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URBAN POPULATION AND AMENITIES

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ABSTRACT

We use a neoclassical general-equilibrium model to explain cross-metro variation in population density based on three broad amenity types: quality of life, productivity in tradables, and productivity in non-tradables. Analytically, we demonstrate the dependence of quantities on amenities through substitution possibilities in consumption and production. Our model clarifies the nature of commonly estimated elasticities of local labor supply and demand. From only differences in wages and housing costs, we explain half of the observed variation in density, especially through quality of life. We show that density information can provide or refine measures of land value and local productivity.

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1 Introduction

In the United States, population densities vary across space far more than the prices of labor and housing; see Figure 1. At the metropolitan level, the average residential density of New York is almost 50 times that of Texarkana. Meanwhile, wage levels in the highest-paying metro are not even twice that of the lowest, and housing costs in the most expensive metro average only four times that of the lowest.

Here, we examine if cross-sectional variation in wages and housing costs across metros is compatible with much greater variation in population density in a frictionless, general-equilibrium, neoclassical framework. We use a model developed by Rosen (1979) and Roback (1982), routinely used to examine prices and amenities, but rarely used for quantities. Each city has two sectors: one produces tradable goods; the other, non-tradable "home" goods, like housing. Each sector uses three factors: labor and capital are mobile across cities; land is not. Local prices and quantities stem from local amenities in three dimensions: "quality of life" for households; "trade productivity" and "home productivity" for firms. The first two relate to the classic problem of whether "jobs follow people or people follow jobs" (Blanco 1963, Borts and Stein 1964).[1] The third dimension determines whether both jobs and people follow available housing, a problem receiving recent attention (Glaeser and Gyourko 2005, Glaeser, Gyourko, and Saks 2006, Saks 2008).

The few articles that use a neoclassical model to examine quantities (e.g., Haughwout and Inman 2001, Rappaport 2008a, 2008b) garner considerable insights, but impose strong restrictions and provide only numerical results, limiting interpretation.[2] Other related articles combine neoclassical elements with ad-hoc alterations, particularly in consumption and the non-tradable/housing sector, which make them unable to address the adequacy of a neoclassical model in explaining cross-metro variation in prices and quantities (e.g., Glaeser et al. 2006, Ahlfeldt et al. 2012, Diamond 2013, Desmet and Rossi-Hansberg 2013, Moretti 2013, Lee and Li forthcoming).[3]

[1] See Hoogstra, Florax, and Dijk (2005) for an interesting meta-analysis of this literature.

[2] Haughwout and Inman (2001) reduce the non-tradable sector to a fixed land market. Rappaport (2008a, 2008b) constrains productivity in each sector to be the same, and assumes the elasticity of substitution between factors in tradable production is one.

[3] Glaeser et al. (2006), Diamond (2013), and Moretti (2013) use an ad-hoc, partial-equilibrium housing supply

We consider the relationship between amenities and quantities both analytically and numerically using a complete and unrestricted neoclassical model, introduced in section 2. Analytically, we show how quantity differences depend on cost and expenditure shares; tax rates; and substitution responses in consumption, and in both types of production.[4] Substitution responses reflect behaviors that raise density, such as people crowding into housing and builders increasing heights. Urban quantities depend on these substitution margins in a first-order manner, while prices do not. A pre-set parametrization for the United States economy from Albouy (2009a), discussed in section 3, suggests that quantities respond much more to amenities than prices do, and that substitution in the home sector is particularly important.

Our analytical exercise in section 4 maps commonly estimated reduced-form elasticities – e.g., of local labor or housing supply – to more elementary structural parameters, and recasts ill-defined partial-equilibrium shifts in supply or demand as general-equilibrium responses to amenity changes – e.g., an increase in labor demand as the response to an increase in trade productivity. The general-equilibrium elasticities, including of local labor supply, are finite. The model produces large (positive) labor supply elasticities, consistent with Bartik (1991) and Notowidigo (2012), and even larger (negative) labor demand elasticities, broadly consistent with Card (2001). Placed in their appropriate long-run context, the results agree with Blanchard and Katz's (1992) finding that migration is the key channel through which local labor markets equilibrate. Moreover, the neoclassical model predicts that density should vary by an order of magnitude more than wages and housing costs. The housing supply elasticities are in the range of estimates in Saiz (2010), but raise the issue that the source of housing demand may affect the estimate.

Our research complements work on agglomeration economies, which examines the reverse relationship of how population affects amenities. For example, if natural advantages increase an

function. Desmet and Rossi-Hansberg (2013) constrain elasticities of substitution in tradable production to be one, and model the non-tradable sector using a mono-centric city at a fixed density. All four assume each household consumes a single housing unit, and preclude analyzing density. Ahlfeldt et al. (2013), who focus on within-city location choices, constrain elasticities of substitution in demand and tradable production to be one. Lee and Li (forthcoming) assume all elasticities of substitution are one, and exclude labor from non-tradable production. Ahlfeldt et al. and Lee and Li consider endogenous quality of life and trade productivity, as we do in Section 2.5.

[4] Our analytic approach builds upon the two sector general-equilibrium analysis of Jones (1965).

area's trade productivity, it will gain population, making it more productive through agglomeration. Agglomeration then creates a multiplier effect, whereby higher productivity begets density, which begets even higher productivity, and so on. We also consider how density may reduce quality of life through congestion. By looking at the two-way relationship between amenities and population, the model helps explain that they are jointly determined. Our numerical results suggest that multiplier effects may be important, but not overwhelming. We also briefly discuss a model extension to account for unobserved preferences or moving frictions.

In a series of novel applications, explained in section 5, we use the neoclassical model to relate prices and amenities to population density in 276 American metropolitan areas using Census data. We begin by inferring quality of life and trade-productivity through measures of wages and housing costs, as in Albouy (2009b). Using these two basic measures, the pre-set parametrization successfully predicts half of the observed variation in density. Our parametrization fits the data considerably better than one which assumes substitution possibilities are inelastic or unit elastic, suggesting that these common assumptions are not innocuous.

If the model is sufficiently accurate, then data on population density may help identify home and trade productivity and infer (typically unobserved) land values. This approach suggests that metro areas such as Chicago, Houston, and El Paso are very home-productive, at least historically. Seattle and San Francisco are much less home-productive, otherwise they would be denser.

Our last exercise explores the relative importance of the three amenity dimensions in explaining where people live. A variance decomposition suggests that quality of life explains a greater fraction of population density than does trade productivity. This conclusion is reinforced if population density increases trade productivity or reduces quality of life. Home productivity explains density more than the other types of amenities, but this may have much to do with how it is inferred, so that it may also reflect path-dependence along with moving frictions. We also simulate how population density might change if federal taxes were made geographically neutral.

The general-equilibrium model of location with homogeneous agents provides a different point of view than dynamic partial equilibrium models of location with heterogenous agents (e.g., Kennan and Walker 2011). Partial-equilibrium approaches typically do not consider how wages and housing costs depend on population. We show that high levels of population relative to wages and housing costs may be due to differences in housing supply, rather than more complex issues such as unobserved preference heterogeneity, or moving costs combined with exogenous (and unexplained) initial population differences. Moreover, the focus of such work is to explain population changes, while we examine differences in population levels, in a manner which eventually will appear rather intuitive and transparent.

2 The Neoclassical Model of Location

2.1 Set-up of Consumption and Production

To explain how prices and quantities vary with amenity levels across cities, we use the model of Albouy (2009a), which adds federal taxes to the general-equilibrium three-equation Roback (1982) model. The national economy contains many cities, indexed by j, which trade with each other and share a homogenous population of mobile households.[5] Households supply a single unit of labor in their city of residence; they consume a numeraire traded good x and a non-traded "home" good y with local price p^j.[6] All input and output markets are perfectly competitive. All prices and quantities are homogenous within cities, but vary across cities.

Cities differ exogenously in three general attributes, each of which is an index meant to summarize the value of amenities to households and firms: (i) quality of life Q^j raises household utility, (ii) trade productivity A_X^j lowers costs in the tradable sector, and (iii) home productivity A_Y^j lowers costs in the non-tradable sector.[7]

[5] Our baseline model does not include unobserved heterogeneity in households for two reasons. First, our model is appropriate for studying long run behavior. While idiosyncratic preferences might be important in explaining short run location decisions, they likely have less power in explaining location decisions over the course of multiple generations. Second, we have no way of identifying unobserved heterogeneity without making ad-hoc functional form assumptions. However, we demonstrate a simple extension to the model which allows for unobserved heterogeneity in Section 2.6.

[6] In our empirical application, the price of the home good is equated with the cost of housing services. Non-housing goods are considered to be a composite commodity of traded goods and non-housing home goods.

[7] All of these attributes depend on a vector of natural and artificial city amenities, $\mathbf{Z}^j = (Z_1^j, ..., Z_K^j)$, through functional relationships $Q^j = \widetilde{Q}(\mathbf{Z}^j)$, $A_X^j = \widetilde{A_X}(\mathbf{Z}^j)$, and $A_Y^j = \widetilde{A_Y}(\mathbf{Z}^j)$. For a consumption amenity, e.g., clement

Firms produce traded and home goods out of land, capital, and labor. Within a city, factors receive the same payment in either sector. Land L is heterogenous across cities, immobile, and receives a city-specific price r^j. Each city's land supply $L^j(r^j)$ may depend positively on r^j. Capital K is fully mobile across cities and receives the price $\bar{\imath}$ everywhere. The supply of capital in each city K^j is perfectly elastic at this price. The national level of capital may be fixed or depend on $\bar{\imath}$. Households N are fully mobile, have identical tastes and endowments, and each supplies a single unit of labor. Household size is fixed. The total number of households is $N^{TOT} = \sum_j N^j$, which may be fixed or determined by international migration.

Households own identical diversified portfolios of land and capital, which pay an income $R = \sum_j r^j L^j / N_{TOT}$ from land and $I = \sum_j \bar{\imath} K^j / N_{TOT}$ from capital. Total income $m^j = w^j + R + I$ varies across cities only as wages vary. Out of this income households pay a linear federal income tax τm^j, which is redistributed in uniform lump-sum payments T.[8] Household preferences are modeled by a utility function $U(x, y; Q^j)$ which is quasi-concave over x, y, and Q^j. The expenditure function for a household in city j is $e(p^j, u; Q^j) \equiv \min_{x,y}\{x + p^j y : U(x, y; Q^j) \geq u\}$. Assume Q enters neutrally into the utility function and is normalized so that $e(p^j, u; Q^j) = e(p^j, u)/Q^j$, where $e(p^j, u) \equiv e(p^j, u; 1)$.[9]

Operating under perfect competition, firms produce traded and home goods according to the functions $X^j = A^j_X F_X(L^j_X, N^j_X, K^j_X)$ and $Y^j = A^j_Y F_Y(L^j_Y, N^j_Y, K^j_Y)$, where F_X and F_Y are concave and exhibit constant returns to scale. We assume Hicks-neutral productivity. Unit cost in the traded good sector is $c_X(r^j, w^j, \bar{\imath}; A^j_X) \equiv \min_{L,N,K}\{r^j L + w^j N + \bar{\imath} K : A^j_X F(L, N, K) = 1\}$. Similar to the relationship between quality of life and the expenditure function, let $c_X(r^j, w^j, \bar{\imath}; A^j_X) = c_X(r^j, w^j, \bar{\imath})/A^j_X$, where $c_X(r^j, w^j, \bar{\imath}) \equiv c_X(r^j, w^j, \bar{\imath}; 1)$ is the uniform unit cost function. A symmetric definition holds for unit cost in the home good sector c_Y.

weather, $\partial \widetilde{Q}/\partial Z_k > 0$; for a trade production amenity, e.g., navigable water, $\partial \widetilde{A_X}/\partial Z_k > 0$; for a home production amenity, e.g., flat geography, $\partial \widetilde{A_Y}/\partial Z_k > 0$. A single amenity may affect more than one attribute at a time.

[8] Our applications adjust for state taxes and tax benefits to owner-occupied housing. The model can be generalized to include nonlinear income taxation.

[9] The model generalizes to a case with heterogenous workers that supply different fixed amounts of labor if these workers are perfect substitutes in production, have identical homothetic preferences, and earn equal shares of income from labor.

2.2 Equilibrium of Prices, Quantities, and Amenities

Each city can be described by a system of sixteen equations in sixteen endogenous variables: three prices p^j, w^j, r^j, and thirteen quantities $x^j, y^j, X^j, Y^j,\ N^j, N_X^j, N_Y^j,\ L^j, L_X^j,\ L_Y^j,\ K^j, K_X^j, K_Y^j$. We begin by having endogenous variables depend on three exogenous attributes Q^j, A_X^j, A_Y^j and a land supply function $L^j(\cdot)$. In this scenario, the system of equations has a block-recursive structure, allowing us to first determine prices, where most researchers stop, then determine per-capita consumption quantities, and finally, production quantities, including total population. The block-recursive structure is broken if amenities depend endogenously on quantities, but the model remains tractable. Endogenizing amenities is more important for comparative statics than measurement. Throughout, we adopt a "small open city" assumption and take nationally determined variables $\bar{u}, \bar{\imath}, I, R, T$ as given for any individual city.

2.2.1 Price Conditions

Since households are fully mobile, they must receive the same utility across all inhabited cities. Higher prices or lower quality of life are compensated with greater after-tax income,

$$e(p^j, \bar{u})/Q^j = (1-\tau)(w^j + R + I) + T, \tag{1}$$

where $\bar{u}$ is the level of utility attained nationally by all households.

Firms earn zero profits in equilibrium. For given output prices, firms in more productive cities must pay higher rents and wages,

$$c_X(r^j, w^j, \bar{\imath})/A_X^j = 1 \tag{2}$$

$$c_Y(r^j, w^j, \bar{\imath})/A_Y^j = p^j. \tag{3}$$

Equations (1), (2), and (3) simultaneously determine the city-level prices p^j, r^j, and w^j as implicit functions of the three attributes Q^j, A_X^j, and A_Y^j. These conditions provide a one-to-one mapping between unobserved city attributes and potentially observable prices. Due to the recursive structure, the price conditions stand alone, founding the insights of Rosen-Roback model on the relationship between prices and amenities. Although quantity predictions are implicit, these conditions do not refer to them. We describe these predictions below.

2.2.2 Consumption Conditions

In choosing their consumption quantities x^j and y^j, households face the budget constraint

$$x^j + p^j y^j = (1 - \tau)(w^j + R + I) + T, \tag{4}$$

where p^j and w^j are determined by the price conditions. Optimal consumption is determined in conjunction with the tangency condition

$$(\partial U / \partial y) \, / \, (\partial U / \partial x) = p^j. \tag{5}$$

As we assume preferences are homothetic, Q^j does not affect the marginal rate of substitution. Thus, in areas where Q^j is higher, but p^j is the same, households consume less of x and y in equal proportions, holding the ratio y/x constant, similar to an income effect. Holding Q^j constant, areas with higher p^j induce households to reduce the ratio y/x through a substitution effect.

2.2.3 Production Conditions

With prices and per-capita consumption levels accounted for, levels of output X^j, Y^j, employment N^j, N_X^j, N_Y^j, capital K^j, K_X^j, K_Y^j, and land L^j, L_X^j, L_Y^j are determined by eleven equations describing production and market clearing. The first six express conditional factor demands using Shephard's Lemma. Because of constant returns to scale and Hicks neutrality, the derivative of the uniform unit cost function equals the ratio of the relevant augmented input to output:

$$\partial c_X/\partial w = A_X^j N_X^j / X^j \tag{6}$$

$$\partial c_X/\partial r = A_X^j L_X^j / X^j \tag{7}$$

$$\partial c_X/\partial i = A_X^j K_X^j / X^j \tag{8}$$

$$\partial c_Y/\partial w = A_Y^j N_Y^j / Y^j \tag{9}$$

$$\partial c_Y/\partial r = A_Y^j L_Y^j / Y^j \tag{10}$$

$$\partial c_Y/\partial i = A_Y^j K_Y^j / Y^j . \tag{11}$$

The next three conditions express the local resource constraints for labor, land, and capital under the assumption that factors are fully employed.

$$N^j = N_X^j + N_Y^j \tag{12}$$

$$L^j = L_X^j + L_Y^j \tag{13}$$

$$K^j = K_X^j + K_Y^j \tag{14}$$

Equation (13) differs from the others as local land is determined by the local supply function,

$$L^j = L^j(r^j). \tag{15}$$

The last condition requires that the local home good market clears.

$$Y^j = N^j y^j \tag{16}$$

Walras' Law makes redundant the market clearing equation for tradable output, which includes per-capita net transfers from the federal government $T - \tau m^j$. The combined assumptions of an internally homogenous open city, exogenous and neutral amenities, and constant returns in the cost and expenditure functions imply that all of the production quantities increase linearly with the quantity of land. If land in a city doubles, labor and capital will enter and also double, so that all prices and per-capita quantities remain the same. We normalize land supply so that $L^j(r^j) = 1$ for all cities and focus on density.[10] This normalization helps in the empirical application, as it allows us to proceed without data on land values or supply elasticities.

2.3 Log-Linearization around National Averages

The system described by conditions (1) to (16) generally is non-linear.[11] To obtain closed-form solutions, we log-linearize these conditions. Hence, we express each city's price and quantity differentials in terms of its amenity differentials, relative to the national average. These differentials are expressed in logarithms so that for any variable z, $\hat{z}^j \equiv \ln z^j - \ln \bar{z} \cong (z^j - \bar{z}) / \bar{z}$ approximates the percent difference in city j of z relative to the national average $\bar{z}$.

The log-linearization requires several economic parameters evaluated at the national average. For households, denote the share of gross expenditures spent on the traded and home good as $s_x \equiv x/m$ and $s_y \equiv py/m$; denote the share of income received from land, labor, and capital income as $s_R \equiv R/m$, $s_w \equiv w/m$, and $s_I \equiv I/m$. For firms, denote the cost share of land, labor, and capital in the traded good sector as $\theta_L \equiv rL_X/X$, $\theta_N \equiv wN_X/X$, and $\theta_K \equiv \bar{\imath}K_X/X$; denote equivalent cost shares in the home good sector as ϕ_L, ϕ_N, and ϕ_K. Finally, denote the share of land, labor, and capital used to produce traded goods as $\lambda_L \equiv L_X/L$, $\lambda_N \equiv N_X/N$, and $\lambda_K \equiv K_X/K$. Assume the home good is more cost-intensive in land relative to labor than the traded good, both absolutely, $\phi_L \geq \theta_L$, and relatively, $\phi_L/\phi_N \geq \theta_L/\theta_N$, implying $\lambda_L \leq \lambda_N$.

[10] In principle, land supply can vary on two different margins. At the extensive margin, an increase in land supply corresponds to a growing city boundary. At the intensive margin, an increase in land supply takes the form of employing previously unused land within a city's border. By normalizing land supply, we rule out extensive margin changes. The assumption of full utilization, seen in equations (13) and (15), rules out intensive margin changes.

[11] One exception is when the economy is fully Cobb-Douglas and there is no income received from land, capital, or government. In Appendix A, we present results from a nonlinear simulation which suggest that the log-linearized model reasonably approximates the nonlinear one.

The first three price conditions are log-linearized as

$$-s_w(1-\tau)\hat{w}^j + s_y\hat{p}^j = \hat{Q}^j \tag{1*}$$

$$\theta_L\hat{r}^j + \theta_N\hat{w}^j = \hat{A}_X^j \tag{2*}$$

$$\phi_L\hat{r}^j + \phi_N\hat{w}^j - \hat{p}^j = \hat{A}_Y^j. \tag{3*}$$

These are explored in detail in Albouy (2009b). Households pay more or get paid less in nicer areas. Firms pay more to their factors in more trade-productive areas. They do the same relative to output prices in more home-productive areas. These expressions involve only cost and expenditure shares and the marginal tax rate.

The log-linearized consumption conditions introduce the elasticity of substitution in consumption, $\sigma_D \equiv -e \cdot (\partial^2 e/\partial p^2)/[\partial e/\partial p \cdot (e - p \cdot \partial e/\partial p)] = -\partial \ln(y/x)/\partial \ln p$,

$$s_x\hat{x}^j + s_y\left(\hat{p}^j + \hat{y}^j\right) = (1-\tau)s_w\hat{w}^j \tag{4*}$$

$$\hat{x}^j - \hat{y}^j = \sigma_D\hat{p}^j. \tag{5*}$$

Substituting equation (1*) into equations (4*) and (5*) produces the solutions $\hat{x}^j = s_y\sigma_D\hat{p}^j - \hat{Q}^j$ and $\hat{y}^j = -s_x\sigma_D\hat{p}^j - \hat{Q}^j$, describing the income and substitution effects discussed earlier.

Although we model homogenous households, one can think of higher values of σ_D as approximating households with heterogeneous preferences who sort across cities. Households with stronger tastes for y will choose to live in areas with a lower home price p. At the equilibrium levels of utility, an envelope of the mobility conditions for each type forms that of a representative household, with greater preference heterogeneity reflected as more flexible substitution.[12]

The log-linearized conditional factor demands describe how input demands depend on output,

[12] Roback (1980) discusses this generalization as well as the below generalizations in production.

productivity, and relative input prices.

$$\hat{N}_X^j = \hat{X}^j - \hat{A}_X^j + \theta_L \sigma_X^{LN} \left(\hat{r}^j - \hat{w}^j\right) - \theta_K \sigma_X^{NK} \hat{w}^j \tag{6*}$$

$$\hat{L}_X^j = \hat{X}^j - \hat{A}_X^j + \theta_N \sigma_X^{LN} (\hat{w}^j - \hat{r}^j) - \theta_K \sigma_X^{KL} \hat{r}^j \tag{7*}$$

$$\hat{K}_X^j = \hat{X}^j - \hat{A}_X^j + \theta_L \sigma_X^{KL} \hat{r}^j + \theta_N \sigma_X^{NK} \hat{w}^j \tag{8*}$$

$$\hat{N}_Y^j = \hat{Y}^j - \hat{A}_Y^j + \phi_L \sigma_Y^{LN} (\hat{r}^j - \hat{w}^j) - \phi_K \sigma_Y^{NK} \hat{w}^j \tag{9*}$$

$$\hat{L}_Y^j = \hat{Y}^j - \hat{A}_Y^j + \phi_N \sigma_Y^{LN} (\hat{w}^j - \hat{r}^j) - \phi_K \sigma_Y^{KL} \hat{r}^j \tag{10*}$$

$$\hat{K}_Y^j = \hat{Y}^j - \hat{A}_Y^j + \phi_L \sigma_Y^{KL} \hat{r}^j + \phi_N \sigma_Y^{NK} \hat{w}^j \tag{11*}$$

The dependence on input prices is determined by partial (Allen-Uzawa) elasticities of substitution in each sector, for each pair of factors, e.g., $\sigma_X^{LN} \equiv c_X \cdot (\partial^2 c_X / \partial w \partial r) \,/\, (\partial c_X / \partial w \cdot \partial c_X / \partial r)$ is for labor and land in the production of X. These values are taken at the national average because we assume that production technology does not differ across cities. To simplify, we also assume that the partial elasticities within each sector are the same, i.e., $\sigma_X^{NK} = \sigma_X^{KL} = \sigma_X^{LN} \equiv \sigma_X$, and similarly for σ_Y, as with a constant elasticity of substitution (CES) production function.

A higher value of σ_X corresponds to more flexible production of the traded good. With a single traded good, firms can vary the proportion of inputs they employ. In a generalization with multiple traded goods sold at fixed prices, firms could adjust their product mix to specialize in producing goods where their input costs are relatively low. For example, areas with high land costs and low labor costs would produce goods that use labor intensively but not land. A representative zero-profit condition can be drawn as an envelope of the zero-profit conditions for each good, with a greater variety of goods reflected as greater substitution possibilities.

A related argument exists for home goods. For example, a high value of σ_Y means that housing producers can use labor and capital to build taller buildings in areas where the price of land is high. If all home goods are perfect substitutes, then an envelope of zero-profit conditions may be used as a representative zero-profit condition.[13] Because housing is durable, it may take time for its

[13] The condition that all home goods are perfect substitutes is sufficient, but might not be necessary. An alternative

market to equilibrate. For non-housing home goods, one can imagine retailers using taller shelves and restaurants hiring extra servers to make better use of space in cities with expensive land.

Log-linearizing the resource constraints for labor, land, and capital yields

$$\hat{N}^j = \lambda_N \hat{N}_X^j + (1 - \lambda_N)\hat{N}_Y^j \tag{12*}$$

$$\hat{L}^j = \lambda_L \hat{L}_X^j + (1 - \lambda_L)\hat{L}_Y^j \tag{13*}$$

$$\hat{K}^j = \lambda_K \hat{K}_X^j + (1 - \lambda_K)\hat{K}_Y^j. \tag{14*}$$

Equations (12*), (13*), and (14*) imply that sector-specific factor changes affect overall changes in proportion to the factor share. The condition for land supply

$$\hat{L}^j = \varepsilon_{L,r}^j \hat{r}^j \tag{15*}$$

uses the elasticity $\varepsilon_{L,r}^j \equiv (\partial L^j / \partial r) \cdot (r^j / L^j)$. Wrapping up, the market clearing condition for home goods is simply

$$\hat{N}^j + \hat{y}^j = \hat{Y}^j. \tag{16*}$$

Because the city is open, and from our other assumptions, production quantities will scale up proportionally to changes in land supply given by $\varepsilon_{L,r}^j \hat{r}^j$, which is zero when we focus on density.

sufficient condition, which holds when considering traded goods, is that relative prices of types of home goods do not vary across cities.

2.4 Solving the Model for Relative Quantity Differences

We express solutions for the endogenous variables in terms of the amenity differentials $\hat{Q}^j$, $\hat{A}^j_X$, and $\hat{A}^j_Y$. Only equations (1*) to (3*) are needed for the price differentials.

$$\hat{r}^j = \frac{1}{s_R}\frac{\lambda_N}{\lambda_N - \tau\lambda_L}\left[\hat{Q}^j + \left(1 - \frac{\tau}{\lambda_N}\right)s_x\hat{A}^j_X + s_y\hat{A}^j_Y\right] \tag{17}$$

$$\hat{w}^j = \frac{1}{s_w}\frac{1}{\lambda_N - \tau\lambda_L}\left[-\lambda_L\hat{Q}^j + (1-\lambda_L)s_x\hat{A}^j_X - \lambda_L s_y\hat{A}^j_Y\right] \tag{18}$$

$$\hat{p}^j = \frac{1}{s_y}\frac{1}{\lambda_N - \tau\lambda_L}\left[(\lambda_N - \lambda_L)\hat{Q}^j + (1-\tau)(1-\lambda_L)s_x\hat{A}^j_X - (1-\tau)\lambda_L s_y\hat{A}^j_Y\right] \tag{19}$$

Higher quality of life leads to higher land and home good prices but lower wages. Higher trade productivity increases all three prices, while higher home productivity increases land prices but decreases wages and the home good price. These first-order predictions only require cost and expenditure shares, which in principle are available from national income accounts. The predictions depend on strong neoclassical assumptions, encompassed in the model, and so do not require much knowledge of behavior.

Putting solution (19) in equations (4*) and (5*) yields the per-capita consumption differentials

$$\hat{x}^j = \frac{\sigma_D(1-\tau)}{\lambda_N - \tau\lambda_L}\left[\frac{\sigma_D(\lambda_N - \lambda_L) - (\lambda_N - \tau\lambda_L)}{\sigma_D(1-\tau)}\hat{Q}^j + (1-\lambda_L)s_x\hat{A}^j_X - \lambda_L s_y\hat{A}^j_Y\right] \tag{20}$$

$$\hat{y}^j = -\frac{s_x}{s_y}\frac{\sigma_D(1-\tau)}{\lambda_N - \tau\lambda_L}\left[\frac{s_x\sigma_D(\lambda_N - \lambda_L) + s_y(\lambda_N - \tau\lambda_L)}{s_x\sigma_D(1-\tau)}\hat{Q}^j + (1-\lambda_L)s_x\hat{A}^j_X - \lambda_L s_y\hat{A}^j_Y\right] \tag{21}$$

Households in home-productive areas substitute towards home goods and away from tradable goods; households in trade-productive areas do the opposite. In nicer areas, households consume fewer home goods; whether they consume fewer tradable goods is ambiguous: the substitution effect is positive, and the income effect is negative.

Solutions for the other quantities, which rely on production equations (6*) through (16*), are more complicated and harder to intuit. To simplify notation, we express the change in each quantity with respect to amenities using three reduced-form elasticities, each composed of structural parameters. For example, the solution for population is written

$$\hat{N}^j = \varepsilon_{N,Q}\hat{Q}^j + \varepsilon_{N,A_X}\hat{A}_X^j + \varepsilon_{N,A_Y}\hat{A}_Y^j, \tag{22}$$

where $\varepsilon_{N,Q}$ is the elasticity of population with respect to quality of life and ε_{N,A_X} and ε_{N,A_Y} are defined similarly. The relationship between the first reduced-form elasticity and structural parameters is

$$\begin{aligned}\varepsilon_{N,Q} = &\frac{\lambda_N - \lambda_L}{\lambda_N} + \sigma_D\left[\frac{s_x(\lambda_N - \lambda_L)^2}{s_y\lambda_N(\lambda_N - \lambda_L\tau)}\right] + \sigma_X\frac{\lambda_L}{\lambda_N - \lambda_L\tau}\left[\frac{\lambda_L}{s_w} + \frac{\lambda_N}{s_R}\right] \\ &+ \sigma_Y\frac{1}{\lambda_N - \lambda_L\tau}\left[\frac{\lambda_L^2(1-\lambda_N)}{s_w\lambda_N} + \frac{\lambda_N(1-\lambda_L)}{s_R} - \frac{(\lambda_N - \lambda_L)^2}{s_y\lambda_N}\right] \\ &+ \varepsilon_{L,r}\left[\frac{\lambda_N}{s_R(\lambda_N - \lambda_L\tau)}\right]\end{aligned} \tag{23}$$

We provide similar expressions for ε_{N,A_X} and ε_{N,A_Y} in Appendix B. The full structural solution to (22) is obtained by substituting in these expressions.

By collecting terms for each structural elasticity in (23), we demonstrate that nicer areas can have higher urban population via five behavioral responses. The first term reflects how households consume fewer goods from the income effect, and thus require less land per capita, e.g. by crowding into existing housing. The second term, with σ_D, captures how households substitute away from land-intensive goods, accepting additional crowding. The third, with σ_X, expresses how firms in the traded sector substitute away from land towards labor and capital, freeing up space for households. The fourth, with σ_Y, reflects how home goods become less land intensive, e.g., buildings get taller. The fifth, with $\varepsilon_{L,r}$, provides the population gain on the extensive margin, from more land being used; this term is zero when we examine density.

Each of the reduced-form elasticities between a quantity and a type of amenity have up to five similar structural effects. The quantity solutions also require knowledge of substitution elasticities, and thus of household and producer behavior.

2.5 Agglomeration Effects

With the above set-up, it is straightforward to introduce simple forms of endogenous amenities.[14] We consider two common forms: positive economies of scale in tradable production, and negative economies in quality of life. For simplicity, we assume both depend on population alone, i.e., $A_X^j = A_{X0}^j (N^j)^\alpha$ and $Q^j = Q_0^j (N^j)^{-\gamma}$, where A_{X0}^j and Q_0^j represent city j's "natural advantages", and $\alpha \geq 0$ and $\gamma \geq 0$ are the reduced-form agglomeration elasticities.[15] These advantages may be determined by local geographic features or local policies. Economies of scale in productivity may be due to non-rival input sharing, improved matching in labor markets, or knowledge spillovers (e.g., Jaffe et al. 1993, Glaeser 1999, Arzaghi and Henderson 2008, Davis and Dingel 2012, Baum-Snow 2013); diseconomies in quality of life may be due to congestion or pollution. The main assumption here is that these processes follow a conventional power law.

The feedback effects on density are easily expressed using the reduced-form notation in (22):

$$\begin{aligned}
\hat{N}^j &= \varepsilon_{N,Q}(\hat{Q}_0^j - \gamma \hat{N}^j) + \varepsilon_{N,A_X}(\hat{A}_{X0}^j + \alpha \hat{N}^j) + \varepsilon_{N,A_Y}\hat{A}_{Y0}^j \\
&= \frac{1}{1 + \gamma\varepsilon_{N,Q} - \alpha\varepsilon_{N,A_X}}\left(\varepsilon_{N,Q}\hat{Q}_0^j + \varepsilon_{N,A_X}\hat{A}_{X0}^j + \varepsilon_{N,A_Y}\hat{A}_{Y0}^j\right) \\
&\equiv \tilde{\varepsilon}_{N,Q}\hat{Q}_0^j + \tilde{\varepsilon}_{N,A_X}\hat{A}_{X0}^j + \tilde{\varepsilon}_{N,A_Y}\hat{A}_{Y0}^j, \qquad (24)
\end{aligned}$$

taking $A_{Y0}^j = A_Y^j$ as fixed. The second line solves for the multiplier $(1 + \gamma\varepsilon_{N,Q} - \alpha\varepsilon_{N,A_X})^{-1}$ for how the impacts of natural advantages are magnified by positive economies or dampened by negative ones. The multiplier depends on the product of the elasticities $\varepsilon_{N,Q}$ and ε_{N,A_X}, i.e., the effect of amenities on population, and the agglomeration parameters γ and α, i.e., the effect of population on amenities. Equation (24) simply modifies the reduced-form elasticities $(\tilde{\varepsilon}_{N,Q}, \tilde{\varepsilon}_{N,A_X}, \tilde{\varepsilon}_{N,A_Y})$ to incorporate the multiplier effects. One limitation of this approach to agglomeration is it does not account for spillovers from one area or city j to another.

[14]Our model incorporates aspects of both locational fundamentals and increasing returns; see Davis and Weinstein (2002). Its unique predictions make it less capable of representing historical path dependence (e.g., Bleakley and Lin 2012), although mobility frictions discussed in the next section can help conserve it.

[15]Our framework could be used to study a variety of more complicated endogenous agglomeration formulations, not just involving population, although these would typically require more complicated solutions.

2.6 Imperfect Mobility and Preference Heterogeneity

We believe the model most accurately depicts a long-run equilibrium, for which idiosyncratic preferences or imperfect mobility seem less important. Yet, the model may be appended to include such features, which could be used to rationalize path dependence. Suppose that quality of life for household i in metro j equals the product of a common term and a household-specific term, $Q_i^j = \underline{Q}^j \xi_i^j$. In addition, assume that ξ_i^j comes from a Pareto distribution with parameter $1/\psi > 0$, common across metros, and distribution function $F(\xi_i^j) = 1 - (\underline{\xi}/\xi_i^j)^{1/\psi}, \xi_i^j \geq \underline{\xi}$. A larger value of ψ corresponds to greater preference heterogeneity; $\psi = 0$ is the baseline value.

For each populated metro, there exists a marginal household, denoted by k, such that

$$\frac{e(p^j, \bar{u})}{\underline{Q}^j \xi_k^j} = (1-\tau)(w^j + R + I) + T. \tag{25}$$

For some fixed constant $N_{\max}^j$, population density in each metro can be written $N^j = N_{\max}^j \Pr[\xi_i^j \geq \xi_k^j] = N_{\max}^j (\underline{\xi}/\xi_k^j)^{1/\psi}$. Log-linearizing this condition yields $\psi \hat{N}^j = -\hat{\xi}_k^j$. The larger is ψ, and the greater the population shift $\hat{N}^j$, the greater the preference gap in between supra- and infra-marginal residents. Log-linearizing the definition of Q_k^j yields $\hat{Q}_k^j = \hat{\underline{Q}}^j + \hat{\xi}_k^j = \hat{Q}_k^j = \hat{\underline{Q}}^j - \psi \hat{N}^j$. Ignoring agglomeration, the relationship between population density and amenities with is now lower

$$\hat{N}^j = \frac{1}{1 + \psi \varepsilon_{N,Q}} \left(\varepsilon_{N,Q} \hat{\underline{Q}}^j + \varepsilon_{N,A_X} \hat{A}_X^j + \varepsilon_{N,A_Y} \hat{A}_Y^j \right)$$

This dampening effect occurs because firms in a city need to be paid incoming migrants an increasing schedule in after-tax real wages to have them overcome their taste differences. With a value of ψ, we may adjust all of the predictions. The comparative statics with imperfect mobility are indistinguishable from congestion effects: ψ and γ are interchangeable. The welfare implications are different as infra-marginal residents share the value of local amenities with land-owners.[16]

[16]Note that log-linearizing equation (25) yields $s_w(1-\tau)\hat{w}^j - s_y \hat{p}^j = \psi \hat{N}^j - \hat{\underline{Q}}^j$. It is straightforward to show that the rent elasticities in (17) is equal to $1/(1 + \psi \varepsilon_{N,Q}) \leq 1$ its previous value. The increase in real income is given by $s_w(1-\tau) d\hat{w}^j - s_y d\hat{p}^j = \psi \hat{N}^j = -s_R d\hat{r}^j$, where "d" denotes price changes between actual and full mobility. The main challenge in operationalizing imperfect mobility is specifying the baseline level of population that deviations $\hat{N}^j$

2.7 Identification of Production Amenities and Land Values

With data on the three price differentials $\hat{r}^j$, $\hat{w}^j$, and $\hat{p}^j$ and the parameters values, we can estimate amenity differentials $\hat{Q}^j$, $\hat{A}_X^j$, and $\hat{A}_Y^j$ with equations (1*), (2*), and (3*). As discussed in Albouy (2009b), data on wages and housing prices (which proxy for home-good prices) are readily available across metros, while land values are generally unavailable, making it impossible to identify trade and home productivity from (2*) and (3*).[17] Combining these equations to eliminate $\hat{r}^j$:

$$\frac{\theta_L}{\phi_L}\hat{p}^j + \left(\theta_N - \phi_N\frac{\theta_L}{\phi_L}\right)\hat{w}^j = \hat{A}_X^j - \frac{\theta_L}{\phi_L}\hat{A}_Y^j. \tag{26}$$

The left hand side of (26) equals tradable producer costs inferred from wages and home good prices.[18] Trade productivity raises these inferred costs, while home productivity lowers them. One way to infer trade productivity is to assume that home productivity is constant, $\hat{A}_Y^j = 0$, so that land values may be inferred from (3*), and $\hat{A}_X^j$ equals inferred costs. The resulting trade productivity estimates are biased downwards in home-productive areas, but only slightly if $\theta_L << \phi_L$. Without such a restriction, the two productivities cannot be identified separately with typical price data alone. Trade productivity raises wages and home good prices, while home productivity reduces them in collinear proportions.

A potential solution is to use readily-available data on population density to infer land values and both productivities. To do this, we first net out density from quality of life by combining equations (1*) and (22) to yield

$$\hat{N}^j - \varepsilon_{N,Q}\underbrace{[s_y\hat{p}^j - s_w(1-\tau)\hat{w}^j]}_{\hat{Q}^j} = \varepsilon_{N,A_X}\hat{A}_X^j + \varepsilon_{N,A_Y}\hat{A}_Y^j. \tag{27}$$

Equation (27) shows that "excess density" not explained by quality of life, on the left, is explained

are taken from, as a baseline of equal density may not be appropriate. Differences in baseline population together with the frictions modeled here, may provide a way of introducing historical path-dependence in the model.

[17] Albouy and Ehrlich (2012) estimate $\hat{r}^j$ using transaction purchase data, which is only available for recent years. Their analysis discusses several conceptual and empirical challenges from this approach.

[18] From equation (2*), recall that the cost differential for tradable producers equals $\hat{A}_X^j$, which is approximately equal to the left hand side of (26) when θ_L/ϕ_L is small, as is true in our parametrization.

by either trade or home productivity, on the right. The resulting system of equations (26) and (27) is exactly identified, so that the inferred amenities *perfectly predict* population densities. This methodology depends strongly on the model and its many parameter values.

Solving the system, we may infer productivity based on the observable differentials $\hat{N}^j, \hat{w}^j$, and $\hat{p}^j$.

$$\hat{A}_X^j = \frac{\theta_L[N^j - \varepsilon_{N,Q}(s_y p^j - s_w(1-\tau)w^j)] + \phi_L \varepsilon_{N,A_Y}[\frac{\theta_L}{\phi_L}p^j + (\theta_N - \phi_N \frac{\theta_L}{\phi_L})w^j]}{\theta_L \varepsilon_{N,A_X} + \phi_L \varepsilon_{N,AY}} \tag{28}$$

$$\hat{A}_Y^j = \frac{\phi_L[N^j - \varepsilon_{N,Q}(s_y p^j - s_w(1-\tau)w^j)] - \phi_L \varepsilon_{N,A_Y}[\frac{\theta_L}{\phi_L}p^j + (\theta_N - \phi_N \frac{\theta_L}{\phi_L})w^j]}{\theta_L \varepsilon_{N,A_X} + \phi_L \varepsilon_{N,AY}} \tag{29}$$

High excess density and high inferred costs imply high trade productivity. Low inferred costs and high excess density imply high home productivity, with the latter effect stronger as $\phi_L > \theta_L$. A land value solution come from substituting the above solutions into (2*) or (3*).

$$\hat{r}^j = \frac{\hat{N}^j - \varepsilon_{N,Q}(s_y \hat{p}^j - s_w(1-\tau)\hat{w}^j) - \varepsilon_{N,A_X}\theta_N \hat{w}^j - \varepsilon_{N,A_Y}(\hat{p}^j - \phi_N \hat{w}^j)}{\theta_L \varepsilon_{N,A_X} + \phi_L \varepsilon_{N,AY}} \tag{30}$$

As seen in the numerator of (30), this rent measure depends on density not explained by quality of life and productivity differences we would estimate if land values were equal.[19]

3 Parameter Choices and Elasticities

3.1 Parameter Choices

Applying the model to the U.S. economy requires several parameter values, some of which are easier to estimate. Cost and expenditure shares require information on the first moments of data (i.e., means) and may be ascertained with some accuracy. Elasticities of substitution require credible identification involving second moments (i.e., covariances of quantities with prices) and thus are subject to greater uncertainty.

[19]i.e., if $\hat{r}^j = 0$, then $\hat{A}_X^j = \theta_N \hat{w}^j$ and $\hat{A}_Y^j = \phi_N \hat{w}^j - \hat{p}^j$.

The main parametrization we use was pre-set in Albouy (2009a) without any reference to density data. It is shown in Table 1. It involves several remarkable features. One, the home good expenditure share inflates spending on housing by 60 percent to account for non-housing home goods. Two, the income shares obey national income identities so that capital and land income are internal to the system. Three, one-sixth of land values are devoted to producing tradable goods. For the substitution elasticities we use $\sigma_D = \sigma_X = \sigma_Y = 0.667$. This is most consistent with evidence for price inelastic housing demand, and cost-shares for land in housing increasing in higher land-value areas. We leave further discussion of these parameters to Appendix C.

We choose relatively large agglomeration elasticities for purposes of illustration. We use $\alpha = 0.06$ for the positive effect of population density on trade productivity and $\gamma = 0.015$ for the negative effect on quality of life.[20]

A few potential complications deserve special attention. First, there are more dimensions in which the parameter values could vary than are feasible to cover in sensitivity analysis. We focus on the substitution elasticities since they seem to be the least well known and the most relevant in this analysis. Second, the log-linearized model is most accurate for small deviations from the national average. We present a non-linear simulation in Appendix A, assuming constant elasticity of substitution functional forms, which suggests that nonlinearities are of limited importance for our range of data. The elasticities of substitution may also vary across cities, particularly those in home good production. Theoretically, taking such heterogeneity into account is rather straightfor-

[20]Ciccone and Hall (1996) estimate an elasticity of labor productivity with respect to population density of 0.06. Rosenthal and Strange (2004) argue that a one percent increase in population leads to no more than a 0.03-0.08 percent increase in productivity. For γ we combine estimated costs of commuting and pollution. First, we estimate an elasticity of transit time with respect to population density of 0.10 (unreported results available by request). Assuming that the elasticity of monetary and after-tax time costs of commuting as a fraction of income is 9 percent, commuting contributes $(0.09)(0.010) \approx 0.009$ to our estimate of γ. Second, Chay and Greenstone (2005) estimate that the elasticity of housing values with respect to total suspended particulates, a measure of air quality, lies between -0.2 and -0.35; we take a middle estimate of -0.3. The Consumer Expenditure Survey reports the gross share of income spent on shelter alone (no utilities) is roughly 0.13. We estimate an elasticity of particulates with respect to population density of 0.15 (unreported results available by request). Together, this implies that the contribution of air quality is $|(0.13)(-0.6)(0.15)| \approx 0.006$. Population density affects quality of life through more than commuting and air quality, but if we assume these effects cancel out, then a plausible value of estimate of $\gamma = 0.009 + 0.006 = 0.015$. Estimates from Combes et al. (2012), using data on French cities, suggest a larger value of $\gamma = 0.041$, but their emphasis is on population, not density. See Rosenthal and Strange (2004) and Glaeser and Gottlieb (2008) for recent discussions of issues in estimating agglomeration elasticities.

ward. Empirically, we would require additional data, such as land values, to distinguish elasticities from home-productivity.

3.2 Reduced-Form Elasticities

Using the main parametrization , assuming $\varepsilon_{L,r} = 0$ with no agglomeration effects, the differential for population density given by (22) is

$$\hat{N}^j \approx 8.26\hat{Q}^j + 2.21\hat{A}_X^j + 2.88\hat{A}_Y^j.$$

In comparing the effects of the three attributes, it is useful to normalize them so that they are of equal value. A one-point increase in $\hat{Q}^j$ has the value of a one-point increase in income, while one-point increases in $\hat{A}_X^j$ and $\hat{A}_Y^j$ have values of s_x and s_y of income due to their sector sizes. Thus,

$$\begin{aligned} \hat{N}^j \approx & \varepsilon_{N,Q}\hat{Q}^j + \frac{\varepsilon_{N,A_X}}{s_x} s_x \hat{A}_X^j + \frac{\varepsilon_{N,A_Y}}{s_y} s_y \hat{A}_Y^j \\ & = 8.26\hat{Q}^j + 3.45 s_x \hat{A}_X^j + 8.00 s_y \hat{A}_Y^j. \end{aligned} \tag{31}$$

Both quality of life and home productivity have large impacts on local population density: increasing their value by one-percent of income results in a density increase of eight percentage points. The impact of trade productivity is less than half. As a result, funds well-spent to attract households directly may be more effective at boosting metropolitan population than funds spent to attract firms.

Setting τ to zero in the parametrization reveals that taxes cause much of these asymmetries:

$$\hat{N}^j \approx 7.09\hat{Q}^j + 5.81 s_x \hat{A}_X^j + 7.55 s_y \hat{A}_Y^j.$$

Taxes push workers away from from trade-productive areas towards high quality of life and home-productive areas.[21] Remaining differences are explained primarily by the income effect from quality of life, discussed earlier, and an output effect from home productivity, which provides additional living space for residents.

In Table 2, we demonstrate how the three reduced-form elasticities for population depend on the structural elasticities, holding constant the values of all other parameters. The population response from quality of life stems from five effects, discussed earlier.

$$\varepsilon_{N,Q} \approx 0.77 + 1.26\sigma_D + 1.95\sigma_X + 8.02\sigma_Y + 11.85\varepsilon_{L,r} \tag{32}$$

Table 2 implies that the most important substitution elasticity for population density is σ_Y.[22] Letting only σ_Y remain a free parameter, we see

$$\hat{N}^j \approx (2.92 + 8.02\sigma_Y)\hat{Q}^j + (1.32 + 3.21\sigma_Y)s_x\hat{A}_X^j + (3.17 + 7.24\sigma_Y)s_y\hat{A}_Y^j.$$

The intuition for this result is simple: increasing population density changing the housing stock strains other substitution margins.[23] Without substitution possibilities in housing, higher densities are accommodated by increasing the occupancy of existing housing structures, or releasing land from the traded-good sector, which is not land intensive.

We gauge how substitution possibilities combined accommodate density in a simple manner by restricting the elasticities to be equal, $\sigma_D = \sigma_X = \sigma_Y \equiv \sigma$. This reveals small constants from income and output effects:

$$\hat{N}^j \approx (0.77 + 11.23\sigma)\hat{Q}^j + (5.17\sigma)s_x\hat{A}_X^j + (0.77 + 8.78\sigma)s_y\hat{A}_Y^j. \tag{33}$$

In a Cobb-Douglas economy, $\sigma = 1$, the implied elasticities are almost 50-percent higher than if

[21] Albouy (2009a) discusses how to make federal taxes "geographically neutral" so that they do not distort household location decisions.

[22] Recall that we set $\varepsilon_{L,r} = 0$ when considering density.

[23] The estimates from assuming $\sigma_Y = 0$ might be more accurate in predicting population flows to negative shocks in the spirit of Glaeser and Gyourko (2005), who highlight the asymmetric impact of durable housing on population flows.

$\sigma = 0.667$.[24] If substitution margins are inelastic, then assuming a Cobb-Douglas economy – as many authors do – may inflate quantity predictions.

The effects of agglomeration feedback are seen most transparently by parameterizing the multiplier in (24).

$$(1 + \gamma\varepsilon_{N,Q} - \alpha\varepsilon_{N,A_X})^{-1} \approx (1 + (0.015)(8.26) - (0.06)(2.21))^{-1} \approx 1.01$$

With the values we posited, the positive and negative economies largely offset each other, and so biases from ignoring agglomeration feedback might be modest. Taken individually, the multiplier for positive feedback (through trade productivity) increases density by 15-percent, while the negative feedback multiplier (through quality of life) reduces density by 11-percent. These numbers are likely bounds for positive or negative effects. Holding an area fixed, basic agglomeration feedback appears relatively weak relative to other forces, such as natural advantages, or other local factors not modeled, such as path dependence. If we examined total city population, and admitted a role for land supply or spillovers between areas, then agglomeration effects might be more important.[25]

While we focus on a single quantity here, population density, many other quantities, such as capital stocks, are worth investigating. One challenge is that across-metro data on most of these quantities is unavailable. Table 3 lists the reduced-form elasticities for all endogenous prices and quantities: Panel A for the baseline parametrization, and Panel B with geographically neutral federal taxes. Appendix Table A.1 contains estimates with the agglomeration effects.

4 General-Equilibrium Elasticities and Empirical Estimates

Commonly estimated elasticities of local labor demand or housing supply are often predicated on partial-equilibrium models that analyze markets separately; the general-equilibrium model here analyzes consumption and labor markets simultaneously. The model complements empirical work

[24] When $\sigma = 1$, we obtain $\hat{N}^j \approx 12.00\hat{Q}^j + 5.18 s_x \hat{A}_X^j + 10.92 s_y \hat{A}_Y^j$

[25] Agglomeration could affect the extensive land supply margin, which might lead to additional feedback effects, if positive and negative economies displayed a sizable imbalance.

in two distinct ways. First, it clarifies restrictions used to identify estimates. Second, it may simulate effects that cannot be credibly estimated.

In this frictionless setting, comparative statics provide prediction for the very long run. The predictions account for changes in the housing stock and tradable-goods production, the amortization of moving costs, and the adaptation of migrants to new surroundings until they resemble locals. Adjustments of this kind may take decades, if not generations, making the model poorly suited for analyzing short-run changes.

4.1 Local Labor Supply and Demand

In partial equilibrium, a local labor supply curve is traced out by increasing demand. The closest analogy to an increase in labor demand is an increase in trade productivity. The resulting labor supply curve slopes upwards: higher density raises demand for home goods and their prices, requiring higher wage compensation. If workers have heterogeneous tastes, then the slope of the supply curve would rise, as higher wages will attract those with weaker tastes for the location — section 2.6. Yet, even with homogeneous households, the labor supply elasticity is finite. A "ceteris paribus" increase in the wage – holding home good prices constant – does not identify a labor supply elasticity. Since trade productivity pushes up home-good prices, keeping the home-good price constant would also mean either quality of life falls, shifting labor supply in, or home productivity rises, shifting housing supply out.[26]

In this framework, the elasticity of labor supply is the ratio of the percent increase in the number of worker-households to the increase in local wages:

$$\left.\frac{\partial \hat{N}}{\partial \hat{w}}\right|_{\hat{Q},\hat{A}_Y} = \frac{\partial \hat{N}/\partial \hat{A}_X}{\partial \hat{w}/\partial \hat{A}_X} \approx \frac{2.210}{1.091} \approx 2.02,$$

[26]More technically, consider a trade productivity differential, $\hat{A}_X^j > 0$. Equation (18) shows that a positive wage differential will result as long as $s_x(1-\lambda_L)\hat{A}_X^j > \lambda_L \hat{Q}^j + s_y \lambda_L \hat{A}_Y^j$. Equation (19), along with the restriction that $\hat{p}^j = 0$, implies $s_x(1-\lambda_L)(1-\tau)\hat{A}_X^j = -(\lambda_N - \lambda_L)\hat{Q}^j + s_y\lambda_L(1-\tau)\hat{A}_Y^j$. Combined, these two conditions show that for any positive trade productivity differential, the equilibrium features a positive wage differential and no home price differential as long as the quality of life differential is negative; this result holds for any home productivity differential.

Many researchers have tried to estimate the supply elasticity using Bartik's (1991) instrumental variable (IV) strategy to isolate labor demand changes.[27] Estimates seen in Bartik and Notowidigdo (2012) are in the range of 2 to 4, which includes the value predicted by the parametrized model. While our value may be low, empirical estimates may also be biased upwards If increases in demand (i.e., increases in A_X) are positively correlated with increases in supply (i.e., increases in Q), as seen below.[28]

A local labor demand curve is traced out by increasing supply. The closest analogy to a shift in supply is an increase in local quality of life, which lowers the wage workers require. The resulting labor demand curve slopes downward: holding productivity (and agglomeration) constant, a larger work force pushes down wages, as firms must complement it with ever scarcer and more expensive land.[29] The elasticity of labor demand is then given by the ratio

$$\left.\frac{\partial \hat{N}}{\partial \hat{w}}\right|_{\hat{A}_X,\hat{A}_Y} = \frac{\partial \hat{N}/\partial \hat{Q}}{\partial \hat{w}/\partial \hat{Q}} \approx \frac{8.261}{-0.359} \approx -23.01$$

Perhaps the best-known empirical analogies for this expression come from studies of the effect of immigration-induced changes in relative labor supply on relative wages. A common empirical strategy emphasizes that existing immigrant enclaves are attractive to new immigrants from similar source countries (e.g., Bartel 1989, Card 2001). Historic immigration patterns generate cross-sectional variation in quality of life. In general, this literature finds relative wages at the city level to be fairly unresponsive to increases in relative labor supply, broadly consistent with the large elasticity above.[30]

[27]Bartik's IV predicts changes in local labor demand based on national changes in industrial composition and a city's past industrial structure. Reconciling the Bartik IV with a frictionless, long run general-equilibrium model is challenging. If labor and capital are fully mobile, then a city's past industrial structure should have little predictive power over its current industrial structure. On the other hand, if a city's past industrial structure is correlated with unobservable determinants of current labor demand, perhaps due to quality of life or home productivity, then the IV is endogenous. Moretti (2011) also discusses difficulties which arise in estimating local labor supply elasticities.

[28]The estimates in Notowidigdo (2012) reveal an increase in housing costs, along with higher wages, that are consistent with a small increase in quality of life. We leave for future research the task of more closely linking existing empirical strategies with a general-equilibrium model.

[29]Some models simply assume a fixed factor in production, e.g., land which is only available for the tradable sector. Here, land in the tradable sector competes with land in the non-tradable sector, causing the price to rise as more households enter and demand home goods.

[30]A number of papers estimate the relationship between immigration-induced (total) labor supply changes and

4.2 Local Housing Supply and Demand

A city's population is closely tied to its housing stock. We assume housing is provided in a perfectly substitutable "efficiency unit" proportionally to non-housing home goods. Empirical evidence suggests that housing accounts for the majority of local price variation (Albouy 2008). The difference between population and housing (interpreted as a fixed fraction of home goods) is due to substitution and income effects in consumption.

$$\begin{aligned}\hat{Y}^j &= \hat{N}^j - 0.43\hat{p}^j - \hat{Q}^j \\ &= 6.17\hat{Q}^j + 2.38 s_x \hat{A}_X^j + 8.21 s_y \hat{A}_Y^j\end{aligned}$$

Relative to population density, housing responds less to quality of life and trade productivity and more to home productivity.

In tracing out a housing supply curve, the source of the demand shift matters considerably. Two candidates are increases in quality of life or trade productivity. The response in supply relative to price is much greater when quality of life shifts demand.

$$\left.\frac{\partial \hat{Y}}{\partial \hat{p}}\right|_{\hat{A}_X,\hat{A}_Y} = \frac{\partial \hat{Y}/\partial \hat{Q}}{\partial \hat{p}/\partial \hat{Q}} \approx \frac{6.175}{2.544} \approx 2.43$$

$$\left.\frac{\partial \hat{Y}}{\partial \hat{p}}\right|_{\hat{Q},\hat{A}_Y} = \frac{\partial \hat{Y}/\partial \hat{A}_X}{\partial \hat{p}/\partial \hat{A}_X} \approx \frac{1.524}{1.608} \approx 0.95.$$

These values are within the range reported in Saiz (2010) of 0.80 to 5.45 for different cities. His

(average) wage changes. In fact, this is the closest empirical analog to $(\partial \hat{N}/\partial \hat{w})|_{\hat{A}_X,\hat{A}_Y}$. However, results from such regressions are typically inconsistent; see Borjas (1999).

We may also model an atypical supply and demand increase due to higher housing productivity, which may be seen as increase in housing supply. In this case, firms may demand more labor to produce more home goods, while the supply of workers increases because the cost-of-living falls. The net result is a large increase in labor relative to wages.

$$\left.\frac{\partial \hat{N}}{\partial \hat{w}}\right|_{\hat{Q},\hat{A}_X} = \frac{\partial \hat{N}/\partial \hat{A}_Y}{\partial \hat{w}/\partial \hat{A}_Y} \approx \frac{2.879}{-0.117} \approx -24.61.$$

We are not aware of any estimates of this elasticity, although work by Saks (2008) and others has highlighted the importance of housing supply in accommodating worker inflows.

empirical strategy uses industrial composition, immigrant enclaves, and sunshine as sources of exogenous variation to identify these elasticities. By combining labor demand and supply variables, the estimates appear to be a hybrid of the two elasticities above. Ostensibly, researchers are more interested in cross-metro variation due to substitution σ_Y and land supply $\varepsilon_{L,r}$. But it is unclear whether the estimated heterogeneity is due to parameter variation or the source of identifying variation. Places with higher estimated housing supply elasticities might have more flexible production or might be identified more from quality of life variation.

Shifts in supply due to home productivity identify metro-level housing demand. Increasing home productivity lowers prices slightly, but by much less than it increases the amount of housing.[31]

$$\left.\frac{\partial \hat{Y}}{\partial \hat{p}}\right|_{\hat{Q},\hat{A}_X} = \frac{\partial \hat{Y}/\partial \hat{A}_Y}{\partial \hat{p}/\partial \hat{A}_Y} \approx \frac{2.953}{-0.172} \approx -17.17$$

Increasing the supply of housing stock requires a greater number of workers to build, maintain, and refresh this stock, which increases the demand for land and housing. Thus, with homogenous preferences, improvements to housing productivity, such as from reducing regulations, will be seen much more in quantities than prices. Even with heterogeneous preferences, it is not clear that this elasticity would become much lower (Aura and Davidoff, 2008).

5 The Relationship between Density, Prices, and Amenities

5.1 Data

We define cities at the Metropolitan Statistical Area (MSA) level using 1999 Office of Management and Budget definitions of consolidated MSAs (e.g., San Francisco is combined with Oakland and San Jose), of which there are 276. We use the 5-percent sample of 2000 United States Census from Ruggles et al. (2004) to calculate wage and housing price differentials, controlling for relevant

[31] Note that increasing the production elasticity σ_Y has no first-order effect on prices; see equation (19).

covariates.[32] Population density also comes from the 2000 Census. At the census tract level we take the ratio of population to land area, and then population average these numbers to form an MSA value of density. Figure 2 displays metro-level density estimates for the year 2000. All of our empirical results below use MSA population weights.

5.2 Density Predictions and Substitution Elasticities

We first consider how well the model predicts population densities using price information alone, examining the accuracy of parametrized model. Following the discussion above, we use $\hat{w}^j$ and $\hat{p}^j$ to estimate $\hat{Q}^j$ and $\hat{A}_X^j$, assuming $\hat{A}_Y^j = 0$, from equations (1*) and (26). Given these amenity estimates and the values for the elasticities above, we predict $\hat{N}^j$ using equation (22) for each city and compare this with actual population density differences.[33]

The variance in log population density differences across MSAs is 0.770. As shown in Table 4, the variance predicted by the model is 0.359, which means that a remarkable 47-percent of density variation is explained by the neoclassical model without fitting a single parameter.

To determine whether we could explain more variation by choosing the elasticities of substitution – i.e., actually calibrating the model – we consider how well combinations of σ_D, σ_X, and σ_Y predict densities. In Figure 3, we graph the variance of the prediction error as a function of the elasticities of substitution. If, for simplicity's sake, we restrict $\sigma_D = \sigma_X = \sigma_Y = \sigma$, as in equation (33), prediction error is minimized at $\sigma = 0.662$, very close to our parametrization. Other values increase prediction error, including the case $\sigma = 1$. The next curve fixes $\sigma_X = 0.667$, which reduces the prediction error for all the other values of $\sigma_D = \sigma_Y$, but only by a small amount. Also fixing $\sigma_D = 0.667$, as in the last curve, reduces prediction error by roughly the same amount. The greatest reduction comes from setting $\sigma_Y = 0.667$, further emphasizing its importance. If σ_Y is set to zero, the model reduces prediction error by only half as much relative to when $\sigma_Y = 0.667$. The

[32] See Appendix D for more details on the calculation of wage and price differentials.

[33] In essence, we predict population density using two simple price estimates, without estimating, or even calibrating, a single parameter, since the parameters are pre-set values taken from the literature in an already-published article; it may be restated as a regression $\hat{N}^j = \beta_w^0 \hat{w}^j + \beta_p^0 \hat{p}^j + \epsilon^j$ where β_w^0 and β_p^0 are set by the model.

takeaway from this exercise is that the pre-set parametrization does quite well relative to potential calibrations.[34]

5.3 Determinants of Population Density

In Table 4, we use a variance decomposition to determine whether quality of life or trade productivity is more important in determining density differences. Quality of life and inferred costs (taken currently as trade productivity) are positively correlated, as seen in the Table and graphically in Figure A.1. Quality of life alone explains nearly half of the explained variance, dominating trade productivity, even though the latter shows greater cross-sectional variation in value, as seen in Appendix Figure A.2. The cross-sectional evidence supports the view that "jobs follow people" more than "people follow jobs."

5.4 Estimating Trade and Home Productivity with Density

We now relax the restriction $\hat{A}_Y^j = 0$ to use density data to identify trade and home productivity separately, using the method in Section 2.7. Panel A of Figure 4 displays estimated measures of inferred cost and excess density (relative to quality of life) for metros from the left hand sides of equations (26) and (27). The figure includes iso-productivity lines for both tradable and home sectors.

To understand how trade productivity is inferred, consider the downward-sloping iso-trade productivity line, along which cities have average trade productivity. Above and to the right of this line, cities have higher excess density or inferred costs, indicating above-average trade productivity. Above and to the left of the upward-sloping iso-home productivity line, cities have high excess

[34] An unrestricted regression of log density on wages and housing costs naturally produces a higher R-squared of $0.72 > 0.47$, with $\hat{N}^j = 4.40\hat{w}^j + 0.90\hat{p}^j + e^j = 0.63\hat{Q}^j + 6.26\hat{A}_X^j + e^j$. Relative to the parametrization, this produces an estimate of $\varepsilon_{N,Q}$ that is very low and ε_{N,A_X} that is very high. The two estimated reduced-form elasticities are insufficient for identifying the three elasticity parameters. Furthermore, since the estimated coefficient on $\hat{Q}^j$ of 0.63 is less than the constant 0.77 in equation (32), then at least one of the substitution elasticities would have to be negative, which is untenable. The parametrized model suggests that e^j, which includes $\hat{A}_Y^j$, is positively correlated with A_X^j or negatively correlated with $\hat{Q}^j$. If we instead constrain the estimates to fit the restriction $\sigma_D = \sigma_X = \sigma_Y = \sigma$, as in equation (33), then we obtain $\hat{N}^j = 8.57\hat{Q}^j + 2.30\hat{A}_X^j + e^j$ implying a $\sigma = 0.680$. Slight differences stem from treatment of state taxes, which allow β_w^0 and β_p^0 to vary somewhat according to within state variation in prices.

density or low inferred costs, indicating high home productivity. Vertical deviations from this line equal the error due to imposing $\hat{A}_Y^j = 0$, as in section 5.2, where $\hat{A}_X^j$ is equated with inferred costs. Since the first line line is almost vertical, and the second almost horizontal, excess density has a small impact on trade productivity measures and a large impact on home productivity measures. If the structural elasticities are assumed larger, the lines become more vertical, as smaller amenity differences are needed to generate excess density.

Panel B of Figure 4 uses the same data as Panel A, but graphs trade and home productivity directly, through a change in coordinates. Philadelphia and Chicago have high levels of trade and home productivity, while New York is most productive overall. San Francisco has the highest trade productivity, but rather low home productivity. San Antonio has low trade productivity and high home productivity. Santa Fe and Myrtle Beach are unproductive in both sectors.[35]

Two important points should be made about the home-productivity estimates. First, they strongly reflect density measures, and rather weakly reflect prices.[36] Second, home productivity appears strongest in large, older cities. We can explain part of this by noting that these cities were largely built prior to World War I, when land-use regulations were largely absent, and high densities offset once-high commuting costs.[37]

To summarize the data and findings, Table 5 contains estimates of population density, wages,

[35]Panel B of Figure 4 also includes isoclines for excess density and inferred costs, which correspond to the axes in Panel A. Holding quality of life constant, trade productivity and home productivity must move in opposite directions to keep population density constant. Holding quality of life constant, home productivity must rise faster than trade productivity to keep inferred costs constant.

[36]According to the parametrization, $\hat{A}_Y^j \approx 0.32\hat{N}^j + 0.73\hat{w}^j - 0.94\hat{p}^j$, which is largely a measure of residual density since density varies so greatly and prices and wages are positively correlated. Trade productivity is $\hat{A}_X^j \approx 0.03\hat{N}^j + 0.84\hat{w}^j + 0.01\hat{p}^j$. Land values reflect all three measures positively, $\hat{r}^j \approx 1.38\hat{N}^j + 0.49\hat{w}^j + 0.28\hat{p}^j$, although density is key. Finally, quality of life depends only on the price measures: $\hat{Q}^j \approx -0.48\hat{w}^j + 0.32\hat{p}^j$. See Appendix Table A.3.

[37]Some of these findings appear to conflict with recent work by Albouy and Ehrlich (2012), who use data on land values to infer productivity in the housing sector, which comprises most of the non-tradable sector. While the two approaches generally agree on which large areas have high home productivity, the land values approach suggests that larger, denser cities generally have lower, rather than higher housing productivity. This apparent contradiction actually highlights what the two methodologies infer differently. Productivity measures based on current land values provide a better insight into the marginal cost of increasing the housing supply, by essentially inferring the replacement cost. Productivity measures based on density are more strongly related to the average cost of the housing supply, thereby reflecting the whole history of building in a city. The distinction matters particularly for older cities where older housing was built on the easiest terrain, and in decades prior strict residential land-use regulations, which typically grandfather pre-existing buildings.

housing costs, inferred costs, land values, and attribute differentials for a selected sample of metropolitan areas. Table A.2 contains a full list of metropolitan and non-metropolitan areas; the table also compares the trade productivity estimates from the two approaches.

Column 1 of Table 6 decomposes the variance of observed (which now equals predicted) population density across all three attributes. As before, quality of life dominates trade productivity. Yet both appear to be dominated by home productivity. While all three attributes are important in explaining density, it appears that "jobs and people follow housing" more than anything else. Given the residual nature of our housing measure, this conclusion should be treated with caution, but it complements the finding that substitution possibilities in housing are key to explaining the responsiveness of population to amenities.

Column 2 of Table 6 explores how the determinants of population density would change if federal taxes were made geographically neutral, ignoring any potential agglomeration feedback.[38] Trade productivity now affects density more than quality of life. Over the long-run, eliminating the geographic distortion in the tax code would cause households to chase employment opportunities more than household amenities, contrary to the current situation.

In a further exercise, shown in (Table A.4), we simultaneously account for agglomeration and congestion forces. The results are straightforward, but worth mentioning. We find feedback reinforces the role of natural advantages in quality of life, as the observed values are reduced through congestion. On the other hand, natural advantages in trade productivity are less important, as much of the differences we observe are created endogenously through agglomeration.

6 Conclusion

Although Rosen and Roback designed the neoclassical model to explain price differences across metro areas, it provides a surprisingly accurate basis for predicting population density. The model

[38] In particular, we use our amenity estimates and parametrized model to predict prices and quantities (including population density) for each city in the absence of location-distorting federal income taxes. Because we estimate amenities using observed density, wage, and housing price data, we cannot estimate amenities in the absence of distortionary federal taxes.

provides microfoundations for elasticities of supply and demand for labor and housing. It also may help provide measures for the productivity of local-good, especially housing, producers, and fill in missing land values. Using pre-set parameters and two simple measures of wages and housing costs, the model explains half of the variation in metropolitan density, with quality of life dominating jobs as a location determinant. Within the neoclassical framework, the other half may be explained by differences in home good productivity, as explored here, or heterogeneity in structural parameters, like the elasticity of substitution in home good production. By extending the model, additional variation in population density might be explained by factor-biased productivity, non-homothetic preferences, or household heterogeneity in skills or preferences. Beyond standard neoclassical factors, issues such as historical path dependence, flexible preference heterogeneity, and mobility frictions (considered only in passing above) might also account for the remaining variation. While the number of complications is quite large, it is surprising that a simple neoclassical model can explain population density so clearly.

Overall, large differences in population density are consistent with small differences in observed differences in wages and housing costs. This results from population being very elastic to amenity differences, even though individual substitution margins in consumption and production appear inelastic. The most important margin appears to be that in housing. Several recent studies address the important task of analyzing housing and labor markets jointly (e.g., Moretti 2011, Notowidigdo 2012, Busso et al. 2013, Diamond 2013, Moretti 2013). However, most work ignores the role of land in tradable production, and labor in non-tradable production, limiting linkages between both markets. Agglomeration effects may be important for many issues in urban and labor economics, but are surprisingly limited in explaining metro density. Future work exploring cross-metro population differences should address the overall amount of land used in an area, which might require addressing the complication that supramarginal land is less valuable than inframarginal land.

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Table 1: U.S. Parametrization

Parameter Name	Notation	Value
Cost and Expenditure Shares		
Home good expenditure share	s_y	0.36
Income share to land	s_R	0.10
Income share to labor	s_w	0.75
Traded good cost share of land	θ_L	0.025
Traded good cost share of labor	θ_N	0.825
Home good cost share of land	ϕ_L	0.233
Home good cost share of labor	ϕ_N	0.617
Share of land used in traded good	λ_L	0.17
Share of labor used in traded good	λ_N	0.70
Tax Parameters		
Average marginal tax rate	τ	0.361
Average deduction level	δ	0.291
Structural Elasticities		
Elasticity of substitution in consumption	σ_D	0.667
Elasticity of traded good production	σ_X	0.667
Elasticity of home good production	σ_Y	0.667
Elasticity of land supply	$\varepsilon_{L,r}$	0.0

Parametrization pre-set in Albouy (2009a). See Appendix C for details.

Table 2: Relationship between Reduced-Form Population and Production Elasticities

	Reduced-form Population Elasticity with Respect to:		
	Quality of Life	Trade Productivity	Home Productivity
	$\varepsilon_{N,Q}$	ε_{N,A_X}	ε_{N,A_Y}
σ_D	1.258	0.795	-0.085
σ_X	1.954	0.467	0.636
σ_Y	8.015	2.052	2.608
$\varepsilon_{L,r}$	11.853	4.009	3.857
Constant	0.773	0.000	0.773

Table 2 decomposes reduced-form population elasticities into substitution elasticities in consumption (σ_D), traded good production (σ_X), and home good production (σ_Y). For example, $\varepsilon_{N,Q} = 0.773 + 1.258\sigma_D + 1.954\sigma_X + 8.015\sigma_Y + 11.853\varepsilon_{L,r}$.

Table 3: Parametrized Relationship between Amenities, Prices, and Quantities

		A: With Taxes (current regime)			B: Neutral Taxes (counterfactual)		
Price/quantity	Notation	Quality of Life $\hat{Q}$	Trade Productivity $\hat{A}_X$	Home Productivity $\hat{A}_Y$	Quality of Life $\hat{Q}$	Trade Productivity $\hat{A}_X$	Home Productivity $\hat{A}_Y$
Land value	$\hat{r}$	11.853	4.009	3.857	10.001	6.400	3.600
Wage	$\hat{w}$	-0.359	1.091	-0.117	-0.303	1.018	-0.109
Home price	$\hat{p}$	2.544	1.608	-0.172	2.146	2.121	-0.227
Trade consumption	$\hat{x}$	-0.389	0.386	-0.041	-0.654	0.728	-0.078
Home consumption	$\hat{y}$	-2.086	-0.686	0.074	-1.916	-0.905	0.097
Population density	$\hat{N}$	8.261	2.210	2.879	7.091	3.721	2.717
Land	$\hat{L}$	0.000	0.000	0.000	0.000	0.000	0.000
Capital	$\hat{K}$	8.008	2.907	2.774	6.864	4.385	2.616
Trade production	$\hat{X}$	8.085	3.414	2.926	7.008	4.805	2.777
Home production	$\hat{Y}$	6.175	1.524	2.953	5.175	2.816	2.815
Trade labor	$\hat{N}_X$	8.324	2.354	3.004	7.210	3.792	2.850
Home labor	$\hat{N}_Y$	8.112	1.869	2.583	6.809	3.551	2.403
Trade land	$\hat{L}_X$	0.178	0.407	0.354	0.337	0.203	0.376
Home land	$\hat{L}_Y$	-0.034	-0.078	-0.067	-0.064	-0.039	-0.071
Trade capital	$\hat{K}_X$	8.045	3.081	2.926	7.008	4.471	2.777
Home capital	$\hat{K}_Y$	7.872	2.596	2.505	6.607	4.230	2.330

Each value in Table 3 represents the partial effect that a one-point increase in each amenity has on each price or quantity, e.g., $\hat{N}^j = 8.261\hat{Q}^j + 2.210\hat{A}_X^j + 2.879\hat{A}_Y^j$ under the current U.S. tax regime. Values in panel A are derived using the parameters in Table 1. Values in panel B are derived using geographically neutral taxes. All variables are measured in log differences from the national average.

Table 4: Fraction of Predicted Population Density Explained by Quality of Life and Trade Productivity

Variance/Covariance Component	Notation	Fraction Explained
Quality of life	$\mathrm{Var}(\varepsilon_{N,Q}\hat{Q})$	0.498
Trade productivity	$\mathrm{Var}(\varepsilon_{N,A_X}\hat{A}_X)$	0.184
Quality of life and trade productivity	$\mathrm{Cov}(\varepsilon_{N,Q}\hat{Q}, \varepsilon_{N,A_X}\hat{A}_X)$	0.318
Variance of Predicted Population Density: 0.359		

Table 4 presents the variance decomposition of predicted population density differences using data on wages and house price differences only.

Table 5: List of Selected Metropolitan Areas, Ranked by Population Density

Name of Metropolitan Area	Population Density $\hat{N}^j$	Wage $\hat{w}^j$	Home Price $\hat{p}^j$	Land Value $\hat{r}^j$	Quality of Life $\hat{Q}^j$	Trade Productivity $\hat{A}_X^j$	Home Productivity $\hat{A}_Y^j$
New York, Northern New Jersey, Long Island, NY-NJ-CT-PA	2.285	0.209	0.411	3.366	0.029	0.264	0.509
Los Angeles-Riverside-Orange County, CA	1.250	0.129	0.450	1.913	0.081	0.159	0.079
San Francisco-Oakland-San Jose, CA	1.209	0.256	0.813	2.000	0.138	0.269	-0.182
Chicago-Gary-Kenosha, IL-IN-WI	1.191	0.136	0.224	1.767	0.005	0.161	0.276
Miami-Fort Lauderdale, FL	0.964	0.001	0.126	1.352	0.041	0.035	0.191
Philadelphia-Wilmington-Atlantic City, PA-NJ-DE-MD	0.958	0.114	0.052	1.393	-0.040	0.133	0.346
San Diego, CA	0.872	0.058	0.479	1.403	0.123	0.085	-0.114
Salinas (Monterey-Carmel), CA	0.863	0.103	0.590	1.435	0.137	0.124	-0.189
Boston-Worcester-Lawrence, MA-NH-ME-CT	0.797	0.123	0.294	1.241	0.034	0.136	0.074
Santa Barbara-Santa Maria-Lompoc, CA	0.713	0.068	0.662	1.255	0.176	0.090	-0.326
. . .							
Johnson City-Kingsport-Bristol, TN-VA	-1.485	-0.179	-0.363	-2.236	-0.028	-0.209	-0.273
Goldsboro, NC	-1.509	-0.183	-0.297	-2.226	-0.007	-0.213	-0.340
Dothan, AL	-1.533	-0.181	-0.404	-2.314	-0.040	-0.214	-0.253
Texarkana, TX-Texarkana, AR	-1.556	-0.185	-0.498	-2.388	-0.068	-0.219	-0.178
Anniston, AL	-1.579	-0.183	-0.424	-2.385	-0.046	-0.216	-0.250
Ocala, FL	-1.582	-0.170	-0.298	-2.363	-0.010	-0.205	-0.362
Florence, SC	-1.606	-0.120	-0.341	-2.381	-0.049	-0.162	-0.292
Hickory-Morganton-Lenoir, NC	-1.624	-0.127	-0.220	-2.356	-0.008	-0.168	-0.412
Rocky Mount, NC	-1.640	-0.111	-0.246	-2.384	-0.024	-0.155	-0.381
Jonesboro, AR	-1.651	-0.240	-0.452	-2.533	-0.026	-0.269	-0.293
Standard Deviation	0.876	0.113	0.280	1.319	0.053	0.127	0.202

Table 5 includes the top and bottom ten metropolitan areas ranked by population density. The first three columns are estimated from Census data, while the last four columns come from the parametrized model. See text for estimation procedure. Standard deviations are calculated among the 276 metropolitan areas using metro population weights. All variables are measured in log differences from the national average.

Table 6: Fraction of Population Density Explained by Quality of Life, Trade Productivity, and Home Productivity

		(1) With Taxes (current regime)	(2) Neutral Taxes (counterfactual)
Variance/Covariance Component	Notation	Fraction Explained	
Quality of life	$\text{Var}(\varepsilon_{N,Q}\hat{Q})$	0.232	0.131
Trade productivity	$\text{Var}(\varepsilon_{N,A_X}\hat{A}_X)$	0.102	0.221
Home productivity	$\text{Var}(\varepsilon_{N,A_Y}\hat{A}_Y)$	0.439	0.300
Quality of life and trade productivity	$\text{Cov}(\varepsilon_{N,Q}\hat{Q}, \varepsilon_{N,A_X}\hat{A}_X)$	0.137	0.151
Quality of life and home productivity	$\text{Cov}(\varepsilon_{N,Q}\hat{Q}, \varepsilon_{N,A_Y}\hat{A}_Y)$	-0.145	-0.090
Trade and home productivity	$\text{Cov}(\varepsilon_{N,A_X}\hat{A}_X, \varepsilon_{N,A_Y}\hat{A}_Y)$	0.235	0.287
Variance of population density	$\text{Var}(\hat{N})$	0.770	1.005

Column 1 presents the variance decomposition using data on population density, wage, and house price differences. Column 2 presents the variance decomposition under geographically neutral taxes and associated price and quantity predictions.

Figure 1: Distribution of Wages, House Prices, and Population Density, 2000

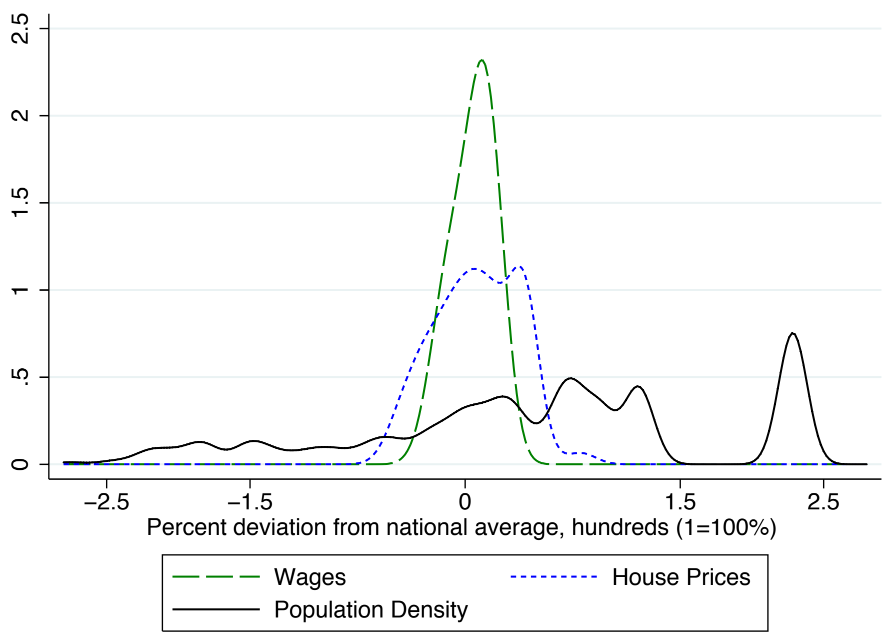


Figure 1 is smoothed with a Gaussian kernel, bandwidth=0.1.

Figure 2: Metropolitan Population Density, Thousands per Square Mile, 2000

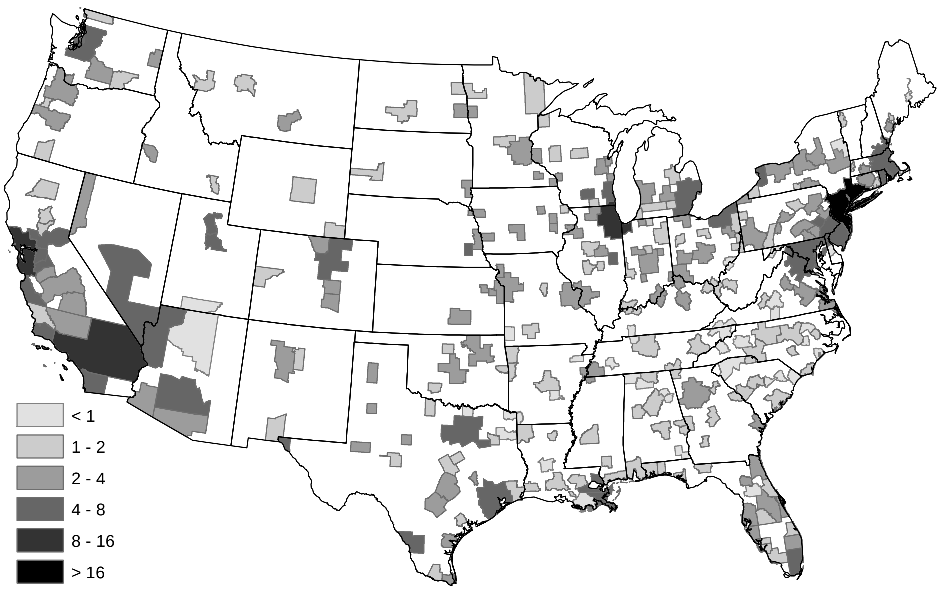


Figure 3: Error in Fitting Population Density using Quality of Life and Trade Productivity Differences, as Function of Substitution Elasticities

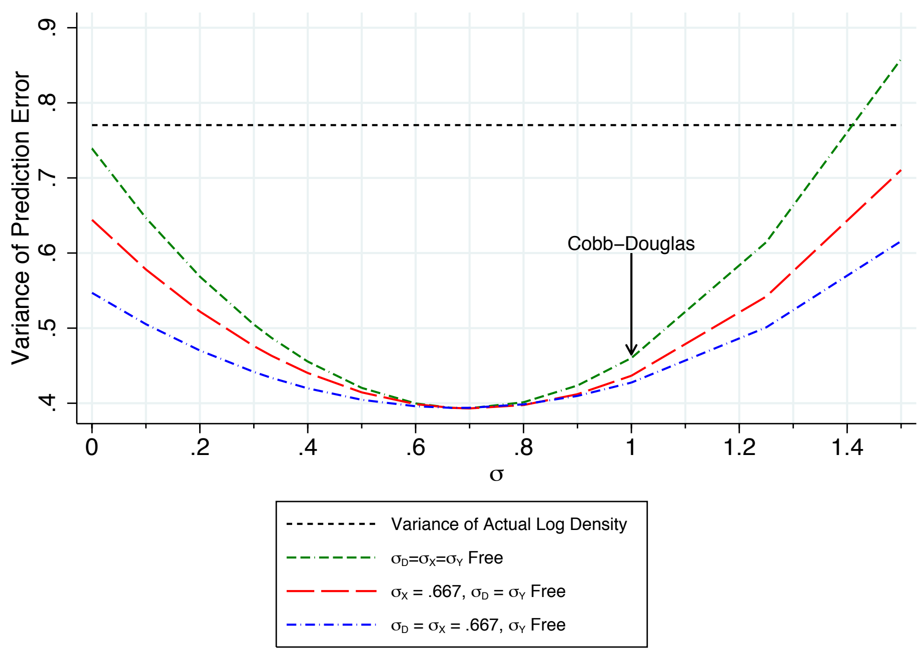
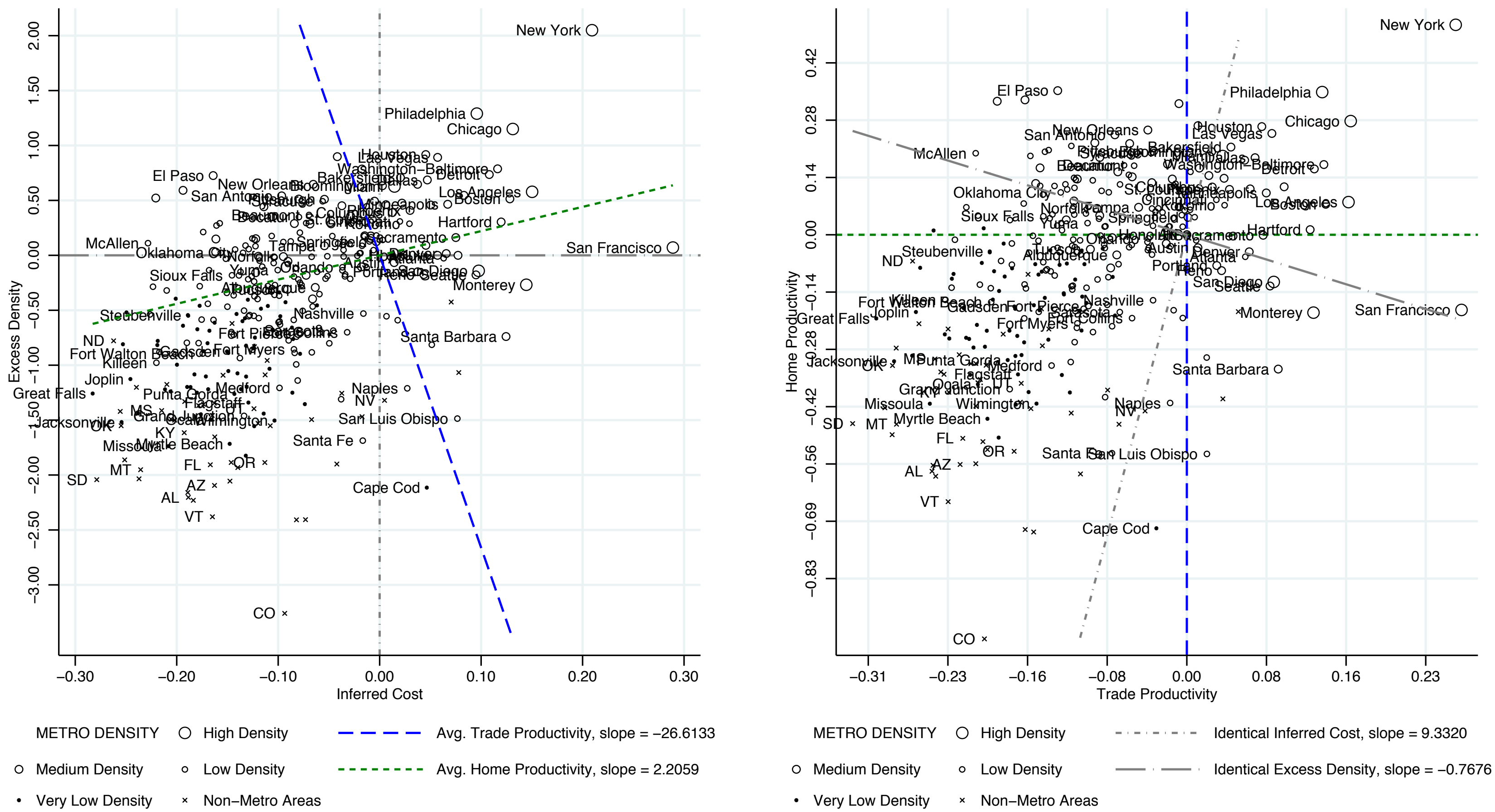


Figure 4: Results of Parametrized Model, 2000



(a) Excess Density and Inferred Cost Estimates

(b) Trade and Home Productivity Estimates

See text for estimation details. High density metros have population density which exceeds the national average by 80 percent, medium density metros are between the national average and 80 percent. Low density and very low density metros are defined symmetrically.

Appendix - For Online Publication

A Comparison of Nonlinear and Log-linear Models

To assess the error introduced by log-linearizing the model, we employ a two-step simulation method to solve a nonlinear version of the model.[39] We assume that utility and production functions display constant elasticity of substitution,

$$U(x, y; Q) = Q(\eta_x x^\alpha + (1 - \eta_x) y^\alpha)^{1/\alpha}$$
$$F_X(L_X, N_X, K_X; A_X) = A_X(\gamma_L L^\beta + \gamma_N N^\beta + (1 - \gamma_L - \gamma_N) K^\beta)^{1/\beta}$$
$$F_Y(L_Y, N_Y, K_Y; A_Y) = A_Y(\rho_L L^\chi + \rho_N N^\chi + (1 - \rho_L - \rho_N) K^\chi)^{1/\chi}$$

where

$$\alpha \equiv \frac{\sigma_D - 1}{\sigma_D}$$
$$\beta \equiv \frac{\sigma_X - 1}{\sigma_X}$$
$$\chi \equiv \frac{\sigma_Y - 1}{\sigma_Y}$$

Throughout, we assume that $\sigma_D = \sigma_X = \sigma_Y = 0.667$. We first consider a "large" city with attribute values normalized so that $Q = A_X = A_Y = 1$. We fix land supply, population, and the rental price of capital $\bar{\iota}$. We then solve a nonlinear system of fifteen equations, corresponding to equations (1)-(14) and (16), for fifteen unknown variables: $\bar{u}, w, r, p, x, y, X, Y, N_X, N_Y, L_X, L_Y, K_X, K_Y, K$. We simultaneously choose values of $\eta_x, \gamma_L, \gamma_N, \rho_L$, and ρ_N so that the model matches values of $s_y, \theta_L, \theta_N, \phi_L$, and ϕ_N in Table 1. The large city solution also yields values for R, I, and T.[40]

We then consider a "small" city, which we endow with land equal to one one-millionth of the large city's land.[41] The population for the small city is endogenous, and the reference utility level $\bar{u}$ is exogenous. The baseline attribute values of the small city are $Q = A_X = A_Y = 1$. While holding two attributes fixed at the baseline, we solve the model after setting the third attribute to be somewhere between 0.8 and 1.2. We solve the same system as for the large city, but now solve for $w, r, p, x, y, X, Y, N_X, N_Y, L_X, L_Y, K_X, K_Y, N, K$.

We compare the nonlinear model to a one-city log-linear model. We use parameter values from Table 1, but set the marginal tax rate $\tau = 0$ and deduction level $\delta = 0$. The baseline attribute differences are $\hat{Q} = \hat{A}_X = \hat{A}_Y = 0$. As with the nonlinear model, we vary a single attribute while holding the other amenities at their baseline value. We can express the entire log-linear system of equations (1*)-(16*):

[39] Rappaport (2008a, 2008b) follows a similar procedure.

[40] To simulate the model, we solve a mathematical program with equilibrium constraints, as described in Su and Judd (2012).

[41] We do this to avoid any feedback effects from the small city to the large one. In particular, this permits use of values of $\bar{u}, \bar{\iota}, R, I$, and T from the large city calibration, which simplifies the procedure considerably.

$$
\left[\begin{array}{cccccccccccccccc}
1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 1 & 0 & -\theta_L & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 1 & -\phi_L & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
\hline
0 & 0 & 0 & 0 & s_x & s_y & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
\hline
0 & 1 & 0 & -\theta_L\sigma_X & 0 & 0 & 1 & 0 & 0 & -1 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 1 & 0 & (1-\theta_L)\sigma_X & 0 & 0 & 0 & 1 & 0 & -1 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 1 & 0 & -\theta_L\sigma_X & 0 & 0 & 0 & 0 & 1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 1 & -\phi_L\sigma_Y & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & -1 & 0 & 0 \\
0 & 0 & 1 & (1-\phi_L)\sigma_Y & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & -1 & 0 & 0 \\
0 & 0 & 1 & -\phi_L\sigma_Y & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & -1 & 0 & 0 \\
\hline
0 & 0 & 0 & 0 & 0 & 0 & \lambda_N & 0 & 0 & 0 & 1-\lambda_N & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & \lambda_L & 0 & 0 & 0 & 1-\lambda_L & 0 & 0 & -1 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \lambda_K & 0 & 0 & 0 & 1-\lambda_K & 0 & 0 & -1 \\
0 & 0 & 0 & \varepsilon_{L,r} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 & 0 \\
0 & 0 & 0 & 0 & 0 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0
\end{array}\right]
\begin{bmatrix} \hat{Q} \\ \hat{A}_X \\ \hat{A}_Y \\ \hat{r} \\ \hat{x} \\ \hat{y} \\ \hat{N}_X \\ \hat{L}_X \\ \hat{K}_X \\ \hat{X} \\ \hat{N}_Y \\ \hat{L}_X \\ \hat{K}_X \\ \hat{Y} \\ \hat{L} \\ \hat{K} \end{bmatrix}
=
\begin{bmatrix} -s_w(1-\tau)\hat{w} + s_y\hat{p} \\ \theta_N\hat{w} \\ \phi_N\hat{w} - \hat{p} \\ s_w(1-\tau)\hat{w} - s_y\hat{p} \\ \sigma_D\hat{p} \\ -(1-\theta_N)\sigma_X\hat{w} \\ \theta_N\sigma_X\hat{w} \\ \theta_N\sigma_X\hat{w} \\ -(1-\phi_N)\sigma_Y\hat{w} \\ \phi_N\sigma_Y\hat{w} \\ \phi_N\sigma_Y\hat{w} \\ \hat{N} \\ 0 \\ 0 \\ 0 \\ \hat{N} \end{bmatrix}
$$

or, in matrix form, as $\mathbf{Av} = \mathbf{C}$. The first three rows of $\mathbf{A}$ correspond to price equations, the second two to consumption conditions, the next six to factor demand equations, and the final five to market clearing conditions.

One can easily rearrange the above matrix so that $\mathbf{C}$ consists only of attribute differentials, which are known in our simulation. The above form demonstrates that, given a parametrization and data on wages, home prices, and population density, the matrices $\mathbf{A}$ and $\mathbf{C}$ are known, so we can solve the above system for the unknown parameters $\mathbf{v}$.

Figure A.3 presents results of both models in terms of reduced-form population elasticities with respect to each amenity.[42] The log-linear model does quite well in approximating density responses to trade and home productivity differences of up to 20-percent, and approximates responses to quality of life quite well for differences of up to 5-percent, the relevant range of estimates for U.S. data in Figure A.2.

B Additional Theoretical Details

B.1 Reduced-Form Elasticities

The analytic solutions for reduced-form elasticities of population with respect to amenities are given below.

$$
\begin{aligned}
\varepsilon_{N,Q} = {} & \left[\frac{\lambda_N - \lambda_L}{\lambda_N}\right] + \sigma_D\left[\frac{s_x(\lambda_N - \lambda_L)^2}{s_y\lambda_N(\lambda_N - \lambda_L\tau)}\right] + \sigma_X\left[\frac{\lambda_L^2}{s_w(\lambda_N - \lambda_L\tau)} + \frac{\lambda_L\lambda_N}{s_R(\lambda_N - \lambda_L\tau)}\right] \\
& + \sigma_Y\left[\frac{\lambda_L^2(1-\lambda_N)}{s_w\lambda_N(\lambda_N - \lambda_L\tau)} + \frac{\lambda_N(1-\lambda_L)}{s_R(\lambda_N - \lambda_L\tau)} - \frac{(\lambda_N - \lambda_L)^2}{s_y\lambda_N(\lambda_N - \lambda_L\tau)}\right] \\
& + \varepsilon_{L,r}\left[\frac{\lambda_N}{s_R(\lambda_N - \lambda_L\tau)}\right]
\end{aligned}
$$

[42]We normalize the elasticities in Figure A.3 for trade and home productivity by s_x and s_y.

$$\varepsilon_{N,A_X} = \sigma_D \left[\frac{s_x^2(\lambda_N - \lambda_L)(1-\lambda_L)(1-\tau)}{s_y \lambda_N(\lambda_N - \lambda_L \tau)} \right] + \sigma_X \left[\frac{s_x \lambda_L(\lambda_N - \tau)}{s_R(\lambda_N - \lambda_L \tau)} - \frac{s_x \lambda_L(1-\lambda_L)}{s_w(\lambda_N - \lambda_L \tau)} \right] +$$
$$\sigma_Y \left[\frac{s_x(1-\lambda_L)(\lambda_N - \tau)}{s_R(\lambda_N - \lambda_L \tau)} - \frac{s_x \lambda_L(1-\lambda_L)(1-\lambda_N)}{s_w \lambda_N(\lambda_N - \lambda_L \tau)} - \frac{s_x(1-\lambda_L)(\lambda_N - \lambda_L)(1-\tau)}{s_y \lambda_N(\lambda_N - \lambda_L \tau)} \right]$$
$$+ \varepsilon_{L,r} \left[\frac{s_x(\lambda_N - \tau)}{s_R(\lambda_N - \lambda_L \tau)} \right]$$

$$\varepsilon_{N,A_Y} = \left[\frac{\lambda_N - \lambda_L}{\lambda_N} \right] + \sigma_D \left[\frac{-s_x \lambda_L(\lambda_N - \lambda_L)(1-\tau)}{\lambda_N(\lambda_N - \lambda_L \tau)} \right] + \sigma_X \left[\frac{s_y \lambda_N \lambda_L}{s_R(\lambda_N - \lambda_L \tau)} + \frac{s_y \lambda_L^2}{s_w(\lambda_N - \lambda_L \tau)} \right]$$
$$+ \sigma_Y \left[-\left(\frac{\lambda_N - \lambda_L}{\lambda_N} \right) + \frac{s_y \lambda_L^2(1-\lambda_N)}{s_w \lambda_N(\lambda_N - \lambda_L \tau)} + \frac{s_y \lambda_N(1-\lambda_L)}{s_R(\lambda_N - \lambda_L \tau)} + \frac{\lambda_L(\lambda_N - \lambda_L)(1-\tau)}{\lambda_N(\lambda_N - \lambda_L \tau)} \right]$$
$$+ \varepsilon_{L,r} \left[\frac{s_y \lambda_N}{s_R(\lambda_N - \lambda_L \tau)} \right]$$

B.2 Special Case: Fixed Per-Capita Housing Consumption

Consider the case in which per-capita housing consumption is fixed, $\hat{y}^j = 0$. The model then yields $\hat{N}^j = \tilde{\varepsilon}_{N,Q}\hat{Q}^j + \tilde{\varepsilon}_{N,A_X}\hat{A}_X^j + \tilde{\varepsilon}_{N,A_Y}\hat{A}_Y^j$, where the coefficients are defined as:

$$\tilde{\varepsilon}_{N,Q} = \sigma_X \left[\frac{\lambda_L^2}{s_w(\lambda_N - \lambda_L \tau)} + \frac{\lambda_L \lambda_N}{s_R(\lambda_N - \lambda_L \tau)} \right] + \varepsilon_{L,r} \left[\frac{\lambda_N}{s_R(\lambda_N - \lambda_L \tau)} \right]$$
$$+ \sigma_Y \left[\frac{\lambda_L^2(1-\lambda_N)}{s_w \lambda_N(\lambda_N - \lambda_L \tau)} + \frac{\lambda_N(1-\lambda_L)}{s_R(\lambda_N - \lambda_L \tau)} - \frac{(\lambda_N - \lambda_L)^2}{s_y \lambda_N(\lambda_N - \lambda_L \tau)} \right]$$
$$\tilde{\varepsilon}_{N,A_X} = \sigma_X \left[\frac{s_x \lambda_L(\lambda_N - \tau)}{s_R(\lambda_N - \lambda_L \tau)} - \frac{s_x \lambda_L(1-\lambda_L)}{s_w(\lambda_N - \lambda_L \tau)} \right] + \varepsilon_{L,r} \left[\frac{s_x(\lambda_N - \tau)}{s_R(\lambda_N - \lambda_L \tau)} \right]$$
$$+ \sigma_Y \left[\frac{s_x(1-\lambda_L)(\lambda_N - \tau)}{s_R(\lambda_N - \lambda_L \tau)} - \frac{s_x \lambda_L(1-\lambda_L)(1-\lambda_N)}{s_w \lambda_N(\lambda_N - \lambda_L \tau)} - \frac{s_x(1-\lambda_L)(\lambda_N - \lambda_L)(1-\tau)}{s_y \lambda_N(\lambda_N - \lambda_L \tau)} \right]$$
$$\tilde{\varepsilon}_{N,A_Y} = \sigma_X \left[\frac{s_y \lambda_N \lambda_L}{s_R(\lambda_N - \lambda_L \tau)} + \frac{s_y \lambda_L^2}{s_w(\lambda_N - \lambda_L \tau)} \right] + \varepsilon_{L,r} \left[\frac{s_y \lambda_N}{s_R(\lambda_N - \lambda_L \tau)} \right]$$
$$+ \sigma_Y \left[\frac{s_y \lambda_L^2(1-\lambda_N)}{s_w \lambda_N(\lambda_N - \lambda_L \tau)} + \frac{s_y \lambda_N(1-\lambda_L)}{s_R(\lambda_N - \lambda_L \tau)} + \frac{\lambda_L(\lambda_n - \lambda_L)(1-\tau)}{\lambda_N(\lambda_N - \lambda_L \tau)} \right]$$

These reduced-form elasticities no longer depend on the elasticity of substitution in consumption σ_D. In addition, above-average quality of life and/or home productivity no longer lead to higher population independently of the substitution elasticities, as seen by the term $(\lambda_N - \lambda_L)/\lambda_N$ dropping out of the elasticities.

B.3 Identification of Elasticity of Substitution in Non-Tradable Production

Consider setting home productivity constant across cites, $\hat{A}_Y^j = 0$, and using population density to estimate the elasticity of non-tradable good production σ_Y^j for each city. In particular, we have

$$\hat{N}^j = \varepsilon_{N,Q}\hat{Q}^j + \varepsilon_{N,A_X}\hat{A}_X^j, \tag{A.1}$$

where $\varepsilon_{N,Q}$ and ε_{N,A_X} are defined in Section B.1, but now depend on a city-specific substitution elasticity σ_Y^j. When home productivity is constant, we can identify trade productivity using inferred costs,

$$\hat{A}_X^j = \frac{\theta_L}{\phi_L}\hat{p}^j + \left(\theta_N - \phi_N \frac{\theta_L}{\phi_L}\right)\hat{w}^j$$

and so equation (A.1) is a single equation in one unknown variable, σ_Y^j. We do not pursue this approach further, but note that it yields city-specific estimates of the elasticity of substitution in non-tradable production, under the restrictive assumption that home productivity does not vary across cities. Without accurate data on land values, which is necessary to jointly identify trade and home productivity, the model does not permit simultaneous identification of $\hat{A}_Y^j$ and σ_Y^j using population density data alone. Data on another quantity difference, such as the housing stock, would permit identification of a city-specific elasticity of non-tradable production and both types of productivity, but we are not aware of reliable data on capital stock differentials across cities.

B.4 Deduction

Tax deductions are applied to the consumption of home goods at the rate $\delta \in [0, 1]$, so that the tax payment is given by $\tau(m - \delta py)$. With the deduction, the mobility condition becomes

$$\begin{aligned}\hat{Q}^j &= (1 - \delta\tau')s_y\hat{p}^j - (1 - \tau')s_w\hat{w}^j \\ &= s_y\hat{p}^j - s_w\hat{w}^j + \frac{d\tau^j}{m}\end{aligned}$$

where the tax differential is given by $d\tau^j/m = \tau'(s_w\hat{w}^j - \delta s_y p^j)$. This differential can be solved by noting

$$\begin{aligned}s_w\hat{w}^j &= s_w\hat{w}_0^j + \frac{\lambda_L}{\lambda_N}\frac{d\tau^j}{m} \\ s_y\hat{p}^j &= s_y\hat{p}_0^j - \left(1 - \frac{\lambda_L}{\lambda_N}\right)\frac{d\tau^j}{m}\end{aligned}$$

and substituting them into the tax differential formula, and solving recursively,

$$\begin{aligned}\frac{d\tau^j}{m} &= \tau' s_w\hat{w}_0^j - \delta\tau' s_y\hat{p}_0^j + \tau'\left[\delta + (1 - \delta)\frac{\lambda_L}{\lambda_N}\right] \\ &= \tau'\frac{s_w\hat{w}_0^j - \delta s_y\hat{p}_0^j}{1 - \tau'\left[\delta + (1 - \delta)\lambda_L/\lambda_N\right]}\end{aligned}$$

We can then solve for the tax differential in terms of amenities:

$$\frac{d\tau^j}{m} = \tau' \frac{1}{1-\tau'\left[\delta + (1-\delta)\lambda_L/\lambda_N\right]} \left[(1-\delta)\left(\frac{1-\lambda_L}{\lambda_N} s_x \hat{A}_X^j - \frac{\lambda_L}{\lambda_N} s_y A_Y^j \right) - \frac{(1-\delta)\lambda_L + \delta\lambda_N}{\lambda_N} \hat{Q}^j \right]$$

This equation demonstrates that the deduction reduces the dependence of taxes on productivity and increases the implicit subsidy for quality-of-life.

B.5 State Taxes

The tax differential with state taxes is computed by including an additional component based on wages and prices relative to the state average, as if state tax revenues are redistributed lump-sum to households within the state. This produces the augmented formula

$$\frac{d\tau^j}{m} = \tau' \left(s_w \hat{w}^j - \delta \tau' s_y \hat{p}^j \right) + \tau_S' [s_w(\hat{w}^j - \hat{w}^S) - \delta_S s_y (\hat{p}^j - \hat{p}^S)] \tag{A.2}$$

where τ_S' and δ_S are are marginal tax and deduction rates at the state-level, net of federal deductions, and $\hat{w}^S$ and $\hat{p}^S$ are the differentials for state S as a whole relative to the entire country.

C Additional Parametrization Details

C.1 Cost and Expenditure Shares

We parametrize the model using the data described below and national values. Starting with income shares, Krueger (1999) argues that s_w is close to 75 percent. Poterba (1998) estimates that the share of income from corporate capital is 12 percent, so s_I should be higher and is taken as 15 percent. This leaves 10 percent for s_R, which is roughly consistent with estimates in Keiper et al. (1961) and Case (2007).[43]

Turning to expenditure shares, Albouy (2008), Moretti (2008), and Shapiro (2006) find that housing costs approximate non-housing cost differences across cities. The cost-of-living differential is $s_y \hat{p}^j$, where $\hat{p}^j$ equals the housing-cost differential and s_y equals the expenditure share on housing plus an additional term which captures how a one percent increase in housing costs predicts a $b = 0.26$ percent increase in non-housing costs.[44] In the Consumer Expenditure Survey (CEX), the share of income spent on shelter and utilities, s_{hous}, is 0.22, while the share of income spent on other goods, s_{oth}, is 0.56, leaving 0.22 spent on taxes or saved (Bureau of Labor Statistics 2002).[45] Thus, our coefficient on the housing cost differential is $s_y = s_{hous} + s_{oth} b = 0.22 + 0.56 \times 0.26 = 36$ percent. This leaves s_x at 64 percent.

We choose the cost shares to be consistent with the expenditure and income shares above. θ_L appears small: Beeson and Eberts (1986) use a value of 0.027, while Rappaport (2008a, 2008b) uses a value of 0.016. Valentinyi and Herrendorff (2008) estimate the land share of tradables at

[43] The values Keiper reports were at a historical low. Keiper et al. (1961) find that total land value was found to be about 1.1 times GDP. A rate of return of 9 percent would justify using $s_R = 0.10$. Case (2007), ignoring agriculture, estimates the value of land to be \$5.6 trillion in 2000 when personal income was \$8.35 trillion.

[44] See Albouy (2008) for details.

[45] Utility costs account for one fifth of s_{hous}, which means that without them this parameter would be roughly 0.18.

4 percent, although their definition of tradables differs from the one here. We use a value of 2.5 percent for θ_L here. Following Carliner (2003) and Case (2007), the cost-share of land in home goods, ϕ_L, is taken at 23.3 percent; this is slightly above values from McDonald (1981), Roback (1982), and Thorsnes (1997) to account for the increase in land cost shares over time described by Davis and Palumbo (2007). Together the cost and expenditure shares imply λ_L is 17 percent, which appears reasonable since the remaining 83 percent of land for home goods includes all residential land and much commercial land; the cost and expenditure shares also agree with s_R at 10 percent.[46] Finally, we choose the cost shares of labor and capital in both production sectors. As separate information on ϕ_K and θ_K does not exist, we set both cost shares of capital at 15 percent to be consistent with s_I. Accounting identities then determine that θ_N is 82.5 percent, ϕ_N is 62 percent, and λ_N is 70.4 percent.

The federal tax rate, when combined with relevant variation in wages with state tax rates, produces an approximate marginal tax rate, τ, of 36.1 percent. Details on this tax rate, as well as housing deductions, are discussed in Appendix C.2.

C.2 Values for Tax Parameters

The federal marginal tax rate on wage income is determined by adding together federal marginal income tax rate and the effective marginal payroll tax rate. TAXSIM gives an average marginal federal income tax rate of 25.1 percent in 2000. In 2000, Social Security (OASDI) and Medicare (HI) tax rates were 12.4 and 2.9 percent on employer and employee combined. Estimates from Boskin et al. (1987, Table 4) show that the marginal benefit from future returns from OASDI taxes is fairly low, generally no more than 50 percent, although only 85 percent of wage earnings are subject to the OASDI cap. HI taxes emulate a pure tax (Congressional Budget Office 2005). These facts suggest adding 37.5 percent of the Social Security tax and all of the Medicare tax to the federal income tax rate, adding 8.2 percent. The employer half of the payroll tax (4.1 percent) has to be added to observed wage levels to produce gross wage levels. Overall, this puts an overall federal tax rate, τ' , of 33.3 percent tax rate on gross wages, although only a 29.2 percent rate on observed wages.

Determining the federal deduction level requires taking into account the fact that many households do not itemize deductions. According to the Statistics on Income, although only 33 percent of tax returns itemize, they account for 67 percent of reported Adjusted Gross Income (AGI). Since the income-weighted share is what matters, 67 percent is multiplied by the effective tax reduction given in TAXSIM, in 2000 of 21.6 percent. Thus, on average these deductions reduce the effective price of eligible goods by 14.5 percent. Since eligible goods only include housing, this deduction applies to only 59 percent of home goods. Multiplying 14.5 percent times 59 percent gives an effective price reduction of 8.6 percent for home goods. Divided by a federal tax rate of 33.3 percent, this produces a federal deduction level of 25.7 percent.

State income tax rates from 2000 are taken from TAXSIM, which, per dollar, fall at an average

[46]These proportions are roughly consistent with other studies. In the base parametrization of the model, 51 percent of land is devoted to actual housing, 32 percent is for non-housing home goods, and 17 percent is for traded goods, including those purchased by the federal government. Keiper et al. (1961) find that about 52.5 of land value is in residential uses, a 22.9 percent in industry, 20.9 percent in agriculture. Case (2007), ignoring agriculture, finds that in 2000 residential real estate accounted for 76.6 percent of land value, while commercial real estate accounted for the remaining 23.4 percent.

marginal rate of 4.5 percent. State sales tax data in 2000 are taken from the Tax Policy Center, originally supplied by the Federation of Tax Administrators. The average state sales tax rate is 5.2 percent. Sales tax rates are reduced by 10 percent to accommodate untaxed goods and services other than food or housing (Feenberg et al. 1997), and by another 8 percent in states that exempt food. Overall state taxes raise the marginal tax rate on wage differences within state by an average of 5.9 percentage points, from zero points in Alaska to 8.8 points in Minnesota.

State-level deductions for housing expenditures, explicit in income taxes, and implicit in sales taxes, should also be included. At the state level, deductions for income taxes are calculated in an equivalent way using TAXSIM data. Furthermore, all housing expenditures are deducted from the sales tax. Overall this produces an average effective deduction level of $\delta = 0.291$.

D Data and Estimation

We use United States Census data from the 2000 Integrated Public-Use Microdata Series (IPUMS), from Ruggles et al. (2004), to calculate wage and housing price differentials. The wage differentials are calculated for workers ages 25 to 55, who report working at least 30 hours a week, 26 weeks a year. The MSA assigned to a worker is determined by their place of residence, rather than their place of work. The wage differential of an MSA is found by regressing log hourly wages on individual covariates and indicators for which MSA a worker lives in, using the coefficients on these MSA indicators. The covariates consist of

- 12 indicators of educational attainment;
- a quartic in potential experience, and potential experience interacted with years of education;
- 9 indicators of industry at the one-digit level (1950 classification);
- 9 indicators of employment at the one-digit level (1950 classification);
- 4 indicators of marital status (married, divorced, widowed, separated);
- an indicator for veteran status, and veteran status interacted with age;
- 5 indicators of minority status (Black, Hispanic, Asian, Native American, and other);
- an indicator of immigrant status, years since immigration, and immigrant status interacted with black, Hispanic, Asian, and other;
- 2 indicators for English proficiency (none or poor).

All covariates are interacted with gender.

This regression is first run using census-person weights. From the regressions a predicted wage is calculated using individual characteristics alone, controlling for MSA, to form a new weight equal to the predicted wage times the census-person weight. These new income-adjusted weights are needed since workers need to be weighted by their income share. The new weights are then used in a second regression, which is used to calculate the city-wage differentials from the MSA indicator variables. In practice, this weighting procedure has only a small effect on the estimated wage differentials.

Housing price differentials are calculated using the logarithm reported gross rents and housing values. Only housing units moved into within the last 10 years are included in the sample to ensure that the price data are fairly accurate. The differential housing price of an MSA is calculated in a manner similar to wages, except using a regression of the actual or imputed rent on a set of covariates at the unit level. The covariates for the adjusted differential are

- 9 indicators of building size;
- 9 indicators for the number of rooms, 5 indicators for the number of bedrooms, number of rooms interacted with number of bedrooms, and the number of household members per room;
- 2 indicators for lot size;
- 7 indicators for when the building was built;
- 2 indicators for complete plumbing and kitchen facilities;
- an indicator for commercial use;
- an indicator for condominium status (owned units only).

A regression of housing values on housing characteristics and MSA indicator variables is first run using only owner-occupied units, weighting by census-housing weights. A new value-adjusted weight is calculated by multiplying the census-housing weights by the predicted value from this first regression using housing characteristics alone, controlling for MSA. A second regression is run using these new weights for all units, rented and owner-occupied, on the housing characteristics fully interacted with tenure, along with the MSA indicators, which are not interacted. The house-price differentials are taken from the MSA indicator variables in this second regression. As with the wage differentials, this adjusted weighting method has only a small impact on the measured price differentials.

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Table A.1: Parametrized Relationship between Amenities, Prices, and Quantities, with Feedback Effects

		A: Trade Productivity Feedback						B: Quality of Life Feedback					
		I: Current Regime			II: Neutral Taxes			I: Current Regime			II: Neutral Taxes		
		Quality of Life	Trade Productivity	Home Productivity	-	-	-	-	-	-	-	-	-
Price/quantity	Notation	$\hat{Q}$	$\hat{A}_{X0}$	$\hat{A}_Y$	$\hat{Q}$	$\hat{A}_{X0}$	$\hat{A}_Y$	$\hat{Q}_0$	$\hat{A}_X$	$\hat{A}_Y$	$\hat{Q}_0$	$\hat{A}_X$	$\hat{A}_Y$
Land value	$\hat{r}$	14.144	4.622	4.655	13.507	8.240	4.944	10.546	3.659	3.401	9.040	5.896	3.232
Wage	$\hat{w}$	0.264	1.257	0.100	0.255	1.311	0.105	-0.319	1.101	-0.103	-0.274	1.033	-0.098
Home price	$\hat{p}$	3.463	1.854	0.148	3.308	2.731	0.218	2.263	1.533	-0.270	1.940	2.013	-0.306
Trade consumption	$\hat{x}$	-0.168	0.445	0.035	-0.255	0.938	0.075	-0.346	0.397	-0.026	-0.591	0.761	-0.054
Home consumption	$\hat{y}$	-2.478	-0.791	-0.063	-2.412	-1.166	-0.093	-1.856	-0.625	0.154	-1.732	-0.809	0.168
Population density	$\hat{N}$	9.524	2.548	3.320	9.130	4.791	3.499	7.350	1.967	2.562	6.409	3.363	2.456
Land	$\hat{L}$	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Capital	$\hat{K}$	9.669	3.351	3.353	9.265	5.645	3.537	7.125	2.670	2.467	6.204	4.038	2.363
Trade production	$\hat{X}$	10.036	3.936	3.606	9.640	6.186	3.786	7.193	3.176	2.615	6.334	4.451	2.519
Home production	$\hat{Y}$	7.046	1.757	3.256	6.717	3.625	3.406	5.494	1.342	2.716	4.677	2.554	2.624
Trade labor	$\hat{N}_X$	9.669	2.714	3.473	9.288	4.883	3.646	7.406	2.108	2.684	6.517	3.429	2.584
Home labor	$\hat{N}_Y$	9.180	2.155	2.955	8.754	4.572	3.148	7.217	1.630	2.271	6.154	3.208	2.152
Trade land	$\hat{L}_X$	0.411	0.469	0.435	0.448	0.261	0.418	0.159	0.402	0.347	0.305	0.185	0.363
Home land	$\hat{L}_Y$	-0.078	-0.089	-0.083	-0.085	-0.050	-0.080	-0.030	-0.076	-0.066	-0.058	-0.035	-0.069
Trade capital	$\hat{K}_X$	9.845	3.552	3.540	9.457	5.757	3.716	7.193	2.843	2.615	6.334	4.118	2.519
Home capital	$\hat{K}_Y$	9.356	2.993	3.022	8.924	5.446	3.218	7.004	2.364	2.202	5.971	3.897	2.086

Each value in Table A.1 represents the partial effect that a one-point increase in each amenity has on each price or quantity. The values in Panel A include feedback effects on trade productivity, where $A_X^j = A_{X0}^j (N^j)^\alpha$ and $\alpha = 0.06$. The values in Panel B include feedback effects on quality of life, where $Q^j = Q_0^j (N^j)^{-\gamma}$ and $\gamma = 0.015$. Each panel includes values for the current regime and geographically neutral taxes. All variables are measured in log differences from the national average.

Table A.2: List of Metropolitan and Non-Metropolitan Areas Ranked by Density

Name of Metropolitan Area	Population Density $\hat{N}^j$	Land Value $\hat{r}^j$	Quality of Life $\hat{Q}^j$	Trade Productivity $\hat{A}_X^j$	Inferred Costs Eq. (26)	Home Productivity $\hat{A}_Y^j$
New York, Northern New Jersey, Long Island, NY-NJ-CT-PA	2.285	3.366	0.029	0.209	0.264	0.509
Los Angeles-Riverside-Orange County, CA	1.250	1.913	0.081	0.150	0.159	0.079
San Francisco-Oakland-San Jose, CA	1.209	2.000	0.138	0.289	0.269	-0.182
Chicago-Gary-Kenosha, IL-IN-WI	1.191	1.767	0.005	0.131	0.161	0.276
Miami-Fort Lauderdale, FL	0.964	1.352	0.041	0.015	0.035	0.191
Philadelphia-Wilmington-Atlantic City, PA-NJ-DE-MD	0.958	1.393	-0.040	0.096	0.133	0.346
San Diego, CA	0.872	1.403	0.123	0.098	0.085	-0.114
Salinas (Monterey-Carmel), CA	0.863	1.435	0.137	0.144	0.124	-0.189
Boston-Worcester-Lawrence, MA-NH-ME-CT	0.797	1.241	0.034	0.128	0.136	0.074
Santa Barbara-Santa Maria-Lompoc, CA	0.713	1.255	0.176	0.125	0.090	-0.326
New Orleans, LA	0.686	0.864	0.005	-0.065	-0.038	0.254
Las Vegas, NV-AZ	0.684	0.987	-0.025	0.057	0.083	0.246
Washington-Baltimore, DC-MD-VA-WV	0.683	1.044	-0.013	0.116	0.135	0.170
Providence-Fall River-Warwick, RI-MA	0.591	0.850	0.014	0.022	0.037	0.137
Milwaukee-Racine, WI	0.573	0.792	-0.009	0.037	0.057	0.181
Stockton-Lodi, CA	0.529	0.794	-0.002	0.083	0.095	0.116
Laredo, TX	0.524	0.532	-0.008	-0.194	-0.159	0.327
Phoenix-Mesa, AZ	0.507	0.714	0.012	0.030	0.042	0.110
Denver-Boulder-Greeley, CO	0.467	0.711	0.054	0.066	0.061	-0.041
Buffalo-Niagara Falls, NY	0.448	0.620	-0.054	-0.042	-0.008	0.318
Provo-Orem, UT	0.447	0.565	0.019	-0.048	-0.034	0.126
Champaign-Urbana, IL	0.435	0.562	-0.009	-0.080	-0.056	0.221
Sacramento-Yolo, CA	0.434	0.694	0.033	0.075	0.075	-0.001
Reading, PA	0.403	0.515	-0.046	-0.017	0.011	0.265
Salt Lake City-Ogden, UT	0.394	0.515	0.026	-0.015	-0.008	0.067
Modesto, CA	0.389	0.575	-0.008	0.050	0.062	0.111
El Paso, TX	0.386	0.349	-0.041	-0.164	-0.127	0.349
Detroit-Ann Arbor-Flint, MI	0.346	0.554	-0.047	0.108	0.125	0.160
Madison, WI	0.333	0.483	0.053	-0.018	-0.020	-0.021
Lincoln, NE	0.330	0.307	0.022	-0.122	-0.108	0.135
Cleveland-Akron, OH	0.329	0.443	-0.016	0.006	0.022	0.143
Seattle-Tacoma-Bremerton, WA	0.324	0.570	0.061	0.095	0.082	-0.124

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Name of Metropolitan Area	Population Density $\hat{N}^j$	Land Value $\hat{r}^j$	Quality of Life $\hat{Q}^j$	Trade Productivity $\hat{A}^j_X$	Inferred Costs Eq. (26)	Home Productivity $\hat{A}^j_Y$
Houston-Galveston-Brazoria, TX	0.323	0.449	-0.072	0.045	0.074	0.262
Dallas-Fort Worth, TX	0.318	0.463	-0.044	0.047	0.067	0.187
Allentown-Bethlehem-Easton, PA	0.308	0.413	-0.022	-0.005	0.012	0.162
State College, PA	0.292	0.341	0.036	-0.120	-0.111	0.082
Reno, NV	0.263	0.454	0.053	0.043	0.034	-0.087
Portland-Salem, OR-WA	0.241	0.361	0.047	0.037	0.029	-0.075
Lafayette, IN	0.236	0.266	-0.006	-0.069	-0.054	0.140
West Palm Beach-Boca Raton, FL	0.235	0.365	0.017	0.046	0.045	-0.003
Fresno, CA	0.232	0.321	-0.008	-0.014	-0.002	0.106
San Antonio, TX	0.222	0.193	-0.039	-0.097	-0.071	0.242
Norfolk-Virginia Beach-Newport News, VA-	0.210	0.228	0.027	-0.095	-0.088	0.064
Minneapolis-St. Paul, MN-WI	0.203	0.292	-0.032	0.067	0.078	0.101
Bakersfield, CA	0.189	0.226	-0.063	0.020	0.043	0.212
Columbus, OH	0.156	0.200	-0.028	0.013	0.025	0.116
Erie, PA	0.153	0.101	-0.035	-0.114	-0.090	0.223
Springfield, MA	0.143	0.235	0.002	-0.003	0.001	0.042
Omaha, NE-IA	0.136	0.037	-0.019	-0.084	-0.068	0.153
Bloomington-Normal, IL	0.126	0.159	-0.061	0.003	0.024	0.201
Tucson, AZ	0.122	0.119	0.052	-0.091	-0.095	-0.035
Pittsburgh, PA	0.119	0.094	-0.047	-0.054	-0.033	0.202
Albuquerque, NM	0.113	0.072	0.049	-0.064	-0.069	-0.049
Toledo, OH	0.113	0.099	-0.041	-0.037	-0.019	0.171
Tampa-St. Petersburg-Clearwater, FL	0.109	0.081	0.003	-0.054	-0.047	0.067
Iowa City, IA	0.103	0.075	0.034	-0.072	-0.073	-0.007
Hartford, CT	0.087	0.255	-0.026	0.120	0.121	0.013
Lubbock, TX	0.075	-0.054	-0.009	-0.161	-0.144	0.162
Corpus Christi, TX	0.074	-0.017	-0.034	-0.106	-0.085	0.187
Austin-San Marcos, TX	0.069	0.128	0.016	0.014	0.011	-0.032
Bryan-College Station, TX	0.063	-0.007	0.027	-0.122	-0.118	0.036
Colorado Springs, CO	0.060	0.041	0.055	-0.066	-0.075	-0.080
St. Louis, MO-IL	0.052	0.016	-0.034	-0.007	0.005	0.111
Brownsville-Harlingen-San Benito, TX	0.048	-0.183	-0.057	-0.221	-0.186	0.324

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Rochester, NY	0.019	0.047	-0.041	-0.029	-0.014	0.135
Spokane, WA	0.011	-0.081	0.008	-0.090	-0.085	0.047
Pueblo, CO	0.006	-0.156	-0.003	-0.162	-0.148	0.124
Anchorage, AK	0.000	0.000	0.023	0.077	0.000	0.000
Honolulu, HI	0.000	0.000	0.204	0.057	0.000	0.000
Non-metro, HI	0.000	0.000	0.126	0.013	0.000	0.000
Non-metro, AK	0.000	0.000	0.012	0.037	0.000	0.000
Lancaster, PA	-0.002	-0.016	-0.011	-0.017	-0.013	0.040
Cincinnati-Hamilton, OH-KY-IN	-0.007	-0.031	-0.038	0.020	0.029	0.085
Bloomington, IN	-0.015	-0.087	0.032	-0.110	-0.111	-0.012
Louisville, KY-IN	-0.016	-0.097	-0.023	-0.047	-0.037	0.089
Albany-Schenectady-Troy, NY	-0.026	-0.013	-0.041	-0.026	-0.013	0.120
Amarillo, TX	-0.028	-0.177	-0.010	-0.142	-0.130	0.118
Memphis, TN-AR-MS	-0.044	-0.130	-0.060	-0.013	0.004	0.153
Fort Collins-Loveland, CO	-0.045	-0.058	0.079	-0.032	-0.054	-0.202
Scranton–Wilkes-Barre–Hazleton, PA	-0.048	-0.163	-0.027	-0.106	-0.092	0.132
Orlando, FL	-0.057	-0.126	0.006	-0.037	-0.038	-0.009
Syracuse, NY	-0.081	-0.126	-0.069	-0.056	-0.035	0.198
Altoona, PA	-0.082	-0.263	-0.045	-0.158	-0.136	0.205
Des Moines, IA	-0.085	-0.203	-0.022	-0.037	-0.031	0.056
Visalia-Tulare-Porterville, CA	-0.087	-0.140	-0.016	-0.036	-0.031	0.041
Green Bay, WI	-0.093	-0.163	-0.011	-0.022	-0.020	0.014
Non-metro, RI	-0.094	-0.042	0.040	0.071	0.051	-0.186
South Bend, IN	-0.094	-0.219	-0.047	-0.072	-0.057	0.145
Fargo-Moorhead, ND-MN	-0.115	-0.355	-0.039	-0.174	-0.153	0.191
Yuma, AZ	-0.121	-0.266	0.002	-0.100	-0.097	0.028
Kansas City, MO-KS	-0.125	-0.259	-0.037	-0.015	-0.008	0.067
Waterloo-Cedar Falls, IA	-0.132	-0.343	-0.023	-0.129	-0.117	0.110
Sarasota-Bradenton, FL	-0.138	-0.208	0.066	-0.046	-0.066	-0.187
Dayton-Springfield, OH	-0.146	-0.244	-0.030	-0.030	-0.024	0.054
Oklahoma City, OK	-0.146	-0.386	-0.020	-0.135	-0.124	0.103
Lexington, KY	-0.150	-0.333	-0.033	-0.095	-0.084	0.107

Table A.2: List of Metropolitan and Non-Metropolitan Areas Ranked by Density

Name of Metropolitan Area	Population Density $\hat{N}^j$	Land Value $\hat{r}^j$	Quality of Life $\hat{Q}^j$	Trade Productivity $\hat{A}_X^j$	Inferred Costs Eq. (26)	Home Productivity $\hat{A}_Y^j$
Odessa-Midland, TX	-0.154	-0.382	-0.063	-0.136	-0.113	0.215
Eugene-Springfield, OR	-0.159	-0.250	0.088	-0.084	-0.108	-0.225
Indianapolis, IN	-0.183	-0.277	-0.039	0.003	0.008	0.043
Appleton-Oshkosh-Neenah, WI	-0.185	-0.318	-0.021	-0.052	-0.048	0.034
Boise City, ID	-0.185	-0.376	0.010	-0.077	-0.080	-0.032
Wichita, KS	-0.187	-0.402	-0.048	-0.079	-0.066	0.122
Davenport-Moline-Rock Island, IA-IL	-0.215	-0.397	-0.041	-0.088	-0.077	0.103
Merced, CA	-0.215	-0.298	-0.012	-0.013	-0.016	-0.028
Lansing-East Lansing, MI	-0.218	-0.304	-0.046	-0.008	-0.002	0.059
Sioux City, IA-NE	-0.220	-0.523	-0.060	-0.161	-0.139	0.201
Harrisburg-Lebanon-Carlisle, PA	-0.222	-0.334	-0.029	-0.020	-0.018	0.020
Richmond-Petersburg, VA	-0.228	-0.354	-0.033	-0.006	-0.004	0.020
Sioux Falls, SD	-0.230	-0.501	-0.006	-0.146	-0.141	0.045
Grand Rapids-Muskegon-Holland, MI	-0.236	-0.328	-0.044	-0.010	-0.005	0.048
Rockford, IL	-0.237	-0.367	-0.069	-0.024	-0.011	0.124
Portland, ME	-0.239	-0.429	0.051	-0.060	-0.078	-0.170
Lawrence, KS	-0.240	-0.440	0.038	-0.129	-0.138	-0.086
Abilene, TX	-0.256	-0.562	0.004	-0.223	-0.216	0.067
Jacksonville, FL	-0.265	-0.438	-0.009	-0.051	-0.054	-0.025
Cedar Rapids, IA	-0.266	-0.469	-0.002	-0.078	-0.081	-0.024
Muncie, IN	-0.272	-0.501	-0.043	-0.122	-0.110	0.114
York, PA	-0.277	-0.425	-0.032	-0.036	-0.033	0.022
Tulsa, OK	-0.280	-0.559	-0.032	-0.104	-0.096	0.068
Yakima, WA	-0.287	-0.442	-0.009	-0.029	-0.034	-0.048
Atlanta, GA	-0.291	-0.382	-0.032	0.063	0.057	-0.053
Gainesville, FL	-0.301	-0.547	0.024	-0.134	-0.141	-0.067
Binghamton, NY	-0.302	-0.458	-0.054	-0.123	-0.109	0.133
Sheboygan, WI	-0.302	-0.483	-0.019	-0.062	-0.062	-0.004
Savannah, GA	-0.307	-0.484	-0.011	-0.080	-0.082	-0.013
Canton-Massillon, OH	-0.322	-0.517	-0.024	-0.083	-0.081	0.020
Rochester, MN	-0.325	-0.494	-0.061	-0.003	0.003	0.060
Charlottesville, VA	-0.329	-0.491	0.054	-0.090	-0.109	-0.185

Table A.2: List of Metropolitan and Non-Metropolitan Areas Ranked by Density

Name of Metropolitan Area	Population Density $\hat{N}^j$	Land Value $\hat{r}^j$	Quality of Life $\hat{Q}^j$	Trade Productivity $\hat{A}_X^j$	Inferred Costs Eq. (26)	Home Productivity $\hat{A}_Y^j$
Billings, MT	-0.329	-0.674	0.013	-0.169	-0.172	-0.021
St. Joseph, MO	-0.347	-0.652	-0.026	-0.168	-0.160	0.076
Topeka, KS	-0.349	-0.642	-0.024	-0.137	-0.132	0.050
La Crosse, WI-MN	-0.355	-0.592	-0.020	-0.126	-0.123	0.028
Melbourne-Titusville-Palm Bay, FL	-0.360	-0.614	-0.000	-0.104	-0.108	-0.042
Utica-Rome, NY	-0.375	-0.568	-0.064	-0.125	-0.111	0.138
Fort Walton Beach, FL	-0.383	-0.675	0.062	-0.174	-0.192	-0.163
Decatur, IL	-0.385	-0.627	-0.089	-0.080	-0.062	0.168
Yuba City, CA	-0.394	-0.555	0.009	-0.066	-0.077	-0.103
Janesville-Beloit, WI	-0.395	-0.612	-0.050	-0.019	-0.017	0.020
Peoria-Pekin, IL	-0.399	-0.597	-0.061	-0.041	-0.034	0.064
Columbia, MO	-0.401	-0.691	0.023	-0.164	-0.172	-0.073
Cheyenne, WY	-0.414	-0.789	0.056	-0.217	-0.231	-0.128
Elmira, NY	-0.415	-0.624	-0.061	-0.132	-0.119	0.122
Naples, FL	-0.424	-0.509	0.095	0.027	-0.016	-0.408
Medford-Ashland, OR	-0.425	-0.623	0.095	-0.099	-0.133	-0.317
Springfield, IL	-0.435	-0.659	-0.039	-0.082	-0.080	0.021
Lewiston-Auburn, ME	-0.435	-0.776	-0.008	-0.123	-0.127	-0.032
Waco, TX	-0.439	-0.744	-0.047	-0.118	-0.111	0.069
Richland-Kennewick-Pasco, WA	-0.440	-0.642	-0.051	0.011	0.009	-0.014
Chico-Paradise, CA	-0.444	-0.579	0.053	-0.067	-0.092	-0.236
Tallahassee, FL	-0.451	-0.719	0.022	-0.098	-0.112	-0.133
Burlington, VT	-0.453	-0.730	0.065	-0.082	-0.110	-0.260
Fort Myers-Cape Coral, FL	-0.454	-0.692	0.049	-0.084	-0.107	-0.215
San Luis Obispo-Atascadero-Paso Robles, CA	-0.458	-0.436	0.124	0.077	0.020	-0.531
Evansville-Henderson, IN-KY	-0.458	-0.749	-0.047	-0.104	-0.099	0.051
Baton Rouge, LA	-0.465	-0.730	-0.031	-0.053	-0.057	-0.030
Roanoke, VA	-0.470	-0.745	-0.017	-0.107	-0.110	-0.030
Williamsport, PA	-0.471	-0.766	-0.031	-0.130	-0.127	0.022
Corvalis, OR	-0.474	-0.688	0.081	-0.081	-0.114	-0.309
San Angelo, TX	-0.487	-0.853	-0.025	-0.177	-0.174	0.036
Columbus, GA-AL	-0.488	-0.819	-0.055	-0.152	-0.141	0.097

Table A.2: List of Metropolitan and Non-Metropolitan Areas Ranked by Density

Name of Metropolitan Area	Population Density $\hat{N}^j$	Land Value $\hat{r}^j$	Quality of Life $\hat{Q}^j$	Trade Productivity $\hat{A}^j_X$	Inferred Costs Eq. (26)	Home Productivity $\hat{A}^j_Y$
Saginaw-Bay City-Midland, MI	-0.489	-0.716	-0.074	-0.035	-0.028	0.064
Raleigh-Durham-Chapel Hill, NC	-0.503	-0.723	0.011	0.018	-0.004	-0.202
Youngstown-Warren, OH	-0.512	-0.804	-0.052	-0.090	-0.086	0.039
Grand Junction, CO	-0.518	-0.771	0.114	-0.134	-0.174	-0.374
Beaumont-Port Arthur, TX	-0.526	-0.857	-0.108	-0.070	-0.052	0.167
Fort Wayne, IN	-0.533	-0.829	-0.063	-0.067	-0.062	0.043
Charleston-North Charleston, SC	-0.534	-0.805	0.025	-0.082	-0.101	-0.179
Nashville, TN	-0.539	-0.767	-0.001	-0.016	-0.033	-0.159
McAllen-Edinburg-Mission, TX	-0.541	-1.015	-0.079	-0.228	-0.207	0.198
Springfield, MO	-0.559	-0.930	0.003	-0.175	-0.182	-0.063
Birmingham, AL	-0.561	-0.852	-0.047	-0.034	-0.037	-0.032
Daytona Beach, FL	-0.562	-0.919	0.019	-0.144	-0.158	-0.130
Columbia, SC	-0.566	-0.874	-0.007	-0.076	-0.088	-0.108
Fayetteville, NC	-0.566	-0.906	0.028	-0.178	-0.192	-0.130
Montgomery, AL	-0.578	-0.921	-0.003	-0.124	-0.134	-0.089
Shreveport-Bossier City, LA	-0.583	-0.956	-0.042	-0.124	-0.122	0.011
Wichita Falls, TX	-0.601	-1.047	-0.008	-0.226	-0.228	-0.012
Kalamazoo-Battle Creek, MI	-0.602	-0.859	-0.056	-0.037	-0.039	-0.018
Sharon, PA	-0.610	-0.975	-0.033	-0.151	-0.151	-0.003
Eau Claire, WI	-0.613	-0.954	-0.026	-0.120	-0.125	-0.042
Kokomo, IN	-0.618	-0.901	-0.110	0.029	0.037	0.072
Fort Pierce-Port St. Lucie, FL	-0.620	-0.938	0.011	-0.078	-0.096	-0.173
Victoria, TX	-0.623	-1.002	-0.074	-0.104	-0.096	0.069
Jackson, MS	-0.627	-1.007	-0.031	-0.099	-0.104	-0.048
Jamestown, NY	-0.633	-0.950	-0.079	-0.157	-0.144	0.119
Las Cruces, NM	-0.638	-1.071	0.019	-0.190	-0.203	-0.121
Santa Fe, NM	-0.641	-0.861	0.127	-0.017	-0.073	-0.529
Killeen-Temple, TX	-0.645	-1.069	0.040	-0.220	-0.237	-0.158
Charlotte-Gastonia-Rock Hill, NC-SC	-0.660	-0.960	-0.013	0.007	-0.013	-0.183
Dubuque, IA	-0.667	-1.096	-0.024	-0.150	-0.155	-0.044
Mobile, AL	-0.676	-1.068	-0.016	-0.128	-0.137	-0.084
Pensacola, FL	-0.676	-1.090	0.003	-0.146	-0.159	-0.121

Table A.2: List of Metropolitan and Non-Metropolitan Areas Ranked by Density

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Terre Haute, IN	-0.676	-1.081	-0.060	-0.139	-0.134	0.040
Duluth-Superior, MN-WI	-0.676	-1.045	-0.069	-0.116	-0.110	0.049
Pittsfield, MA	-0.689	-0.929	0.014	-0.050	-0.073	-0.222
Little Rock-North Little Rock, AR	-0.699	-1.107	-0.011	-0.100	-0.113	-0.125
Grand Forks, ND-MN	-0.700	-1.188	-0.046	-0.210	-0.205	0.046
Bellingham, WA	-0.701	-0.962	0.074	-0.038	-0.080	-0.394
Owensboro, KY	-0.702	-1.136	-0.041	-0.144	-0.145	-0.015
Elkhart-Goshen, IN	-0.707	-1.049	-0.043	-0.059	-0.067	-0.071
Tuscaloosa, AL	-0.714	-1.093	-0.013	-0.099	-0.112	-0.123
Lake Charles, LA	-0.721	-1.126	-0.064	-0.085	-0.085	-0.002
Jackson, MI	-0.722	-1.029	-0.064	-0.034	-0.038	-0.037
Mansfield, OH	-0.722	-1.102	-0.048	-0.110	-0.112	-0.027
Panama City, FL	-0.723	-1.131	0.026	-0.138	-0.159	-0.203
Athens, GA	-0.729	-1.077	0.016	-0.125	-0.145	-0.187
Lakeland-Winter Haven, FL	-0.759	-1.193	-0.023	-0.119	-0.130	-0.099
New London-Norwich, CT-RI	-0.765	-0.944	0.006	0.051	0.019	-0.298
Greenville, NC	-0.766	-1.164	-0.022	-0.085	-0.098	-0.129
Lima, OH	-0.787	-1.198	-0.062	-0.103	-0.105	-0.014
Biloxi-Gulfport-Pascagoula, MS	-0.818	-1.289	-0.026	-0.135	-0.146	-0.097
Casper, WY	-0.833	-1.399	-0.002	-0.219	-0.231	-0.107
Macon, GA	-0.844	-1.260	-0.068	-0.079	-0.082	-0.033
Greensboro–Winston Salem–High Point, NC	-0.848	-1.253	-0.016	-0.049	-0.070	-0.196
Punta Gorda, FL	-0.859	-1.307	0.049	-0.143	-0.176	-0.304
St. Cloud, MN	-0.859	-1.269	-0.048	-0.110	-0.118	-0.070
Albany, GA	-0.860	-1.293	-0.063	-0.099	-0.103	-0.038
Monroe, LA	-0.867	-1.350	-0.036	-0.133	-0.142	-0.090
Lafayette, LA	-0.874	-1.369	-0.057	-0.130	-0.134	-0.038
Tyler, TX	-0.884	-1.329	-0.025	-0.106	-0.121	-0.142
Augusta-Aiken, GA-SC	-0.895	-1.351	-0.057	-0.093	-0.100	-0.071
Missoula, MT	-0.905	-1.450	0.101	-0.208	-0.252	-0.410
Huntsville, AL	-0.908	-1.360	-0.055	-0.062	-0.073	-0.102
Hattiesburg, MS	-0.910	-1.450	-0.029	-0.180	-0.189	-0.088

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Name of Metropolitan Area	Population Density $\hat{N}^j$	Land Value $\hat{r}^j$	Quality of Life $\hat{Q}^j$	Trade Productivity $\hat{A}_X^j$	Inferred Costs Eq. (26)	Home Productivity $\hat{A}_Y^j$
Johnstown, PA	-0.911	-1.451	-0.062	-0.201	-0.199	0.016
Wilmington, NC	-0.914	-1.313	0.071	-0.104	-0.148	-0.409
Charleston, WV	-0.917	-1.446	-0.052	-0.117	-0.125	-0.073
Bismarck, ND	-0.918	-1.566	-0.048	-0.250	-0.248	0.010
Knoxville, TN	-0.937	-1.426	-0.011	-0.125	-0.144	-0.183
Benton Harbor, MI	-0.938	-1.332	-0.029	-0.081	-0.099	-0.165
Lawton, OK	-0.942	-1.547	-0.016	-0.253	-0.262	-0.080
Rapid City, SD	-0.948	-1.536	0.033	-0.212	-0.237	-0.241
Auburn-Opelika, AL	-0.950	-1.448	-0.015	-0.132	-0.150	-0.171
Great Falls, MT	-0.957	-1.624	0.036	-0.283	-0.305	-0.203
Chattanooga, TN-GA	-0.970	-1.457	-0.035	-0.105	-0.121	-0.145
Non-metro, CA	-0.982	-1.282	0.059	-0.017	-0.067	-0.459
Fort Smith, AR-OK	-1.010	-1.635	-0.045	-0.194	-0.201	-0.068
Redding, CA	-1.011	-1.375	0.041	-0.074	-0.115	-0.382
Steubenville-Weirton, OH-WV	-1.023	-1.603	-0.058	-0.189	-0.193	-0.041
Wheeling, WV-OH	-1.026	-1.613	-0.058	-0.189	-0.193	-0.043
Enid, OK	-1.041	-1.674	-0.032	-0.219	-0.229	-0.095
Pocatello, ID	-1.042	-1.660	-0.061	-0.141	-0.149	-0.071
Non-metro, PA	-1.057	-1.601	-0.053	-0.145	-0.156	-0.096
Fayetteville-Springdale-Rogers, AR	-1.066	-1.621	0.005	-0.132	-0.160	-0.261
Wausau, WI	-1.066	-1.576	-0.049	-0.086	-0.103	-0.150
Huntington-Ashland, WV-KY-OH	-1.072	-1.695	-0.074	-0.177	-0.180	-0.022
Jackson, TN	-1.073	-1.622	-0.063	-0.098	-0.110	-0.109
Danville, VA	-1.088	-1.661	-0.057	-0.163	-0.171	-0.081
Flagstaff, AZ-UT	-1.089	-1.595	0.030	-0.129	-0.166	-0.338
Jacksonville, NC	-1.094	-1.659	0.051	-0.254	-0.287	-0.307
Barnstable-Yarmouth (Cape Cod), MA	-1.111	-1.371	0.121	0.046	-0.030	-0.712
Non-metro, ND	-1.113	-1.839	-0.041	-0.262	-0.269	-0.064
Non-metro, CT	-1.122	-1.420	-0.007	0.078	0.035	-0.398
Alexandria, LA	-1.127	-1.738	-0.031	-0.173	-0.190	-0.157
Pine Bluff, AR	-1.128	-1.788	-0.053	-0.168	-0.179	-0.101
Greenville-Spartanburg-Anderson, SC	-1.149	-1.701	-0.031	-0.078	-0.103	-0.232

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Non-metro, WA	-1.186	-1.683	0.037	-0.067	-0.113	-0.432
Houma, LA	-1.194	-1.802	-0.054	-0.123	-0.139	-0.153
Glens Falls, NY	-1.201	-1.663	-0.020	-0.109	-0.136	-0.254
Joplin, MO	-1.216	-1.889	-0.011	-0.246	-0.266	-0.187
Non-metro, NY	-1.246	-1.755	-0.050	-0.123	-0.143	-0.179
Non-metro, ID	-1.256	-1.902	0.012	-0.174	-0.207	-0.312
Clarksville-Hopkinsville, TN-KY	-1.275	-1.955	-0.004	-0.206	-0.233	-0.251
Non-metro, UT	-1.315	-1.909	0.010	-0.124	-0.162	-0.360
Dover, DE	-1.327	-1.896	-0.009	-0.086	-0.123	-0.340
Lynchburg, VA	-1.331	-1.962	-0.031	-0.140	-0.166	-0.245
Asheville, NC	-1.343	-1.927	0.058	-0.132	-0.185	-0.492
Decatur, AL	-1.356	-2.008	-0.072	-0.085	-0.105	-0.184
Longview-Marshall, TX	-1.360	-2.048	-0.057	-0.149	-0.168	-0.179
Bangor, ME	-1.365	-2.084	-0.018	-0.169	-0.198	-0.271
Non-metro, MA	-1.376	-1.833	0.063	-0.042	-0.104	-0.580
Non-metro, OR	-1.377	-1.966	0.062	-0.113	-0.169	-0.525
Non-metro, OH	-1.387	-2.020	-0.052	-0.111	-0.135	-0.228
Sumter, SC	-1.391	-2.106	-0.037	-0.182	-0.206	-0.218
Parkersburg-Marietta, WV-OH	-1.394	-2.121	-0.072	-0.170	-0.184	-0.136
Florence, AL	-1.398	-2.098	-0.042	-0.149	-0.174	-0.232
Myrtle Beach, SC	-1.402	-2.028	0.038	-0.148	-0.196	-0.446
Non-metro, WY	-1.402	-2.121	0.007	-0.165	-0.203	-0.351
Non-metro, NV	-1.409	-1.928	-0.011	0.005	-0.041	-0.427
Cumberland, MD-WV	-1.434	-2.099	-0.040	-0.171	-0.196	-0.233
Non-metro, MD	-1.441	-1.973	-0.022	-0.037	-0.078	-0.376
Gadsden, AL	-1.446	-2.185	-0.069	-0.150	-0.169	-0.174
Sherman-Denison, TX	-1.449	-2.138	-0.028	-0.137	-0.168	-0.294
Non-metro, MT	-1.461	-2.262	0.059	-0.236	-0.285	-0.459
Non-metro, NM	-1.482	-2.255	0.002	-0.202	-0.238	-0.338
Johnson City-Kingsport-Bristol, TN-VA	-1.485	-2.236	-0.028	-0.180	-0.209	-0.273
Non-metro, KS	-1.488	-2.276	-0.035	-0.240	-0.263	-0.216
Non-metro, IN	-1.500	-2.187	-0.050	-0.113	-0.142	-0.269

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Goldsboro, NC	-1.509	-2.226	-0.007	-0.176	-0.213	-0.340
Non-metro, IL	-1.519	-2.214	-0.052	-0.154	-0.180	-0.241
Non-metro, WV	-1.523	-2.324	-0.042	-0.210	-0.234	-0.228
Dothan, AL	-1.533	-2.314	-0.040	-0.186	-0.214	-0.253
Non-metro, IA	-1.554	-2.351	-0.027	-0.192	-0.223	-0.291
Texarkana, TX-Texarkana, AR	-1.556	-2.388	-0.068	-0.200	-0.219	-0.178
Anniston, AL	-1.579	-2.385	-0.046	-0.190	-0.216	-0.250
Ocala, FL	-1.582	-2.363	-0.010	-0.166	-0.205	-0.362
Non-metro, NE	-1.592	-2.448	-0.021	-0.256	-0.285	-0.275
Florence, SC	-1.606	-2.381	-0.049	-0.131	-0.162	-0.292
Hickory-Morganton-Lenoir, NC	-1.624	-2.356	-0.008	-0.124	-0.168	-0.412
Rocky Mount, NC	-1.640	-2.384	-0.024	-0.114	-0.155	-0.381
Jonesboro, AR	-1.651	-2.533	-0.026	-0.238	-0.269	-0.293
Non-metro, MN	-1.735	-2.498	-0.047	-0.163	-0.197	-0.316
Non-metro, WI	-1.761	-2.535	-0.028	-0.120	-0.163	-0.406
Non-metro, VT	-1.775	-2.599	0.073	-0.165	-0.234	-0.647
Non-metro, AZ	-1.789	-2.580	0.037	-0.163	-0.222	-0.557
Non-metro, FL	-1.823	-2.683	0.010	-0.167	-0.220	-0.493
Non-metro, OK	-1.830	-2.782	-0.034	-0.255	-0.289	-0.317
Non-metro, LA	-1.846	-2.745	-0.058	-0.178	-0.212	-0.312
Non-metro, TX	-1.848	-2.767	-0.043	-0.206	-0.241	-0.333
Non-metro, MI	-1.864	-2.632	-0.038	-0.108	-0.153	-0.421
Non-metro, VA	-1.908	-2.771	-0.031	-0.163	-0.207	-0.415
Non-metro, MS	-1.956	-2.950	-0.066	-0.215	-0.247	-0.301
Non-metro, ME	-2.004	-2.934	0.027	-0.184	-0.246	-0.585
Non-metro, SD	-2.036	-3.119	0.001	-0.279	-0.328	-0.458
Non-metro, MO	-2.048	-3.045	-0.023	-0.251	-0.296	-0.419
Non-metro, NH	-2.059	-2.915	0.042	-0.082	-0.159	-0.715
Non-metro, KY	-2.086	-3.091	-0.057	-0.193	-0.233	-0.382
Non-metro, NC	-2.164	-3.115	-0.013	-0.148	-0.207	-0.555
Non-metro, SC	-2.203	-3.192	-0.033	-0.140	-0.196	-0.521
Non-metro, GA	-2.219	-3.178	-0.040	-0.146	-0.200	-0.501

Table A.2: List of Metropolitan and Non-Metropolitan Areas Ranked by Density

Name of Metropolitan Area	Population Density $\hat{N}^j$	Land Value $\hat{r}^j$	Quality of Life $\hat{Q}^j$	Trade Productivity $\hat{A}_X^j$	Inferred Costs Eq. (26)	Home Productivity $\hat{A}_Y^j$
Non-metro, AR	-2.267	-3.383	-0.028	-0.237	-0.289	-0.485
Non-metro, DE	-2.322	-3.242	0.010	-0.073	-0.150	-0.720
Non-metro, CO	-2.333	-3.236	0.112	-0.094	-0.199	-0.980
Non-metro, TN	-2.470	-3.614	-0.038	-0.189	-0.249	-0.559
Non-metro, AL	-2.761	-4.025	-0.067	-0.189	-0.250	-0.573

Population density is estimated from Census data, while the last five columns come from the parametrized model. See text for estimation procedure. Inferred costs equal $(\theta_L/\phi_L)\hat{p} + (\theta_N - \phi_N\theta_L/\phi_L)\hat{w}$, as given by equation (26). Quality of life and inferred costs are identical to those reported in Albouy (2009b).

Table A.3: Relationship between Model-Implied Variables and Data

		Data		
Model-Implied Variable	Notation	Wage $\hat{w}$	Home Price $\hat{p}$	Population Density $\hat{N}$
Quality of life	$\hat{Q}$	-0.478	0.324	0.000
Trade productivity	$\hat{A}_X$	0.837	0.007	0.034
Home productivity	$\hat{A}_Y$	0.730	-0.935	0.320
Land value	$\hat{r}$	0.485	0.278	1.373
Trade consumption	$\hat{x}$	0.478	-0.084	0.000
Home consumption	$\hat{y}$	0.478	-0.751	0.000
Land	$\hat{L}$	0.000	0.000	0.000
Capital	$\hat{K}$	0.618	0.030	0.989
Trade production	$\hat{X}$	1.117	-0.084	1.055
Home production	$\hat{Y}$	0.468	-0.741	0.998
Trade labor	$\hat{N}_X$	0.171	-0.086	1.044
Home labor	$\hat{N}_Y$	-0.442	0.237	0.892
Trade land	$\hat{L}_X$	0.515	-0.271	0.128
Home land	$\hat{L}_Y$	-0.098	0.052	-0.024
Trade capital	$\hat{K}_X$	0.838	-0.086	1.044
Home capital	$\hat{K}_Y$	0.225	0.237	0.892

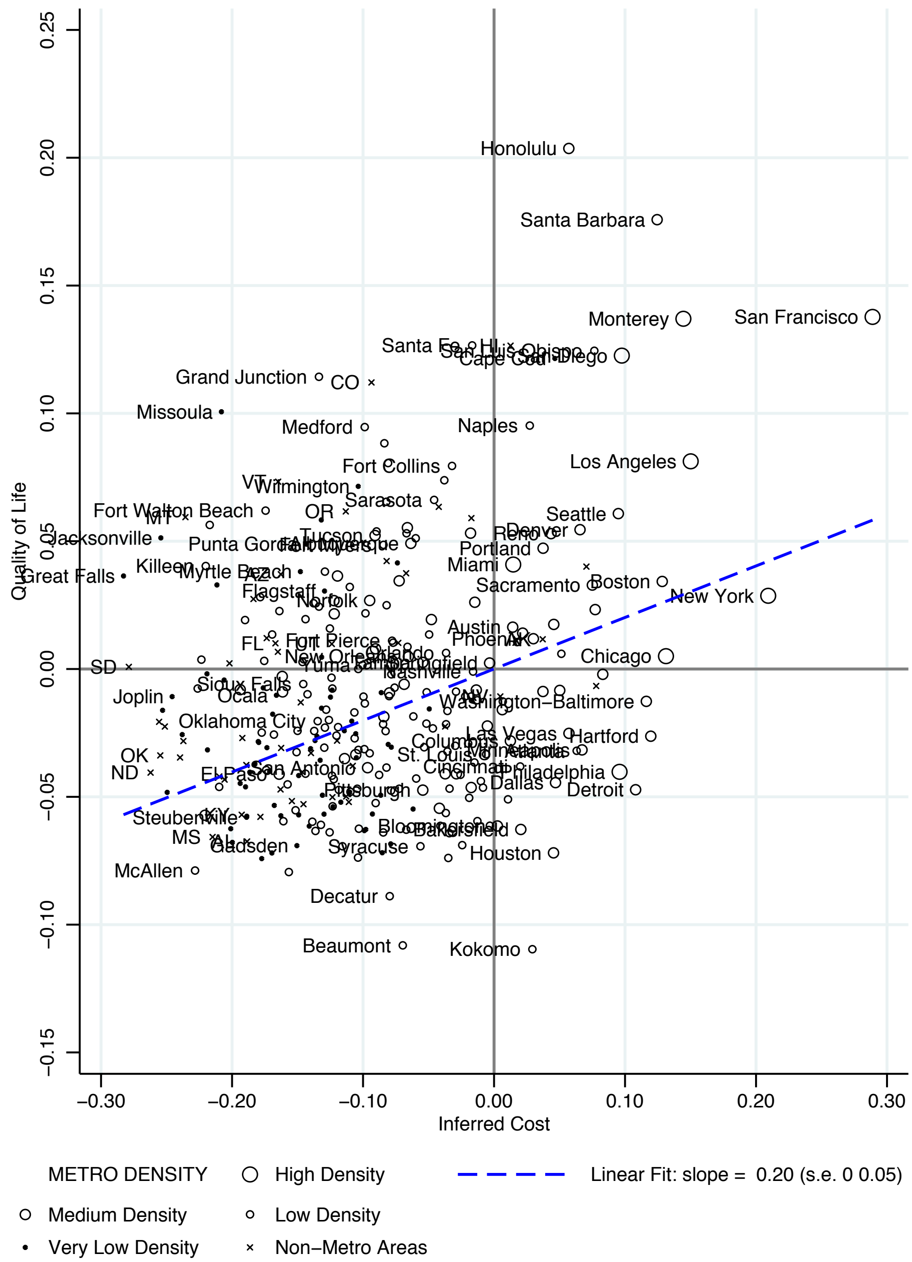
Each row presents the relationship between a model-implied amenity, price, or quantity and data on wages, home prices, and population density. For example, the parametrized model implies $\hat{Q}^j = -0.478\hat{w}^j + 0.324\hat{p}^j$. All variables are measured in log differences from the national average.

Table A.4: Fraction of Population Density Explained by Quality of Life, Trade Productivity, and Home Productivity, With Feedback Effects

		(1) With Taxes (current regime)	(2) Neutral Taxes (counterfactual)
Variance/Covariance Component	Notation	Fraction Explained	
Quality of life	Var$(\varepsilon_{N,Q}\hat{Q})$	0.309	0.213
Trade productivity	Var$(\varepsilon_{N,A_X}\hat{A}_X)$	0.044	0.116
Home productivity	Var$(\varepsilon_{N,A_Y}\hat{A}_Y)$	0.447	0.372
Quality of life and trade productivity	Cov$(\varepsilon_{N,Q}\hat{Q}, \varepsilon_{N,A_X}\hat{A}_X)$	0.116	0.157
Quality of life and home productivity	Cov$(\varepsilon_{N,Q}\hat{Q}, \varepsilon_{N,A_Y}\hat{A}_Y)$	-0.025	-0.019
Trade and home productivity	Cov$(\varepsilon_{N,A_X}\hat{A}_X, \varepsilon_{N,A_Y}\hat{A}_Y)$	0.109	0.161
Variance of population density	Var$(\hat{N})$	0.770	0.825

Column 1 presents the variance decomposition using data on population density, wages, and house prices. Column 2 presents the variance decomposition under geographically neutral taxes. Table includes both quality of life and trade productivity feedback effects.

Figure A.1: Quality of Life and Inferred Costs, 2000



See text for estimation details. High density metros have population density which exceeds the national average by 80 percent, medium density metros are between the national average and 80 percent. Low density and very low density metros are defined symmetrically.

Figure A.2: Estimated Amenity Distributions, 2000

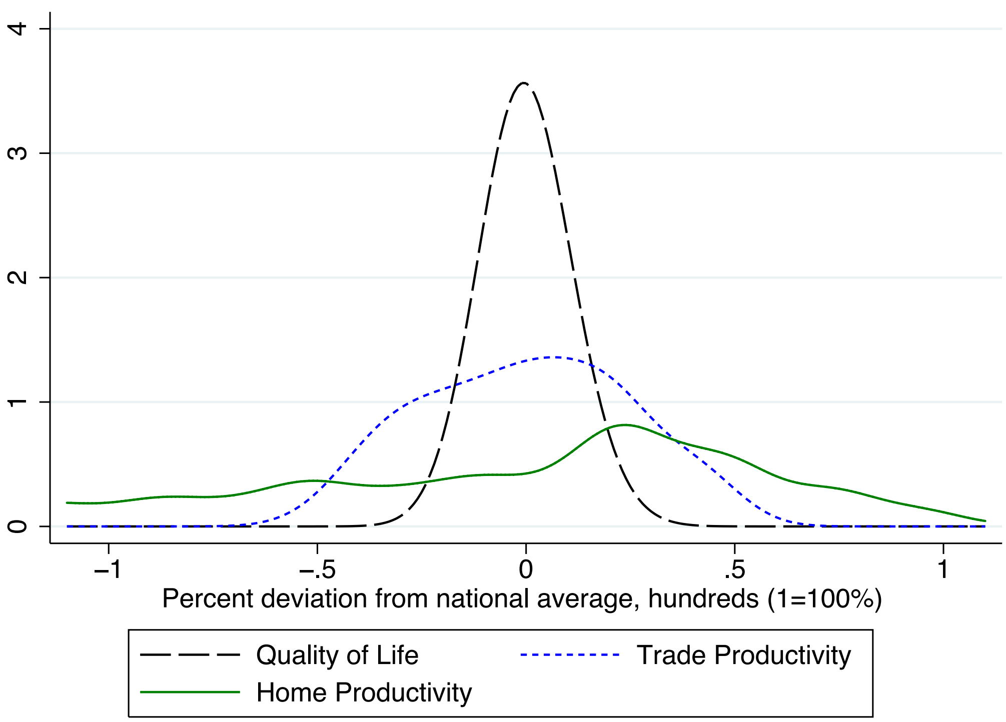
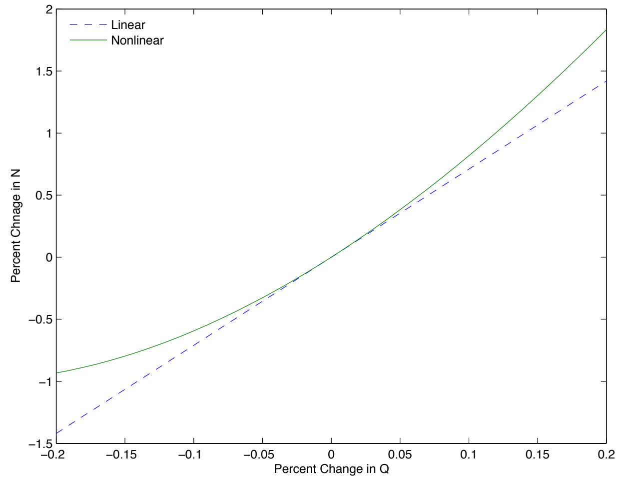
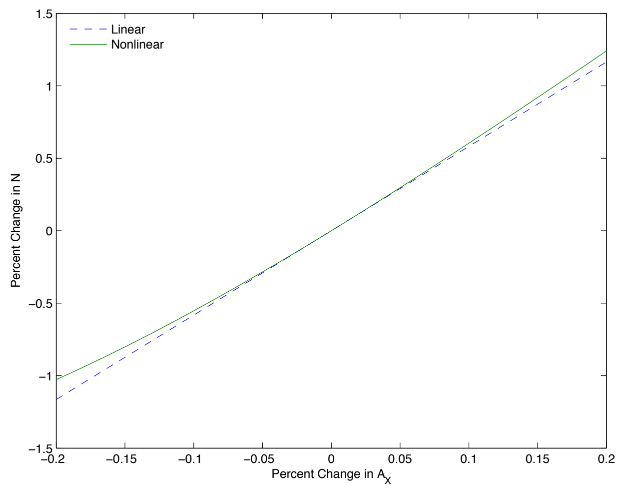


Figure A.2 is smoothed with a Gaussian kernel, bandwidth=0.1. Amenities are normalized to have equal value: trade productivity corresponds to $\hat{A}_X/s_x$ and home productivity to $\hat{A}_Y/s_y$.

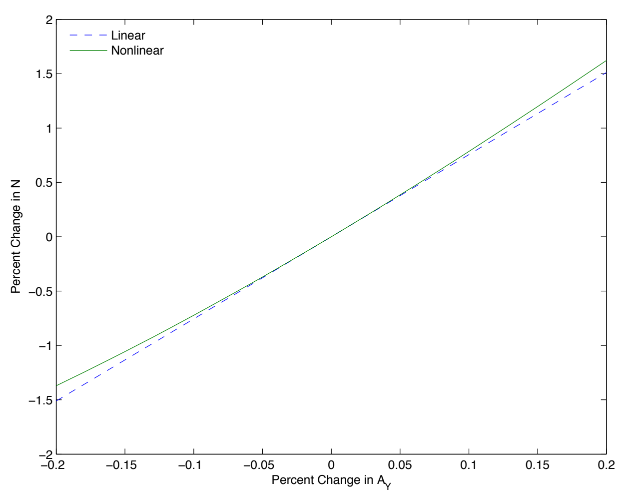
Figure A.3: Comparison of Nonlinear and Linear Model



(a) Quality of Life



(b) Trade Productivity



(c) Home Productivity