, the same specification is applied, but with local productivity replaced with local wages. In this specification, which maps the same data set used in the primary estimation to a specification comparable with the existing literature, the agglomeration elasticity is on the higher end of the range of existing estimates. Specifically, the IV estimate of $\alpha$ is 0.0708, which implies that a doubling of the employment density in a location increases the productivity in that location by 7.1%. The difference between this result and the structural estimate suggests that the use of estimates of agglomeration spillover elasticities specified in terms of wage effects may overstate agglomeration spillovers in economic geography models. One noteworthy feature of the wage-based estimation is that the relative difference between the OLS and IV results is reduced compared to the structural estimates. This implies that the finding from the wage-based literature that OLS and IV estimates of $\alpha$ are mostly the same does not hold when using structural measures of productivity (Melo, Graham, and Noland 2009).

Table 3: Wage-based Agglomeration Spillovers

| | OLS | IV |
|---|---|---|
| | Log(Payroll Per Capita) | Log(Payroll Per Capita) |
| Log(Total Employment Density) | 0.0918*** | 0.0708*** |
| | (0.004) | (0.009) |
| (Year)x(State) Fixed Effects. | Yes | Yes |
| N | 8418 | 7333 |
| Kleibergen-Paap rk Wald F-stat | | 94.224 |

*Note*: This table reports the estimated values of the reduced-form agglomeration spillover elasticity from regressions of payroll per capita on total employment density. The log-log form from Equations (19) and (20) has been altered by making the log of payroll per capita the dependent variable. The first column presents the results of OLS estimation and the second column presents the results of IV estimation using implied base employment density as an instrument for total employment density. Standard errors are in parentheses and clustered at the county-level ( $^{*}$ $p < 0.05$, $^{**}$ $p < 0.01$, $^{***}$ $p < 0.001$).

With respect to the difference between the OLS and IV structural estimates in Table 2, the magnitude of both $\alpha$ and $\beta$ are reduced with the addition of the proposed base employment instrument. For $\alpha$, this aligns with the bias that is implied by the model. Specifically, since workers will choose locations with high natural productivities, the effect of employment density on composite productivity is biased upwards. The IV estimate is not biased in the same way because the proposed base employment instrument captures shocks to local employment that were independent of workers' location decisions. Further, the shocks were determined based on changing military objectives in a process that is insulated from political interference so they are not likely to be correlated with the changing economic characteristics of locations. A Kleibergen-Paap rk Wald F-stat equal to 94 alleviates concerns of potential weak instrument bias and suggests a strong first-stage relationship. The benefits of these estimates is that the are estimated with the same structural assumptions as in Allen and Arkolakis (2014) which is nested in Fajgelbaum and Gaubert (2020). While these parameters do not capture all the mechanisms in the generalized version of the model in

Fajgelbaum and Gaubert (2020), such as multiple worker skill types, they can be used in combination with data on each additional mechanism in order to decompose $\alpha$ and $\beta$ into more specific components. An additional aspect of the estimation is that the set of included counties is limited to those with a military installation. As noted in Section 4.1, military base counties impacted by BRAC and those not impacted by BRAC have similar local composite amenities and productivities. Building on Allen and Arkolakis (2014), the model has a single agglomeration and congestion spillover elasticity. However, this can be relaxed, which raises a question of external validity. The finding from Kline and Moretti (2014) that the agglomeration elasticity does not vary with the amount economic activity in a location supports that these estimates of $\alpha$ and $\beta$ hold across space.

In Appendix A, several robustness exercises are presented. First, in Appendix A.1, estimation of $\alpha$ and $\beta$ with alternative specifications of the CES parameter are reported. Specifically, results are included for two alternative parameterizations: $\sigma = 4$, as in Farrokhi and Jinkins (2019), and $\sigma = 9$, as in Allen and Arkolakis (2014). The estimated parameter values are similar to the baseline results reported in Table 2, which use composite productivity and amenities values recovered with $\sigma = 5$, which aligns with both Head and Mayer (2014) and Fajgelbaum and Gaubert (2020). In particular, the magnitude of both the agglomeration and congestion spillover elasticities is slightly larger with $\sigma = 4$ and slightly smaller with $\sigma = 9$. Second, in Appendix A.2, estimates of $\alpha$ and $\beta$ using an alternative specification that replaces the baseline IV with a shift-share IV that is more directly comparable with Nakamura and Steinsson (2014) and Zou (2018) are reported. One potential drawback to using a shift-share IV is that it makes less use of the available heterogeneity in the data. However, the resulting estimates of the parameter values are similar to the baseline results that use the proposed base employment IV. To be specific, estimates of both the agglomeration and congestion spillover elasticities are slightly larger in magnitude when using the shift-share IV. Finally, in Appendix A.3, estimates of $\alpha$ and $\beta$ from two alternative specifications that use transformations of variables to address the missing observations that arise due to the log-log form of the structural estimating equations are reported. Both transformations can introduce bias in the estimates, but overall the results are similar to the baseline specification. In particular, the congestion spillover elasticity is unchanged and the magnitude of the agglomeration spillover elasticity increases slightly with the introduction each transformation.

### 5.2 Natural geography

In Figure 8, the natural amenities and productivities for the U.S. in 2007 that are recovered through the inversion of Equations (2) and (3) with the estimates of $\alpha$ and $\beta$ from the previous section are presented.

Location fundamentals show that the regions that are most densely populated (the Northeast Corridor, Great Lakes, Southern California, etc.) are precisely the regions with the highest natural amenities and productivities. This aligns with the determinants of the labor supply as expressed in Equation (10). On the other hand, areas with limited populations, such as in the Great Plains are characterized by having both low amenities and productivities. Exceptions include regions like the counties surrounding the Bakken Formation in western North Dakota, which are home to high wages due to oil extraction. The opposite effect is apparent along the southern border of Texas, where the population is high and wages are low, which is characterized by modest natural productivity but some counties with very high natural amenities.

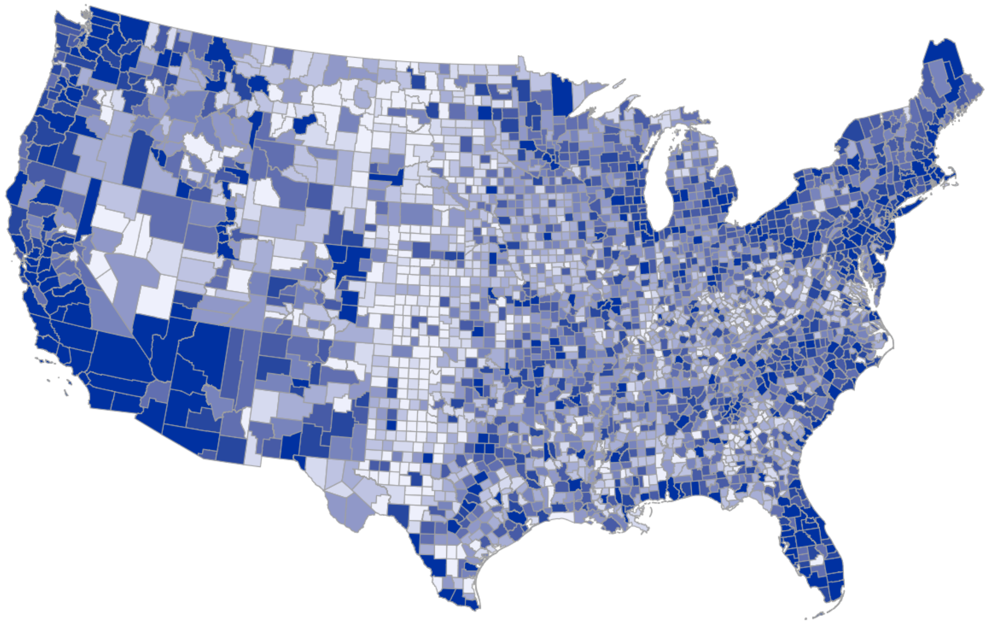
With the natural amenities and productivities, the competitive equilibrium can be recovered through an iterative procedure that parallels the model inversion procedure using Equation (10). In the quantitative implementation, the competitive equilibrium is equivalent to reducing government employment at military installations to zero and allowing workers to adjust location accordingly.

## 6 Optimal Spatial Policy

In this section, the estimates of $\alpha$ and $\beta$ from the preferred specification are applied to find the competitive equilibrium and the distribution of economic activity under the optimal spatial policy to illustrate the impact of the lower estimate of $\beta$.

Equation (13) describes the unique optimal spatial policy that the social planner would implement to maximize the welfare of workers. In the case that $\alpha + \beta < 0$, which applies

(a) Natural Amenities



(b) Natural Productivities

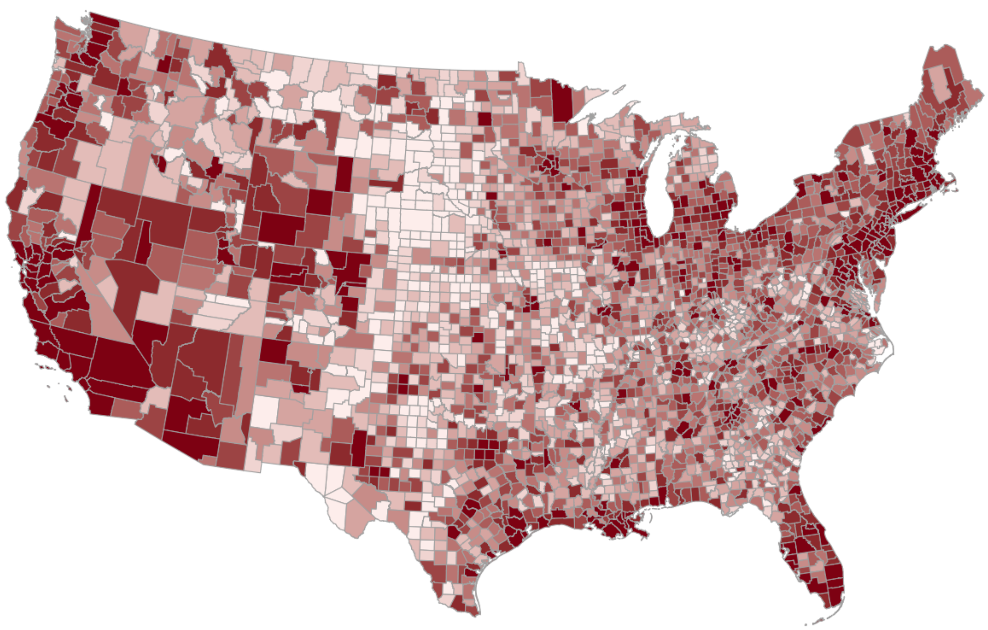


Figure 8: Natural Geographic Variables by County (2007)

*Note*: Each figure presents counties by decile of the respective variable (with the darkest color representing the highest decile and the lightest color the lowest decile).

with $\alpha = 0.0570$ and $\beta = -0.0781$, the optimal spatial policy takes the form an income tax with a lump sum transfer. This redistribution of income from high-wage areas to low-wage areas accounts for the net effect of the productivity and amenity externalities that arise from workers' location decisions. Specifically, the estimates of $\alpha$ and $\beta$ from the previous section imply an optimal income tax rate of 1.95%. The optimal tax rate is primarily a function of two attributes of $\alpha$ and $\beta$, the absolute difference between the two parameters and the magnitude of $\beta$. The difference is important because the productivity externality offsets the congestion externality in part. The greater the difference, the less this is the case. Further, the magnitude of $\beta$ captures the overall presence of spillovers in the economy. Since the estimated $\alpha$ and $\beta$ are close in value, most of the congestion externality is offset by the production externality. Further, because the magnitude of $\beta$ is modest, the overall scale of spillovers in the economy is not large. Combined, a modest income tax is capable of offsetting the externalities and bringing the distribution of economic activity to its optimum. This also implies that the welfare gains between the social planner's equilibrium and the competitive equilibrium will be relatively modest.

In order to explore the quantitative implications of the estimates of $\alpha$ and $\beta$, I solve for both the distribution of economic activity under the competitive equilibrium and the social planner's solution. Given that the quantitative implementation takes the allocation of defense employment as given, the observed equilibrium does not represent the competitive equilibrium. It follows that the competitive equilibrium can be solved for by conducting a counterfactual that removes the transfers that support the observed allocative equilibrium with military employment. The specific solution method involves taking the natural productivities and amenities for each location and solving the equilibrium conditions directly with an iterative procedure. Figure 9 presents the ratio local employment under the competitive equilibrium and the allocative equilibrium. The primary result of removing the implied spatial policy that supports the observed distribution of defense employment is that locations with a large share of local civilian employment by the DoD see large declines in employment. In particular, rural locations that lose the presence of large military installations see relatively large declines in local employment (e.g., Minot Air Force Base in North Dakota and Mountain Home Air Force Base in Idaho). There are also secondary effects of small gains

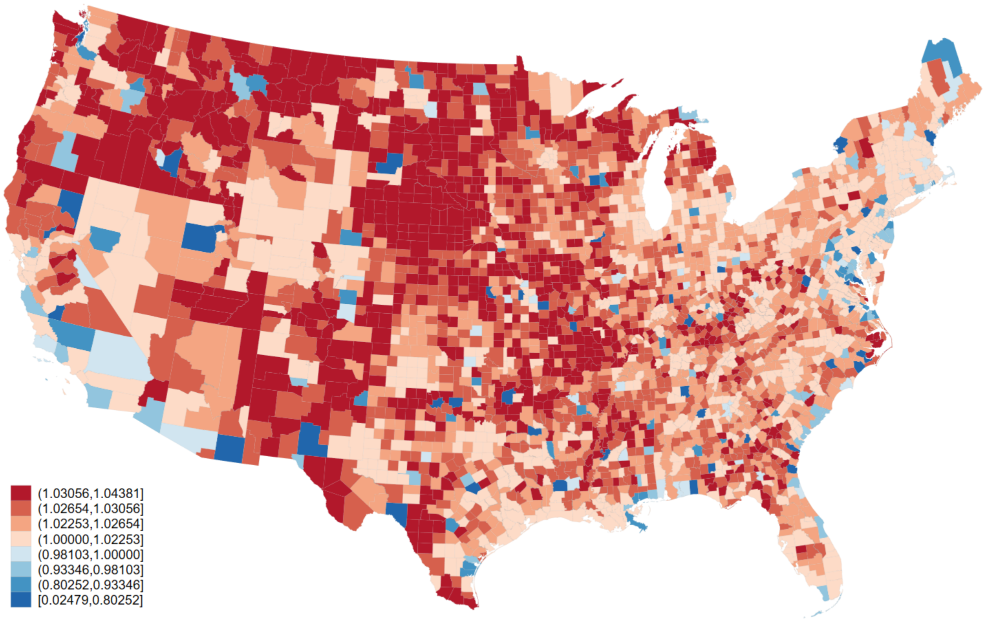



Figure 9: Ratio of Local Employment (Alloc. Eq. to Comp. Eq.)

*Notes*: This figure presents the ratio of local employment under the competitive equilibrium and the allocative equilibrium. In particular, counties shaded red have a ratio above one (more employment under the competitive equilibrium than under the allocative equilibrium). Darker shading indicates a greater gain. The opposite is true for counties shaded blue.

and loses in neighboring counties and a general reallocation of the civilian DoD workforce across space. Within the county that is no longer supported by the policy, the shock to labor demand reduces employment and subsequently productivity and wages. This effect is mitigated by a decrease in local congestion.

The solution to the social planner's problem, i.e., the optimal spatial policy, is then the set of transfers that maximizes workers' welfare. While the competitive equilibrium is recovered through an iterative procedure similar to the method outlined in Section 3.1, the social planner's solution is found through constrained optimization. In Figure 10, local net transfers (the combination of the income tax on earnings and the lump sum subsidy) are plotted for each county as a function of the local per capita labor income. This illustrates how the income tax of 1.95% and the lump-sum subsidy combine to create redistribution from high-wage locations to low-wage locations. For low-wage locations, the positive net transfer has a maximum of approximately 2.5% of local per capita labor income. In terms of the negative net transfer for high-wage locations, the optimal spatial policy has a minimum

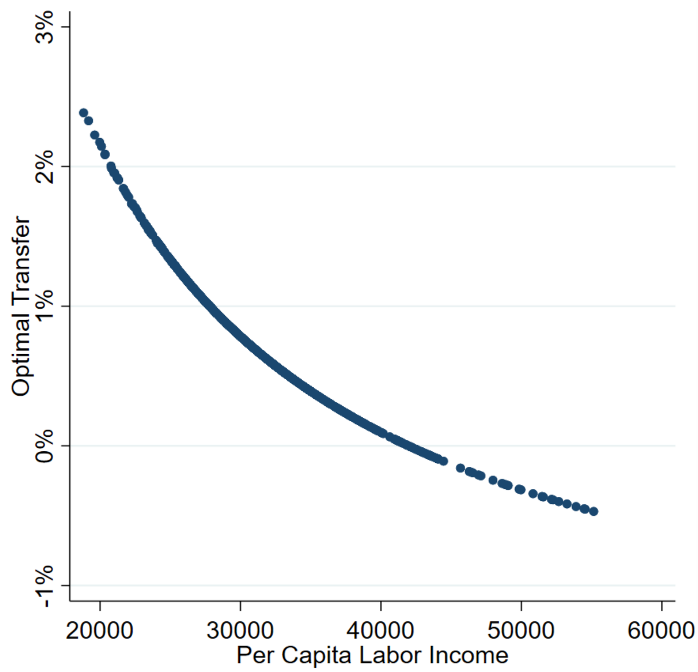



Figure 10: Net Transfers with the Optimal Spatial Policy

*Notes*: This figure plots the relationship between the optimal transfers (as a percent of labor income) and the optimal wages in the equilibrium where the optimal spatial policy is implemented.

of approximately -0.5% of local per capita labor income. Figure 11 maps the same net transfers by county.

In terms of employment, Figure 12 maps the ratio of local employment under the optimal spatial policy and under the competitive equilibrium. The implementation of the optimal spatial policy creates a general movement of workers away from densely populated locations (e.g., the Northeast Corridor, Bay Area, and Southern California) and towards less dense locations (suburban, exurban, and rural counties). The six counties with the largest decline in employment under the optimal spatial policy are all located in the Bay Area (with the largest decline of 3.29% observed in San Mateo County). In terms of increases in employment, about 50 rural counties that are mostly located in the Great Plains see an employment increase of over 10% under the optimal spatial policy.

Comparing Figure 11 and 12, illustrates the importance of the economic connections between counties in the model. While the suburban and exurban counties surrounding many major urban centers receive positive net transfers under the optimal spatial policy, in some

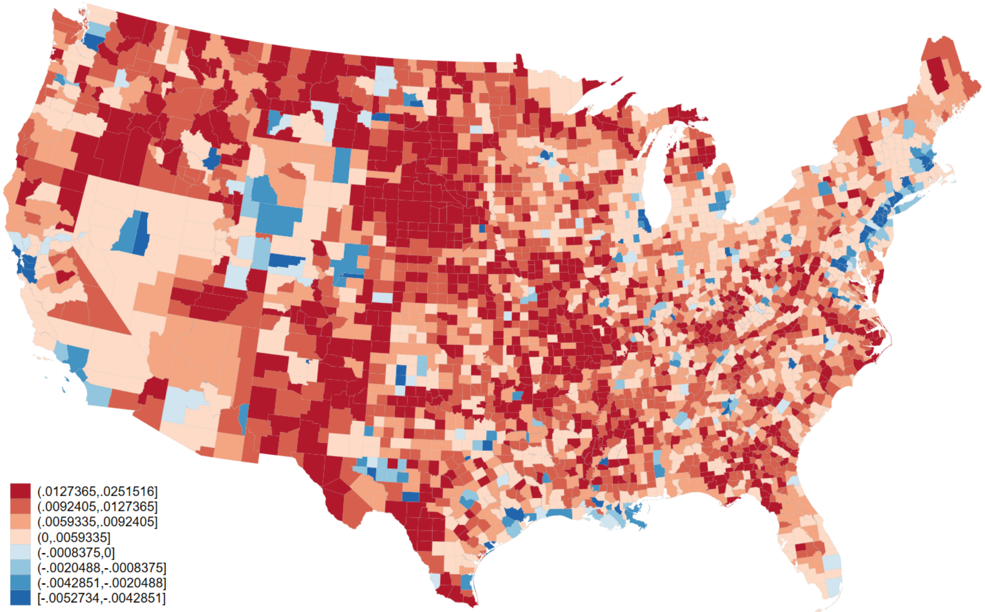



Figure 11: Net Transfers with the Optimal Spatial Policy

*Notes*: This figure presents the net transfer (as a percent of local income) under the optimal spatial policy by county. In particular, counties shaded red receive a positive net transfer under the optimal spatial policy. Darker shading indicates a greater gain. The opposite is true for counties shaded blue.

regions these same counties do not see increases in employment. In both the Bay Area and Southern California there are many examples of this phenomenon. Despite the positive net transfers for workers that choose to locate in these counties, the negative consumption effects due to the decreasing economic activity in large and well-connected neighboring counties (that receive negative net transfers) outweighs the direct positive net transfers in the county and results in an overall decline in employment.

Changes to welfare from implementing the optimal spatial policy can similarly be decomposed into two parts: returning to the competitive equilibrium and implementing the optimal policy from the competitive equilibrium. In total, under the estimates of $\alpha$ and $\beta$ from Section 5, the welfare gain from implementing the optimal spatial policy instead of the observed allocation is 0.0524%. The majority of this effect is due to the gains from unwinding the defense equilibrium and not from the implementation of the optimal spatial policy.[13]

[13]The welfare effect of moving from the observed to competitive equilibrium assumes that there is no value to the defense produced from domestic civilian employment by the DoD and thus solely reflects the allocative impact. However, this counterfactual is relevant as it provides an economic cost of defense spending that

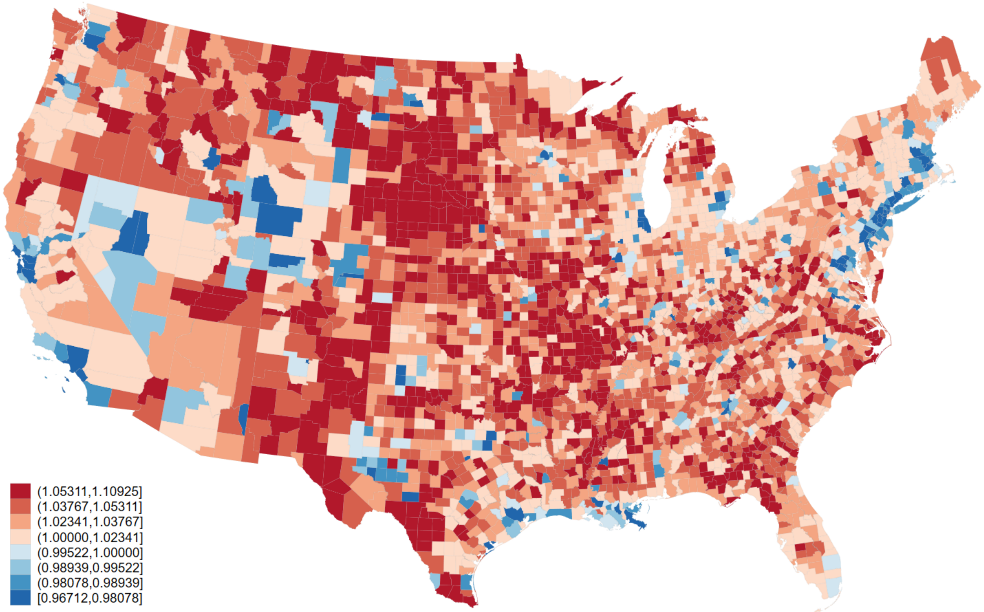



Figure 12: Ratio of Local Employment (Comp. Eq. to Social Planner's Eq.)

*Notes*: This figure presents the ratio of local employment under the social planner's equilibrium and the competitive equilibrium . In particular, counties shaded red have a ratio above one (more employment under the social planner's equilibrium than under the competitive equilibrium). Darker shading indicates a greater gain. The opposite is true for counties shaded blue.

However, as noted in Section 5, the estimated congestion spillover elasticity is smaller than is commonly used in the literature. Keeping $\alpha$ constant and increasing $\beta$ will increase the optimal income tax level, resulting in more transfers between high-wage and low-wage regions. In addition, it will increase the gain from implementing the optimal spatial policy. In Table 4, the change in welfare that occurs when moving from the observed equilibrium to the competitive equilibrium, from the competitive equilibrium to the equilibrium under the optimal spatial policy, and the combined impact are presented for three different values of $\beta$: -0.078, -0.190, and -0.300.

Two distinct changes occur as the magnitude of $\beta$ increases. First, the expected increase in the welfare gain to implementing the optimal spatial policy is observed. The total gain in welfare due to implementing the optimal spatial policy is nearly five times larger with $\beta = -0.300$ compared to the gain when $\beta = -0.078$. Second, the allocative cost of the implied spatial policy due to the distribution of civilian defense employment decreases as $\beta$

can be compared to an estimate of the defense value by policy makers.

increases. Since this represents the net effect of removing the transfers necessary to maintain employment at military installations, the value of the transfers to low-wage areas compared to the transfers in high-wage areas must be higher with a stronger congestion externality.

Overall, these results show that the specific value of the congestion elasticity is significant in determining the potential gains from implementing the optimal spatial policy and the costs of implementing a non-optimal spatial policy. A lower congestion spillover elasticity suggests that the benefits of redistribution from high-wage locations to low-wage locations may not be as large as previous estimates would suggest. While the welfare effects are generally small in this specification of the model, the scale of welfare gains increases as additional frictions are included. For example, in Fajgelbaum and Gaubert (2020) the addition of frictions such as a housing market and two worker skill groups bring the scale of welfare gains within the range of 2% to 6%. However, the same basic relationship between the magnitude of $\beta$ and the welfare gains of different spatial policies applies under those conditions as well, which suggests that the range would lower under a parameterization based on a $\beta$ of -0.0781.

Table 4: Welfare Changes by Parameterization

| | Obs. to Comp. Eq. | Comp. Eq. to Opt. | Combined |
|---|---|---|---|
| $\beta = -0.078$ | 0.0472% | 0.0052% | 0.0524% |
| $\beta = -0.190$ | 0.0306% | 0.1286% | 0.1592% |
| $\beta = -0.300$ | 0.0203% | 0.2996% | 0.2517% |

*Notes*: This table presents the welfare gains from moving to the competitive equilibrium from the observed equilibrium, to the optimal allocation from the competitive equilibrium, and the combined gain under different parameterizations of $\beta$.

# 7 Conclusion

In this paper, I use data on proposed changes to civilian employment at military installations to estimate the the strength of agglomeration and congestion spillovers. These parameters are central to determining the relative importance of natural advantages and employment density externalities for the distribution of economic activity. However, the structure of the model that is used to recover the productivities and amenities for each location used to estimate the agglomeration and congestion spillovers suggests that OLS estimates using observed changes in employment as a source of variation will be biased. For this reason, I make use of changes in civilian employment by the DoD and, in particular, the institutional features of the BRAC process, to instrument for local employment and separately identify the agglomeration and congestion spillovers.

I estimate that the agglomeration spillover elasticity, $\alpha$, is equal to 0.057 and estimate that the congestion spillover elasticity, $\beta$, is equal to -0.078. These estimates imply that a doubling of the employment density in a county will increase local productivity by 5.7% and decrease local amenities by 7.8%. Compared to the existing literature, the magnitude of the agglomeration spillover elasticity falls within the range of previous estimates. However, the magnitude of the congestion spillover elasticity is smaller than values used in previous parameterizations of quantitative economic geography models. The implication of a smaller congestion spillover elasticity is that less of the variation in amenities across space is due to differences in employment density. I solve for the equilibrium distribution of economic activity under the optimal spatial policy to illustrate the primary implications of the smaller congestion spillover elasticity. First, the allocative cost of the observed equilibrium of civilian defense employment is higher with a $\beta$ that is smaller in magnitude. Second, the gains from implementing the optimal spatial policy decrease as the magnitude of $\beta$ decreases. Combined, these results suggest that the costs of implementing suboptimal spatial policy are higher and the gains from implementing optimal spatial policy are lower than would be implied under previous parameterizations in the literature.

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# A Robustness

## A.1 Constant elasticity of substitution

As noted in Section 3.2, the CES parameter, $\sigma$, is equal to 5 in the quantitive implementation. However, since the recovered amenities, productivities, and trade costs are a function of $\sigma$, it is important to test the robustness of the estimates of the spillover elasticities to different specifications. While $\sigma = 5$ is consistent with both Head and Mayer (2014) and Fajgelbaum and Gaubert (2020), it is not a universal parameterization. Allen and Arkolakis (2014) calibrate their model with $\sigma = 9$ and Farrokhi and Jinkins (2019) calibrate their model with $\sigma = 4$. In Table 5, the main regression specifications are replicated with the only difference being that the value of $\sigma$ is set to 9 in the calibration of trade costs as well as the inversion of the model.

Table 5: Agglomeration and Congestion Spillovers ($\sigma = 9$)

| | OLS | | IV | |
|---|---|---|---|---|
| | Log(Productivity) | Log(Amenity) | Log(Productivity) | Log(Amenity) |
| Log(Tot. Emp. Den.) | 0.1247*** | -0.0960*** | 0.0452* | -0.0747*** |
| | (0.006) | (0.005) | (0.018) | (0.009) |
| (Year)x(State) F.E. | Yes | Yes | Yes | Yes |
| N | 8418 | 8418 | 7333 | 7333 |
| Kleibergen-Paap rk Wald F-stat | | | 94.224 | 94.224 |

*Note*: This table reports the estimated values of $\alpha$ and $\beta$ from regressions of composite productivities and amenities on total employment density, respectively. The log-log form of the estimating equations is from Equations (19) and (20). The first two columns present the results of OLS estimation and the last two columns present the results of IV estimation using implied base employment density as an instrument for total employment density. Standard errors are in parentheses and clustered at the county-level ( $^{*}$ $p < 0.05$, $^{**}$ $p < 0.01$, $^{***}$ $p < 0.001$).

Similarly, in Table 6, the main regression specifications are replicated with $\sigma$ set equal to 4 for the estimation of trade costs as well as the recovery of composite amenities and productivities.

Table 6: Agglomeration and Congestion Spillovers ($\sigma = 4$)

| | OLS | | IV | |
|---|---|---|---|---|
| | Log(Productivity) | Log(Amenity) | Log(Productivity) | Log(Amenity) |
| Log(Tot. Emp. Den.) | 0.1594*** | -0.1020*** | 0.0648** | -0.0804*** |
| | (0.007) | (0.005) | (0.021) | (0.009) |
| (Year)x(State) F.E. | Yes | Yes | Yes | Yes |
| N | 8418 | 8418 | 7333 | 7333 |
| Kleibergen-Paap rk Wald F-stat | | | 94.224 | 94.224 |

*Note*: This table reports the estimated values of $\alpha$ and $\beta$ from regressions of composite productivities and amenities on total employment density, respectively. The log-log form of the estimating equations is derived from equations (19) and (20). The first two columns present the results of OLS estimation and the last two columns present the results of IV estimation using implied base employment density as an instrument for total employment density. Standard errors are in parentheses and clustered at the county-level ( $^{*}$ $p < 0.05$, $^{**}$ $p < 0.01$, $^{***}$ $p < 0.001$).

Overall, the only feature that substantially differs with the changes to $\sigma$ is the magnitude of the spillover elasticities. As $\sigma$ increases, which implies consumers view the goods as more homogenous, the magnitude of the estimated spillovers increase. However, the relative magnitude of the estimates of $\alpha$ and $\beta$ is relatively consistent.

## A.2 Shift-share IV

In Table 7, estimates for $\alpha$ and $\beta$ are reported from a specification that is the same as the one used in Section 5 except that the proposed base employment IV is replaced by a shift-share instrument. The shift-share instrument takes the total of the proposed changes in civilian employment at military bases for an entire state and applies the proposed percentage change in employment to each location with a military installation based on its initial base employment. This aligns closely with the specification in Nakamura and Steinsson (2014) and especially Zou (2018).

Table 7: Agglomeration and Congestion Spillovers (Alternative IV)

| | OLS | | IV | |
|---|---|---|---|---|
| | Log(Prod.) | Log(Amen.) | Log(Prod.) | Log(Amen.) |
| Log(Tot. Emp. Den.) | 0.1456*** | -0.0996*** | 0.0751*** | -0.0863*** |
| | (0.006) | (0.005) | (0.016) | (0.008) |
| (Year)x(State) F.E. | Yes | Yes | Yes | Yes |
| N | 8418 | 8418 | 7636 | 7636 |
| Kleibergen-Paap rk Wald F-stat | | | 103.245 | 103.245 |

*Note*: This table reports the estimated values of $\alpha$ and $\beta$ from regressions of composite productivities and amenities on total employment density, respectively. The log-log form of the estimating equations is derived from equations (19) and (20). The first two columns present the results of OLS estimation and the last two columns present the results of IV estimation using a shift-share of BRAC proposals within each state as an instrument for total employment density. Standard errors are in parentheses and clustered at the county-level ( $^{*}$ $p < 0.05$, $^{**}$ $p < 0.01$, $^{***}$ $p < 0.001$).

Overall, the results are similar, with an estimate of $\alpha = 0.0751$ and $\beta = -0.0863$. The primary difference is that both estimates are of a larger magnitude. In Table 8, the results of the wage-based agglomeration elasticity is reported. This value is also similar to the estimate found with the proposed base employment instrument, although it is slightly larger at 0.0785 compared to 0.0708. The difference in the magnitude between the wage-based and productivity-based agglomeration elasticity is smaller than with the proposed base employment instrument. However, it is still larger in magnitude like was found with the preferred specification.

Table 8: Wage-based Agglomeration Spillovers (Alternative IV)

| | OLS | IV |
|---|---|---|
| | Log(Pay. Per Cap.) | Log(Pay. Per Cap.) |
| Log(Tot. Emp. Den.) | 0.0918*** | 0.0785*** |
| | (0.004) | (0.008) |
| (Year)x(State) F.E. | Yes | Yes |
| N | 8418 | 7636 |
| Kleibergen-Paap rk Wald F-stat | | 103.245 |

*Note*: This table reports the estimated values of the reduced-form agglomeration spillover elasticity from regressions of payroll per capita on total employment density. The log-log form of the estimating equations yields an elasticity. The first column presents the results of OLS estimation and the second column presents the results of IV estimation using a shift-share of BRAC proposals within each state as an instrument for total employment density. Standard errors are in parentheses and clustered at the county-level ( $^{*}$ $p < 0.05$, $^{**}$ $p < 0.01$, $^{***}$ $p < 0.001$).

## A.3 Log-log specification

In the baseline specification reported in Table 2, there is a difference in the number of observations between the OLS and IV results. This follows from the fact that the log-log specification of the structural estimating equations necessitates taking the log transformation of the IV for use in the IV specifications. This results in observations being dropped from the regression analysis when the IV is equal to zero. One method to address this is to apply a transformation to the IV that approximates the log transformation of the IV but is defined at zero. In Table 9, estimates for $\alpha$ and $\beta$ using such a transformation are reported. In particular, the inverse hyperbolic sign transformation of the IV is used instead of the log transformation (Burbidge, Magee, and Robb 1988). However, such a transformation can introduce bias in the estimates, which is the reason it is not included in the baseline results.

Table 9: Estimating Spillovers

| | IV (log) | | IV (asinh) | |
|---|---|---|---|---|
| | Log(Productivity) | Log(Amenity) | Log(Productivity) | Log(Amenity) |
| Log(Tot. Emp. Den.) | 0.0570** | -0.0781*** | 0.0648*** | -0.0781*** |
| | (0.020) | (0.009) | (0.016) | (0.009) |
| (Year)x(State) F.E. | Yes | Yes | Yes | Yes |
| N | 7333 | 7333 | 8418 | 8418 |
| Kleibergen-Paap rk Wald F-stat | 94.224 | 94.224 | 76.213 | 76.213 |

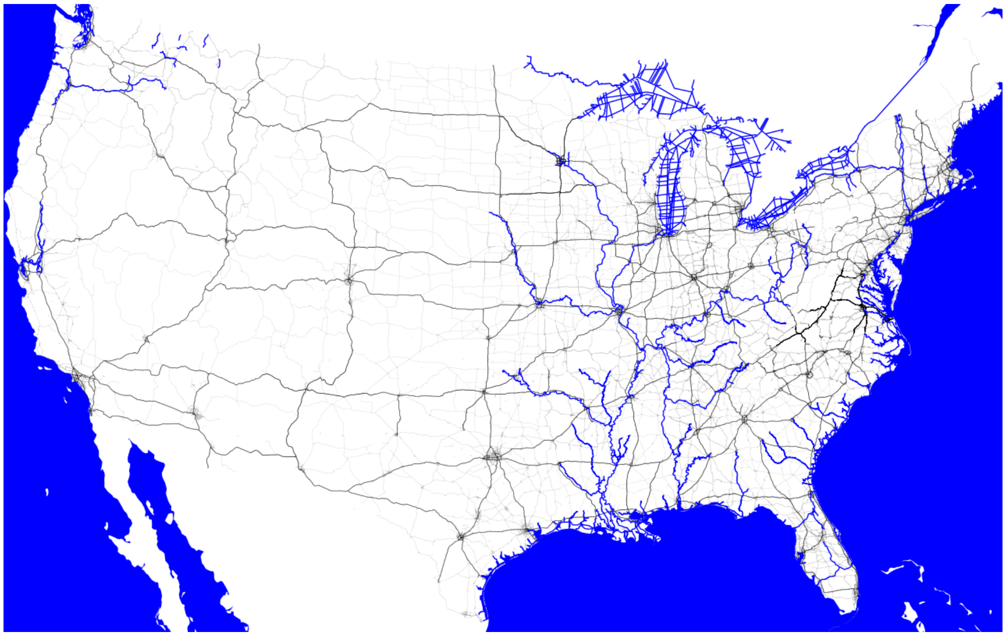
*Note*: This table reports the estimated values of $\alpha$ and $\beta$ from regressions of composite productivities and amenities on total employment density, respectively. The log-log form of the estimating equations is from Equations (19) and (20). The first two columns present the results of IV estimation with the log transformation of the IV and the last two columns present the results of IV estimation using the inverse hyperbolic sine transformation of the IV. Standard errors are in parentheses and clustered at the county-level ( $^{*}$ $p < 0.05$, $^{**}$ $p < 0.01$, $^{***}$ $p < 0.001$).

The estimates of $\alpha$ and $\beta$ using this alternative transformation are similar to the baseline results in Table 2. In particular, the congestion spillover elasticity is unchanged with the alternative specification. On the other hand, the agglomeration spillover elasticity is slightly larger than the baseline value, but estimate from the alternative specification is still consistent with the existing literature.

# B Transportation Networks

The transportation networks used to recover trade costs between each county in the contiguous U.S. is presented in Figure B.1. Three specific networks are mapped: rail, road, and navigable waterways. The railroad network was sourced from the Department of Homeland Security (DHS) and the road and commercially navigable waterway networks were sourced from the Department of Transportation (DOT). The relative speed within each network (i.e. the speed of "interstates" relative to "other roads") are parameterized following Allen and Arkolakis (2014).

(a) Roads and Navigable Waterways



(b) Railroads and Navigable Waterways

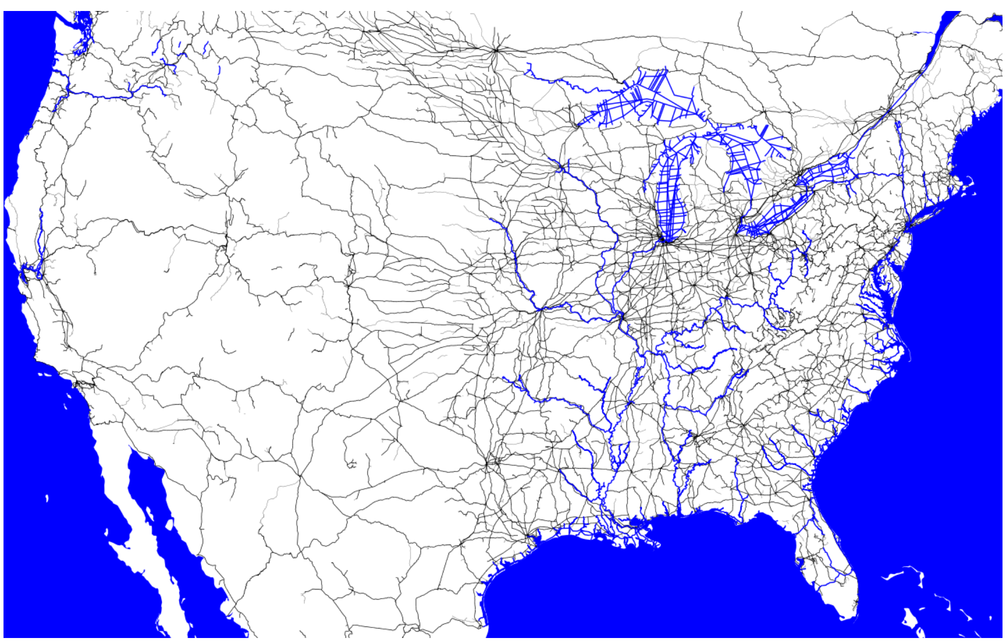


Figure B.1: Transportation Networks for the Contiguous U.S.