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URBAN POPULATION AND AMENITIES: THE NEOCLASSICAL MODEL OF LOCATION*

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We develop a neoclassical general equilibrium model to explain cross-metro variation in population and density. We provide new methods to estimate traded and nontraded productivities, and elasticities of housing and land supply, using density and land area data. From wage and housing cost indices, the model explains half of U.S. density and population variation and finds that quality of life determines location choices more than trade productivity; productivity and factor substitution in housing matter most, but are weak in nicer areas. Relaxing land use regulations would increase population in the West, raising both quality of life and productivity experienced by residents.

1. INTRODUCTION

Economists and policymakers are interested in knowing why incomes, prices, and populations vary across locations. Most research on this question uses a spatial equilibrium model in which individuals and firms choose their location in response to differences in economic fundamentals that vary across space (Rosen, 1979; Roback, 1988). This "neoclassical" model has been used to understand how amenities—broadly defined—determine wages and housing costs, but many of its core quantitative predictions, particularly about the cross-sectional distribution of population, have never been examined.[2]

This article studies the implications of the canonical spatial equilibrium model for household location decisions. We make two methodological innovations that generate new evidence on how population is distributed across space. First, we develop predictions of the full competitive model featuring three factors—mobile labor, capital, and immobile land—and two outputs—a good tradable across cities and a home good that is not. Cities vary in their amenities along three dimensions: quality of life for households, trade productivity, and home productivity for firms. We highlight how home (nontradable) production plays a large role in location decisions, and develop a technique that estimates how observable variables influence both scale (productivity)

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[2] We use the term "neoclassical" as it relies on standard elements in consumer and producer theory, resembling the two-sector models of Heckscher (1919) and Ohlin (1924) on trade, Uzawa (1961) and Stiglitz (1967) on growth, and Harberger (1962) on tax incidence.

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and substitution parameters in such production. This allows us to estimate housing production functions that differ for each metro in the United States using a simple cross section of data on population density, wages, and housing costs. In addition, it circumvents the pervasive problem of missing land price data using the structure of the model with population and land area data.

We derive the structural relationships between quantities, such as population, and the three amenity types that also uniquely determine wages, housing costs, and land prices. Through log-linear analytical expressions, we show for the first time how these relationships depend on expenditure shares, land supply, tax rates, and—importantly—substitution responses in consumption and production. By imposing fewer restrictions, we nest many models in the literature, especially by letting elasticities of substitution differ from one. The model's assumptions make a city's prices invariant with its land supply, while its quantities rise in proportion with it. This simplifies matters, as population differences due to density may be examined separately from such differences due to land area.

Turning to data, we assess how well the neoclassical model explains observed population and density differences across 274 metropolitan areas in the United States. We first restrict the model to have constant home productivity across metro areas, as this generates population and density predictions using only wage and housing cost data. The parametrized model explains half of the observed variation in population density across cities. We then relax that assumption and use the density data and the full model for estimation purposes. This produces new trade-productivity and home-productivity differentials, as well as elasticities of housing and land supply, for all 274 metros.

We then examine what drives population and density differences across cities. Quality of life determines location size more than trade productivity, although home productivity may dominate both.[3] Less home-productive areas have stricter land use regulations and rugged geography. Furthermore, we find that these variables reduce factor substitution in the home sector and the responsiveness of urban land supply. Thus, differences in the home sector and land supply critically shape where people live, and how much they can take advantage of places with higher quality of life and trade productivity.

Finally, we conduct counterfactual simulations that relax land use constraints. By increasing substitution possibilities in home production, this change allows households to take better advantage of local amenities. For example, the population of San Francisco would rise by 1.4 million people (20%); Los Angeles by 1.9 million (12%). Overall, population would rise by 6% in the West, and fall in the Midwest and South. The total value of amenities experienced by households would rise by 0.6% of income.

This article contributes to a broad literature on spatial equilibrium models that study the distribution of economic activity across space (e.g., Rappaport, 2008a, 2008b; Glaeser and Gottlieb, 2009; Saiz, 2010; Desmet and Rossi-Hansberg, 2013; Lee and Li, 2013; Suárez Serrato and Zidar, 2016; Diamond, 2016; Hsieh and Moretti, 2019).[4] Our technique of using a cross section of easily observed data—wages, rents, population, and land area—is particularly novel

[3] The first two attributes concern the problem of whether "jobs follow people" or "people follow jobs" (e.g., Carlino and Mills, 1987; Hoogstra et al., 2017), whereas the third addresses whether both jobs and people follow housing (e.g., Glaeser et al., 2005). The cross-sectional method we employ assesses the relative importance of these dimensions without relying on timing assumptions necessary in studies based on time-series evidence.

[4] We discuss the relationship between our model and previous work in detail in Online Appendix A. Haughwout and Inman (2001) develop a similar model for one city without home production. Rappaport (2008a, 2008b) derives quantitative implications of roughly the same model in a setting with two cities, one large and one small. Glaeser and Gottlieb (2009) assume unitary elasticities of substitution, fix separate land supplies in home and traded production, and derive analytical expressions, without applying them to data. Lee and Li (2013) use a similar model to explain Zipf's law of city sizes, without identifying particular cities or amenities. Saiz (2010) and Desmet and Rossi-Hansberg (2013) apply their models directly to city-level data using monocentric models with inelastic housing demand and constant density, and without land in trade production or labor in home production. Modeling decadal changes, Suárez Serrato and Zidar (2016) and Diamond (2016) exclude labor from nontraded production and land from traded production, and assume at least two unitary elasticities of substitution while introducing heterogeneous tastes for cities. Allen and Arkolakis (2014), Bartelme (2015), Caliendo et al. (2018), and Fajgelbaum et al. (2015) consider trade costs and monopolistic competition in models that start from, yet restrict, the benchmark neoclassical model. Our results on the role of land

and easy to apply. It generates new estimates of local home-productivity differences, as well as quality of life, and (amended) trade productivity.[5] It also provides a method of estimating housing and land supply elasticities from a single cross section of data. With this method, one may estimate how these vary across cities with additional geographic or regulatory data.

2. THE NEOCLASSICAL MODEL OF LOCATION

2.1. *System of Cities with Consumption and Production.* The national economy contains many cities, indexed by j, which trade with each other and share a homogeneous population of mobile households. Cities differ in three attributes, each of which is an index summarizing the value of amenities: quality of life Q^j raises household utility, trade productivity A_X^j lowers costs in the traded sector, and home productivity A_Y^j lowers costs in the nontraded sector. Households supply a single unit of labor in their city of residence, earning local wage w^j. They consume a numeraire traded good x and a nontraded "home" good y with local price p^j. All input and output markets are perfectly competitive, and all prices and per capita quantities are homogeneous within cities.

Firms produce traded and home goods out of land, capital, and labor. Land L^j is heterogeneous across cities, immobile, and receives a city-specific price r^j. Each city's land supply $L_0^j \tilde{L}(r^j)$ depends on an exogenous endowment L_0^j and a common supply function $\tilde{L}(r^j)$. The supply of capital in each city K^j is perfectly elastic at the price $\bar{\imath}$. Labor N^j is supplied by households who have identical size and tastes, and own 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, where $N_{TOT} = \sum_j N^j$ is the total population. 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 that is redistributed in uniform lump-sum payments T.[6] Household preferences are modeled by a utility function $U(x, y; Q^j)$ that is quasi concave over x, y, and Q^j. The expenditure function for a household in city j is $e(p^j, u; Q^j) \equiv \min_{x,y}\{x + p^j y : U(x, y; Q^j) \geq u\}$. Quality of life Q^j enters neutrally into the utility function and is normalized so that $e(p^j, u; Q^j) = e(p^j, u)/Q^j$, where $e(p^j, u) \equiv e(p^j, u; 1)$.

Firms produce traded and home goods according to the function $X^j = A_X^j F_X(L_X^j, N_X^j, K_X^j)$ and $Y^j = A_Y^j F_Y(L_Y^j, N_Y^j, K_Y^j)$, where F_X and F_Y are weakly concave and exhibit constant returns to scale, with Hicks-neutral productivity. Unit cost in the traded good sector is $c_X(r^j, w^j, \bar{\imath}; A_X^j) \equiv \min_{L,N,K}\{r^j L + w^j N + \bar{\imath} K : A_X^j F(L, N, K) = 1\}$. Let $c_X(r^j, w^j, \bar{\imath}; A_X^j) = c_X(r^j, w^j, \bar{\imath})/A_X^j$, 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.

2.2. *Equilibrium of Prices, Quantities, and Amenities.* Each city is described by a block-recursive system of 16 equations in 16 endogenous variables: 3 prices (p^j, w^j, r^j), 2 per capita consumption quantities (x^j, y^j), and 11 city-level production quantities $(X^j, Y^j, N^j, N_X^j, N_Y^j, L^j, L_X^j, L_Y^j, K^j, K_X^j, K_Y^j)$. The endogenous variables depend on three exogenous attributes Q^j, A_X^j, A_Y^j, and the land endowment L_0^j. As in the Hecksher–Ohlin model, the system first determines prices—where most researchers stop—then, per capita consumption quantities and city-level production quantities.[7] We adopt a "small open city" assumption and take nationally determined variables $\bar{u}, \bar{\imath}, I, R, T$ as given.

use regulations complement recent work by Hsieh and Moretti (2019), who focus on how these regulations affected economic growth between 1964 and 2009.

[5] Previous work estimating quality of life and trade-productivity differences includes Beeson (1991), Gabriel and Rosenthal (2004), Shapiro (2006), and Albouy (2016).

[6] The model can be generalized to allow nonlinear income taxes. Our empirical implementation adjusts for state taxes and tax benefits to owner-occupied housing.

[7] The recursive structure vanishes if workers have idiosyncratic preferences for cities or amenities depend endogenously on quantities, as described below.

We log-linearize the system, as in Jones (1965), to obtain a model that can be solved analytically with linear methods. This allows us to analyze models in which the economy is not fully Cobb–Douglas. The full nonlinear system is explained in Online Appendix B. In Online Appendix C, we verify that the log-linearized model approximates the nonlinear model well for the values in our data.

The log-linearized model involves several economic parameters, evaluated at the national average. For households, denote the shares of gross expenditures spent on the traded and home good as $s_x \equiv x/m$ and $s_y \equiv py/m$; the shares 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 shares of land, labor, and capital in the traded good sector as $\theta_L \equiv rL_X/X$, $\theta_N \equiv wN_X/X$, and $\theta_K \equiv \bar{\imath}K_X/X$; the equivalents in the home good sector are ϕ_L, ϕ_N, and ϕ_K. Finally, denote the shares of land, labor, and capital used to produce traded goods as $\lambda_L \equiv L_X/L$, $\lambda_N \equiv N_X/N$, and $\lambda_K \equiv K_X/K$. To fix ideas, 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 $\lambda_L \leq \lambda_N$. For any variable z, we denote the log differential by $\hat{z}^j \equiv \ln z^j - \ln \bar{z} \approx (z^j - \bar{z})/\bar{z}$, where $\bar{z}$ is the national average.

2.2.1. *Equilibrium price conditions for households and firms.* Since households are fully mobile, they receive the same utility $\bar{u}$ across all inhabited cities. Firms earn zero profits in equilibrium. These conditions imply

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

$$\theta_L\hat{r}^j + \theta_N\hat{w}^j = \hat{A}_X^j, \tag{1b}$$

$$\phi_L\hat{r}^j + \phi_N\hat{w}^j - \hat{p}^j = \hat{A}_Y^j. \tag{1c}$$

Equations (1a)–(1c) simultaneously determine the city-level prices $\hat{p}^j$, $\hat{r}^j$, and $\hat{w}^j$ as functions of the three attributes $\hat{Q}^j$, $\hat{A}_X^j$, and $\hat{A}_Y^j$. The tax rate and cost and expenditure shares that determine the relative importance of these prices are evaluated at the national average. These conditions provide a one-to-one mapping between unobservable city attributes and potentially observable prices. Households pay more for housing and get paid less in nicer areas. Firms pay more to their factors in more trade-productive areas, and they do the same relative to output prices in more home-productive areas. Albouy (2009, 2016) examines these conditions in detail.

2.2.2. *Consumption conditions for households.* In their consumption $\hat{x}^j$ and $\hat{y}^j$, households face a budget constraint and obey a tangency condition:

$$s_x\hat{x}^j + s_y\left(\hat{p}^j + \hat{y}^j\right) = (1-\tau)s_w\hat{w}^j \tag{2a}$$

$$\hat{x}^j - \hat{y}^j = \sigma_D\hat{p}^j, \tag{2b}$$

where $\hat{w}^j$ and $\hat{p}^j$ are determined by the price conditions. Equation (2b) depends on the elasticity of substitution in consumption, $\sigma_D \equiv -e \cdot (\partial^2 e/\partial p^2)/[\partial e/\partial p \cdot (e - p \cdot \partial e/\partial p)] = -\partial \ln(y/x)/\partial \ln p$. Substituting Equation (1a) into Equations (2a) and (2b) produces the consumption solutions $\hat{x}^j = s_y\sigma_D\hat{p}^j - \hat{Q}^j$ and $\hat{y}^j = -s_x\sigma_D\hat{p}^j - \hat{Q}^j$. Because of homothetic preferences, in areas where Q^j is higher, but p^j is the same, households consume less of x and y in equal proportions, so the ratio y/x remains 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.

In a more general model, household types could vary in their taste for home goods. In such a model, households with stronger tastes for y sort to areas with a lower p, and higher values of σ_D correspond to cases where households vary more in their tastes for home goods.

2.2.3. *Production conditions for traded and home good sectors.* Given prices and per capita consumption, output $\hat{X}^j$, $\hat{Y}^j$, employment $\hat{N}^j$, $\hat{N}^j_X$, $\hat{N}^j_Y$, capital $\hat{K}^j$, $\hat{K}^j_X$, $\hat{K}^j_Y$, and land $\hat{L}^j$, $\hat{L}^j_X$, $\hat{L}^j_Y$ are determined by 11 equations describing production and market clearing. The first six are conditional factor demands describing how input demands depend on output, productivity, and relative input prices:

$$\hat{N}^j_X = \hat{X}^j - \hat{A}^j_X + \theta_L \sigma_X^{LN}(\hat{r}^j - \hat{w}^j) - \theta_K \sigma_X^{NK} \hat{w}^j, \tag{3a}$$

$$\hat{L}^j_X = \hat{X}^j - \hat{A}^j_X + \theta_N \sigma_X^{LN}(\hat{w}^j - \hat{r}^j) - \theta_K \sigma_X^{KL} \hat{r}^j, \tag{3b}$$

$$\hat{K}^j_X = \hat{X}^j - \hat{A}^j_X + \theta_L \sigma_X^{KL} \hat{r}^j + \theta_N \sigma_X^{NK} \hat{w}^j, \tag{3c}$$

$$\hat{N}^j_Y = \hat{Y}^j - \hat{A}^j_Y + \phi_L \sigma_Y^{LN}(\hat{r}^j - \hat{w}^j) - \phi_K \sigma_Y^{NK} \hat{w}^j, \tag{3d}$$

$$\hat{L}^j_Y = \hat{Y}^j - \hat{A}^j_Y + \phi_N \sigma_Y^{LN}(\hat{w}^j - \hat{r}^j) - \phi_K \sigma_Y^{KL} \hat{r}^j, \tag{3e}$$

$$\hat{K}^j_Y = \hat{Y}^j - \hat{A}^j_Y + \phi_L \sigma_Y^{KL} \hat{r}^j + \phi_N \sigma_Y^{NK} \hat{w}^j. \tag{3f}$$

The dependence on input prices is determined by partial (Allen-Uzawa) elasticities of substitution in each sector for each pair of factors, for example, $\sigma_X^{LN} \equiv c_X \cdot (\partial^2 c_X/\partial w \partial r) / (\partial c_X/\partial w \cdot \partial c_X/\partial r)$. Our baseline model assumes that production technology does not differ across cities, implying constant elasticities; we relax this assumption for the home good sector below. To simplify, we also assume that partial elasticities within each sector are the same—that is, $\sigma_X^{NK} = \sigma_X^{KL} = \sigma_X^{LN} \equiv \sigma_X$, and similarly for σ_Y—as with a constant elasticity of substitution (CES) production function.

Higher values of σ_X correspond to more flexible production of the traded good, as firms can vary the proportion of inputs they employ. In a generalization with multiple traded goods sold at fixed prices, firms specialize in producing goods for which their input costs are relatively low.[8] A related argument exists for home goods. A higher value of σ_Y means that housing producers can better combine labor and capital to build taller buildings in areas with expensive land. For nonhousing home goods, retailers may use taller shelves and restaurants would hire extra servers to make better use of space.

Three conditions express the local resource constraints for labor, land, and capital under the assumption that factors are fully employed:

$$\hat{N}^j = \lambda_N \hat{N}^j_X + (1 - \lambda_N)\hat{N}^j_Y, \tag{4a}$$

$$\hat{L}^j = \lambda_L \hat{L}^j_X + (1 - \lambda_L)\hat{L}^j_Y, \tag{4b}$$

[8] For example, areas with high land costs and low labor costs would produce goods that use labor intensively. A representative zero-profit condition is formed by an envelope of the zero-profit conditions for each good, with a greater variety of goods reflected in greater substitution possibilities.

$$\hat{K}^j = \lambda_K \hat{K}_X^j + (1-\lambda_K)\hat{K}_Y^j. \tag{4c}$$

Equations (4a)–(4c) imply that sector-specific factor changes affect overall changes in proportion to the factor share. Local land is determined by the supply function in log differences

$$\hat{L}^j = \hat{L}_0^j + \varepsilon_{L,r}\hat{r}^j, \tag{5}$$

with the endowment differential $\hat{L}_0^j$ and the land supply elasticity $\varepsilon_{L,r} \equiv (\partial\tilde{L}^j/\partial r)\cdot(r^j/\tilde{L}^j)$.

Finally, the market clearing condition for home goods that demand equals supply is

$$\hat{N}^j + \hat{y}^j = \hat{Y}^j. \tag{6}$$

Walras' Law makes redundant the market clearing equation for traded output, which includes per capita net transfers from the federal government.

2.2.4. *Total population, density, and land.* The log-linearized model readily separates intensive margin population differences holding land supply constant, that is, density, from extensive margin differences driven by land supply. If we define population density as $N_*^j \equiv N^j/L^j$, then the total population differential is a linear function of differentials in density, the land endowment, and land supply determined by rent:

$$\hat{N}^j = \hat{N}_*^j + \hat{L}_0^j + \varepsilon_{L,r}\hat{r}^j, \tag{7}$$

where $\hat{N}_*^j$ and $\hat{r}^j$ depend on amenities $\hat{Q}^j, \hat{A}_X^j, \hat{A}_Y^j$, but the land endowment $\hat{L}_0^j$ does not.[9]

2.3. *Solving the Model for Relative Quantity Differences.* We express solutions for the endogenous variables in terms of the amenity differentials $\hat{Q}^j$, $\hat{A}_X^j$, and $\hat{A}_Y^j$. Only Equations (1a)–(1c) are needed to solve the price differentials:

$$\hat{r}^j = \frac{1}{s_R}\frac{\lambda_N}{\lambda_N - \tau\lambda_L}\left[\hat{Q}^j + \left(1-\frac{\tau}{\lambda_N}\right)s_x\hat{A}_X^j + s_y\hat{A}_Y^j\right], \tag{8a}$$

$$\hat{w}^j = \frac{1}{s_w}\frac{1}{\lambda_N - \tau\lambda_L}\left[-\lambda_L\hat{Q}^j + (1-\lambda_L)s_x\hat{A}_X^j - \lambda_L s_y\hat{A}_Y^j\right], \tag{8b}$$

$$\hat{p}^j = \frac{1}{s_y}\frac{1}{\lambda_N - \tau\lambda_L}\left[(\lambda_N-\lambda_L)\hat{Q}^j + (1-\tau)(1-\lambda_L)s_x\hat{A}_X^j - (1-\tau)\lambda_L s_y\hat{A}_Y^j\right]. \tag{8c}$$

Higher quality of life leads to higher land and home good prices but lower wages. Higher trade productivity increases all three prices, whereas higher home productivity increases land prices but decreases wages and the home good price.

Putting solution (8c) in Equations (2a) and (2b) yields the per capita consumption differentials:

[9] 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. Extensive margin differences can be driven by the land endowment $\hat{L}_0^j$ or the supply function $\varepsilon_{L,r}\hat{r}^j$. At the intensive margin, an increase in land supply takes the form of employing previously unused land within a city's border. The assumption of full utilization in (4b) and (5) rules out intensive changes.

$$\text{(9a)} \qquad \hat{x}^j = \frac{\sigma_D(1-\tau)}{\lambda_N - \tau\lambda_L}\left[\frac{\sigma_D(\lambda_N - \lambda_L) - (\lambda_N - \tau\lambda_L)}{\sigma_D(1-\tau)}\hat{Q}^j + (1-\lambda_L)s_x\hat{A}_X^j - \lambda_L s_y \hat{A}_Y^j\right],$$

$$\text{(9b)} \quad \hat{y}^j = -\frac{s_x}{s_y}\frac{\sigma_D(1-\tau)}{\lambda_N - \tau\lambda_L}\left[\frac{s_x\sigma_D(\lambda_N - \lambda_L) + s_y(\lambda_N - \tau\lambda_L)}{s_x\sigma_D(1-\tau)}\hat{Q}^j + (1-\lambda_L)s_x\hat{A}_X^j - \lambda_L s_y \hat{A}_Y^j\right].$$

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

Solutions for the other quantities, which rely on Equations (3a)–(6), 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 our central example, the population differential is written

$$\text{(10)} \qquad \hat{N}^j = \varepsilon_{N,Q}\hat{Q}^j + \varepsilon_{N,A_X}\hat{A}_X^j + \varepsilon_{N,A_Y}\hat{A}_Y^j + \hat{L}_0^j,$$

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

$$\text{(11)} \qquad \begin{aligned} \varepsilon_{N,Q} = {} & \frac{\lambda_N - \lambda_L}{\lambda_N} + \sigma_D\left[\frac{s_x}{s_y}\frac{(\lambda_N - \lambda_L)^2}{\lambda_N(\lambda_N - \lambda_L\tau)}\right] + \sigma_X\left[\frac{\lambda_L}{\lambda_N - \lambda_L\tau}\left(\frac{\lambda_L}{s_w} + \frac{\lambda_N}{s_R}\right)\right] \\ & + \sigma_Y\left[\frac{1}{\lambda_N - \lambda_L\tau}\left(\frac{\lambda_L^2(1-\lambda_N)}{s_w\lambda_N} + \frac{\lambda_N(1-\lambda_L)}{s_R} - \frac{(\lambda_N - \lambda_L)^2}{s_y\lambda_N}\right)\right] \\ & + \varepsilon_{L,r}\left[\frac{1}{s_R}\frac{\lambda_N}{(\lambda_N - \tau\lambda_L)}\right]. \end{aligned}$$

We provide similar expressions for ε_{N,A_X} and ε_{N,A_Y} in Online Appendix D. The full structural solution to (10) is obtained by substituting in these expressions.

Collecting terms for each structural elasticity in (11) highlights that nicer areas can have higher 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, for example, 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 toward labor and capital, freeing up space for households. The fourth, with σ_Y, reflects how home goods become less land intensive, for example, buildings get taller. The fifth, with $\varepsilon_{L,r}$, provides the population gain on the extensive margin from more land being used.

Each reduced-form elasticity between a quantity and amenity has up to five similar structural effects. Unlike the price solutions, (8a)–(8c), the quantity solutions require more epistemically demanding knowledge of substitution elasticities, that is, of behavioral responses to prices. Below we initially focus on quantity differences holding geography constant, focusing on density. This case sets $\hat{L}^j = 0$. In Section 6, we consider how to estimate $\varepsilon_{L,r}$ and $\hat{L}_0^j$.

2.4. *Identification of Production Amenities and Land Values.* Although cross-metro data on wages and housing rents (which proxy for home good prices) are readily available, land values are not. As a result, we cannot identify trade and home productivity from (1b) and (1c).[10] Our

[10] Albouy et al. (2018) 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. Moreover, land value data are generally not available in most years in most countries.

solution is to use widely available data on population density as a replacement for land values. Consider combining Equations (1b) and (1c) to eliminate $\hat{r}^j$:

$$\text{(12)} \qquad \text{Inferred costs}^j \equiv \frac{\theta_L}{\phi_L}\hat{p}^j + \left(\theta_N - \phi_N\frac{\theta_L}{\phi_L}\right)\hat{w}^j = \hat{A}_X^j - \frac{\theta_L}{\phi_L}\hat{A}_Y^j.$$

The left-hand side of (12) equals traded producer costs inferred from wages and home good prices. Trade productivity raises these inferred costs, whereas home productivity lowers them. Albouy (2016) assumes that home productivity is constant, $\hat{A}_Y^j = 0$, so that land values may be inferred from (1c), and $\hat{A}_X^j$ equals the inferred costs. The ensuing estimates are biased downward in home-productive areas, although $\hat{A}_X$ is only slightly biased if $\theta_L << \phi_L$.

Combining Equations (1a) and the analog of Equation (10) for density yields the following expression, which says that "excess density" not explained by quality of life, on the left, must be explained by either trade or home productivity, on the right:

$$\text{(13)} \qquad \text{Excess density}^j \equiv \hat{N}_*^j - \varepsilon_{N_*,Q}\underbrace{[s_y\hat{p}^j - s_w(1-\tau)\hat{w}^j]}_{\hat{Q}^j} = \varepsilon_{N_*,A_X}\hat{A}_X^j + \varepsilon_{N_*,A_Y}\hat{A}_Y^j.$$

Equations (12) and (13) are exactly identified: the inferred amenities *perfectly predict* density. Solving these equations identifies each productivity from observable differentials $\hat{N}_*^j$, $\hat{w}^j$, and $\hat{p}^j$:

$$\text{(14a)} \quad \hat{A}_X^j = \frac{\theta_L\Big[\hat{N}_*^j - \varepsilon_{N_*,Q}\big(s_y p^j - s_w(1-\tau)w^j\big)\Big] + \phi_L\varepsilon_{N_*,A_Y}\Big[\frac{\theta_L}{\phi_L}p^j + \Big(\theta_N - \phi_N\frac{\theta_L}{\phi_L}\Big)w^j\Big]}{\theta_L\varepsilon_{N_*,A_X} + \phi_L\varepsilon_{N_*,AY}}$$

$$\text{(14b)} \quad \hat{A}_Y^j = \frac{\phi_L\Big[\hat{N}_*^j - \varepsilon_{N_*,Q}\big(s_y p^j - s_w(1-\tau)w^j\big)\Big] - \phi_L\varepsilon_{N_*,A_X}\Big[\frac{\theta_L}{\phi_L}p^j + \Big(\theta_N - \phi_N\frac{\theta_L}{\phi_L}\Big)w^j\Big]}{\theta_L\varepsilon_{N_*,A_X} + \phi_L\varepsilon_{N_*,AY}}$$

High excess density and high inferred costs imply high trade productivity. High excess density with low inferred costs imply high home productivity. Home productivity is identified more from density than trade productivity, as $\phi_L > \theta_L$. The value of land is found by substituting (14a) into (1b), yielding:

$$\text{(14c)} \qquad \hat{r}^j = \frac{\hat{N}_*^j - \varepsilon_{N_*,Q}\big(s_y\hat{p}^j - s_w(1-\tau)\hat{w}^j\big) - \varepsilon_{N_*,A_X}\theta_N\hat{w}^j - \varepsilon_{N_*,A_Y}\big(\phi_N\hat{w}^j - \hat{p}^j\big)}{\theta_L\varepsilon_{N_*,A_X} + \phi_L\varepsilon_{N_*,AY}}.$$

As seen in the numerator of (14c), this rent measure depends on density not explained either by quality of life or productivity differences inferred from nonland prices.

The key to this approach is that an observed quantity, population density, replaces an unobserved price, land rents. In principle, one could use data on total metro population and land supply instead of density, but that would require a value for the land supply elasticity $\varepsilon_{L,r}$. There is no consensus on the appropriate value of this parameter, although we attempt to estimate it below.

2.5. *Incorporating Preference Heterogeneity.* Here we consider an extension in which individuals have idiosyncratic preferences over destinations. Although such preferences are arguably less important for the long-run equilibrium captured by our model, this extension provides a clear connection to discrete choice models.

Suppose that the indirect utility of worker i in city j is money metric, with $V_i^j = v(p^j, w^j; Q^j) + \epsilon_i^j$, where $v(p^j, w^j; Q^j)$ is a function common to households and ϵ_i^j is an idiosyncratic preference shock. Following the literature—for example, Kline and Moretti (2014), Suárez Serrato and Zidar (2016), and Hsieh and Moretti (2019)—we make the convenient assumption that ϵ_i^j is distributed i.i.d. Type 1 Extreme Value with scale parameter $\psi \geq 0$. This implies that population in city j is

$$N^j = \frac{\exp[v(p^j, w^j; Q^j)/\psi]}{\sum_{j'=1}^{J} \exp[v(p^{j'}, w^{j'}; Q^{j'})/\psi]}. \tag{15}$$

Log-linearizing equation (15) yields a modified mobility condition,

$$-s_w(1-\tau)\hat{w}^j + s_y\hat{p}^j + \psi\hat{N}^j = \hat{Q}_N^j, \tag{16}$$

where the subscript on $\hat{Q}_N^j$ distinguishes this from the quality of life differential in Equation (1a). With idiosyncratic preferences, we observe willingness-to-pay of a resident on the margin of moving to another metro, that is, $\hat{Q}^j = \hat{Q}_N^j - \psi\hat{N}^j$. The greater the population, the lower will be this willingness-to-pay for a given quality of life. $\hat{Q}_N^j$ then recovers this value, netting out changes in willingness-to-pay due to population differences. As seen in Equation (16), identifying quality of life with idiosyncratic preferences requires not only data on wages and housing casts, but also data on population. As ψ approaches zero, there is no dispersion in idiosyncratic preferences, returning the original Equation (1a).

Preference heterogeneity dampens the relationship between population and amenities, as can be seen by combining Equations (1a), (10), and (16):

$$\hat{N}^j = \frac{1}{1+\psi\varepsilon_{N,Q}}\left(\varepsilon_{N,Q}\hat{Q}_N^j + \varepsilon_{N,A_X}\hat{A}_X^j + \varepsilon_{N,A_Y}\hat{A}_Y^j + \hat{L}_0^j\right). \tag{17}$$

This dampening occurs because firms in a city need to pay incoming migrants an increasing schedule in after-tax real wages to have them overcome their taste differences. Preference heterogeneity does not affect the estimates of trade and home productivity in Equations (14a) and (14b).

3. PARAMETER CHOICES AND REDUCED-FORM ELASTICITIES

3.1. *Parameter Choices.* The parametrization we use, shown in Table 1, was set in Albouy (2009). It is based on a literature review that does not refer to population data. We focus on the substitution elasticities, as they are rarely considered. The parametrization sets them to $\sigma_D = \sigma_X = \sigma_Y = 0.667$. This is consistent with households having higher housing expenditures in high-rent areas and housing having a higher cost-share of land in high-value areas (Albouy et al., 2016a; Albouy and Ehrlich, 2018). When we incorporate preference heterogeneity, we use a value of $\psi = 0.07$ from Notowidigdo (Forthcoming) or $\psi = 0.30$ from Hsieh and Moretti (2019).[11] Online Appendix E contains additional details on the parametrization. We report several sensitivity analyses below. Starting in Subsection 5.4, σ_Y is estimated and allowed to vary by city.

3.2. *Parametrized Reduced-Form Elasticities.* Panel A of Table 2 demonstrates how the three reduced-form elasticities for population depend on the structural elasticities. For example, the five responses in the elasticity of population to quality of life from (11) are given by the sum: $\varepsilon_{N,Q} = 0.77 + 1.14\sigma_D + 1.95\sigma_X + 8.01\sigma_Y + 11.85\varepsilon_{L,r}$. Numerically, the extensive margin of land

[11] The parameter σ in Notowidigdo's moving cost function is analogous to $-\psi$ in Equation (16). Notowidigdo estimates $\sigma^H = -0.066$ for high-skill workers and $\sigma^L = -0.065$ for low-skill workers. The relationship to Hsieh and Moretti (2019) is straightforward (see their discussion on p. 18).

TABLE 1
NOTATION AND CONSTANT GEOGRAPHY PARAMETRIZATION

Parameter Name	Notation	Value
Cost and Expenditure Shares		
Home good expenditure share	s_y	0.360
Income share to land	s_R	0.100
Income share to labor	s_w	0.750
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	0.160
Share of labor used in traded good	λ_N	0.704
Tax Parameters		
Average marginal tax rate	τ	0.392
Average deduction level	δ	0.284
Substitution 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 or city-specific
Miscellaneous Elasticities		
Dispersion of idiosyncratic preferences	ψ	0.07 or 0.30 (see text)
Elasticity of land supply	$\varepsilon_{L,r}$	0 or see text
City-specific Attributes		
Quality of life	Q^j	city-specific
Trade productivity	A_X^j	city-specific
Home productivity	A_Y^j	constant or city-specific

NOTES: Parametrization for all but miscellaneous elasticities preset in Albouy (2009). Elasticity of land supply set to zero for determining reduced-form elasticities in Section 4, constant geography exercises in Table 3, and density exercises in Table 4. Substitution elasticities estimated by city in Table 5. See Online Appendix E for details on parametrization.

TABLE 2
RELATIONSHIP BETWEEN REDUCED-FORM AND STRUCTURAL ELASTICITIES, POPULATION, AND HOUSING

	A: Reduced-Form Population Elasticity with Respect to:		
	Quality of Life $\varepsilon_{N,Q}$	Trade Productivity ε_{N,A_X}	Home Productivity ε_{N,A_Y}
σ_D	1.142	0.719	−0.077
σ_X	1.953	0.468	0.636
σ_Y	8.012	2.055	2.608
$\varepsilon_{L,r}$	11.848	4.014	3.856
Constant	0.773	0.000	0.773

	B: Reduced-Form Housing Elasticity with Respect to:		
	Quality of Life $\varepsilon_{Y,Q}$	Trade Productivity ε_{Y,A_X}	Home Productivity ε_{Y,A_Y}
σ_D	−0.336	−0.212	0.023
σ_X	1.953	0.468	0.636
σ_Y	8.012	2.055	2.608
$\varepsilon_{L,r}$	11.848	4.014	3.856
Constant	−0.227	0.000	0.773

NOTES: Table 2 decomposes reduced-form elasticities into substitution elasticities in consumption (σ_D), traded good production (σ_X), home good production (σ_Y), and the elasticity of land supply ($\varepsilon_{L,r}$). For example, the reduced-form elasticity of population with respect to quality of life is $\varepsilon_{N,Q} = 0.773 + 1.142\sigma_D + 1.953\sigma_X + 8.012\sigma_Y + 11.848\varepsilon_{L,r}$.

supply is critical. On the intensive margin of population density, the substitution parameter in the housing sector stands out as the most important. The intuition is straightforward: increasing population density without building densely strains other substitution margins. Higher densities would be achieved only by increasing the occupancy of existing structures or releasing land from the traded good sector. When $\sigma_D = \sigma_X = 0.667$ and $\hat{L}^j = 0$, density and amenities are related through σ_Y as

$$\hat{N}_*^j = (2.84 + 8.01\sigma_Y)\hat{Q}^j + (0.79 + 2.06\sigma_Y)\hat{A}_X^j + (1.15 + 2.61\sigma_Y)\hat{A}_Y^j. \tag{18}$$

Setting $\sigma_Y = 0.667$ produces $\hat{N}_*^j = 8.18\hat{Q}^j + 2.16\hat{A}_X^j + 2.88\hat{A}_Y^j$. The elasticity of substitution in nontraded production accounts for about two-thirds of the reduced-form elasticities.

A one-point increase in $\hat{Q}^j$ is equal in value to a one-point increase in income, whereas 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. To make the productivity elasticities comparable in value, they can be normalized:

$$\hat{N}_*^j = 8.18\hat{Q}^j + 3.38 s_x \hat{A}_X^j + 8.01 s_y \hat{A}_Y^j. \tag{19}$$

Quality of life and home productivity have large impacts on local population density: raising their value by 1% of income increases density by 8 percentage points. Trade productivity's impact is less than half as large. As a result, funds spent to attract households directly may be more effective at boosting population than funds spent to attract firms.

Setting the marginal tax rate τ to zero reveals that taxes cause much of these asymmetries: $\hat{N}_*^j = 6.32\hat{Q}^j + 5.81 s_x \hat{A}_X^j + 7.55 s_y \hat{A}_Y^j$. Taxes push workers away from trade-productive areas toward high quality of life and home-productive areas (Albouy, 2009). Remaining asymmetries arise from other sources. The income effect from quality of life makes households more willing to crowd into existing residential space, whereas an output effect from home productivity, provides additional space. Trade productivity, on the other hand, raises labor costs in the home sector, putting a brake on growth.

In a Cobb–Douglas economy, $\sigma_D = \sigma_X = \sigma_Y = 1$, the implied reduced-form elasticities are 37–50% higher than if $\sigma = 0.667$. If substitution margins are inelastic, then assuming a Cobb–Douglas economy—as many do—could inflate quantity predictions and associated welfare calculations.

Table 3 displays the reduced-form elasticities for all endogenous prices and quantities. Online Appendix Table A.1 contains results with preference heterogeneity (discussed above) and feedback effects between population density and amenities (discussed in Online Appendix D.7). Although we focus on population and density here, many other quantities—such as capital stocks—could be investigated with additional data. A key challenge for these other quantities is that accurate data on them are often unavailable at the metro level.

Online Appendix E.2 discusses alternative parametrizations using different sets of share parameters from Haughwout (2002), Glaeser and Gottlieb (2009), and Rappaport (2008a, 2008b), and Online Appendix E.3 describes results from these alternatives. After normalizing the elasticities by the size of the traded and nontraded sectors as in Equation (19), the results from our preferred parametrization always lie within the range of values implied by these three alternatives. In the exercises that follow, these parametrizations generally imply a stronger role for trade productivity and a weaker role for quality of life, but this is largely due to how those attributes are estimated.

4. GENERAL EQUILIBRIUM ELASTICITIES AND PREVIOUS ESTIMATES

Elasticities characterizing how population and housing respond to changes in prices are regularly estimated. The general equilibrium framework here models consumption, labor, and

TABLE 3
PARAMETRIZED RELATIONSHIP BETWEEN AMENITIES, PRICES, AND QUANTITIES

Price/Quantity	Notation	Quality of Life $\hat{Q}$	Trade Productivity $\hat{A}_X$	Home Productivity $\hat{A}_Y$
Land value	$\hat{r}$	11.848	4.014	3.856
Wage	$\hat{w}$	−0.359	1.090	−0.117
Home price	$\hat{p}$	2.543	1.609	−0.172
Trade consumption	$\hat{x}$	−0.446	0.349	−0.037
Home consumption	$\hat{y}$	−1.986	−0.621	0.067
Population	$\hat{N}$	8.181	2.162	2.885
Capital	$\hat{K}$	7.937	2.865	2.779
Land	$\hat{L}$	0.000	0.000	0.000
Trade production	$\hat{X}$	7.962	3.338	2.934
Home production	$\hat{Y}$	6.195	1.541	2.951
Trade labor	$\hat{N}_X$	8.202	2.278	3.012
Home labor	$\hat{N}_Y$	8.131	1.887	2.581
Trade capital	$\hat{K}_X$	7.962	3.005	2.934
Home capital	$\hat{K}_Y$	7.891	2.615	2.503
Trade land	$\hat{L}_X$	0.060	0.328	0.362
Home land	$\hat{L}_Y$	−0.011	−0.063	−0.069

NOTES: Each value in Table 3 represents the partial effect that a one-point increase in each amenity has on each price or quantity, for example, $\hat{N}^j = 8.181\hat{Q}^j + 2.162\hat{A}_X^j + 2.885\hat{A}_Y^j$. All variables are measured in log differences from the national average.

land markets simultaneously, complementing empirical work in two ways.[12] First, it provides a useful lens for understanding existing empirical strategies. Price and quantity shifts depend ultimately on fundamental shifts in quality of life, trade productivity, and home productivity. As shown, a shift in one amenity—for example, quality of life—typically changes all prices and quantities. Second, similarities between elasticities in the parametrized model and prior empirical work help tell us if a parametrization is sensible.

4.1. *Local Labor Supply and Demand.* In partial equilibrium, increasing demand traces out a local labor supply curve. The immediate analogy of an increase in labor demand here is an increase in trade productivity, and so the following ratio provides a "local" general equilibrium elasticity of labor supply:

$$\left.\frac{\partial \hat{N}_*}{\partial \hat{w}}\right|_{\hat{Q},\hat{A}_Y} = \frac{\partial \hat{N}_*/\partial \hat{A}_X}{\partial \hat{w}/\partial \hat{A}_X} = 0.66\sigma_D + 0.43\sigma_X + 1.88\sigma_Y = 1.98. \tag{20}$$

The resulting labor supply curve slopes upward as higher density raises demand for home goods and their prices, requiring higher wage compensation. A ceteris paribus increase in the wage, holding home good prices constant, does not identify a labor supply elasticity in this model. Since trade productivity increases both wages and home good prices, a constant home good price requires either a simultaneous decrease in quality of life, shifting in labor supply, or an increase in home productivity, shifting out housing supply.

Longer run labor supply elasticity estimates are usually in the range of 1–4 (Bartik, 1991; Blanchard and Katz, 1992; Notowidigdo, Forthcoming; Albouy et al., 2019), close to the values predicted in (20), for a range of substitution elasticities.[13]

[12] The model features a "local" general equilibrium, in the sense that there are interactions between input and output markets within each metro, while each metro is assumed to be small enough not to affect the nationwide variables $\bar{u}$ or $\bar{\iota}$.

[13] Most researchers from Bartik (1991) onward do not find that these elasticities differ much between 10-year and longer horizons. Notowidigdo (Forthcoming) estimates a preference dispersion parameter of $\psi = 0.07$ in a model that holds quality of life constant. In our model, this reduces the elasticity of labor to nominal wages to 1.22 (see Table A.1).

Increasing supply traces out a local labor demand curve. The closest analogy to a shift in supply is an increase in quality of life. The resulting labor demand curve slopes downward: holding productivity constant, a larger work force pushes down wages, as firms complement labor with ever scarcer land. The parametrized elasticity of labor demand is

$$\left.\frac{\partial \hat{N}_*}{\partial \hat{w}}\right|_{\hat{A}_X,\hat{A}_Y} = \frac{\partial \hat{N}_*/\partial \hat{Q}}{\partial \hat{w}/\partial \hat{Q}} = -2.15 - 3.18\sigma_D - 5.44\sigma_X - 22.31\sigma_Y = -22.79.$$

This large value is broadly consistent with evidence that immigration-induced increases in local labor supply have only weak effects on relative wages (e.g., Bartel, 1989; Card, 2001).[14]

Panel A of Figure 1 illustrates how general equilibrium elasticities of labor supply and demand vary with elasticities of substitution in consumption and production, assumed to be equal ($\sigma_D = \sigma_X = \sigma_Y \equiv \sigma$). Without substitution responses, $\sigma = 0$, labor supply is perfectly inelastic, and labor demand has a smaller elasticity of -2.15, due only to income effects from Q. The size of the structural substitution parameters is instrumental in determining both demand and supply elasticities.

4.2. *Local Housing Supply and Demand.* A city's housing stock is closely tied to its population. The difference between the two depends only on substitution and income effects in consumption:

$$\hat{Y}^j = \hat{N}^j - s_x\sigma_D\hat{p}^j - \hat{Q}^j = 6.20\hat{Q}^j + 2.41s_x\hat{A}_X^j + 8.20s_y\hat{A}_Y^j. \tag{21}$$

Relative to population, housing responds less to quality of life and trade productivity and more to home productivity. This relationship holds both for total numbers and density.

Two potential demand shifts may trace out a housing supply curve: quality of life or trade productivity. The elasticity is generally greater for the former than the latter:

$$\left.\frac{\partial \hat{Y}}{\partial \hat{p}}\right|_{\hat{A}_X,\hat{A}_Y} = \frac{\partial \hat{Y}/\partial \hat{Q}}{\partial \hat{p}/\partial \hat{Q}} = -0.09 - 0.13\sigma_D + 0.77\sigma_X + 3.15\sigma_Y + 4.66\varepsilon_{L,r} \tag{22a}$$

$$\left.\frac{\partial \hat{Y}}{\partial \hat{p}}\right|_{\hat{Q},\hat{A}_Y} = \frac{\partial \hat{Y}/\partial \hat{A}_X}{\partial \hat{p}/\partial \hat{A}_X} = -0.13\sigma_D + 0.29\sigma_X + 1.28\sigma_Y + 2.49\varepsilon_{L,r}. \tag{22b}$$

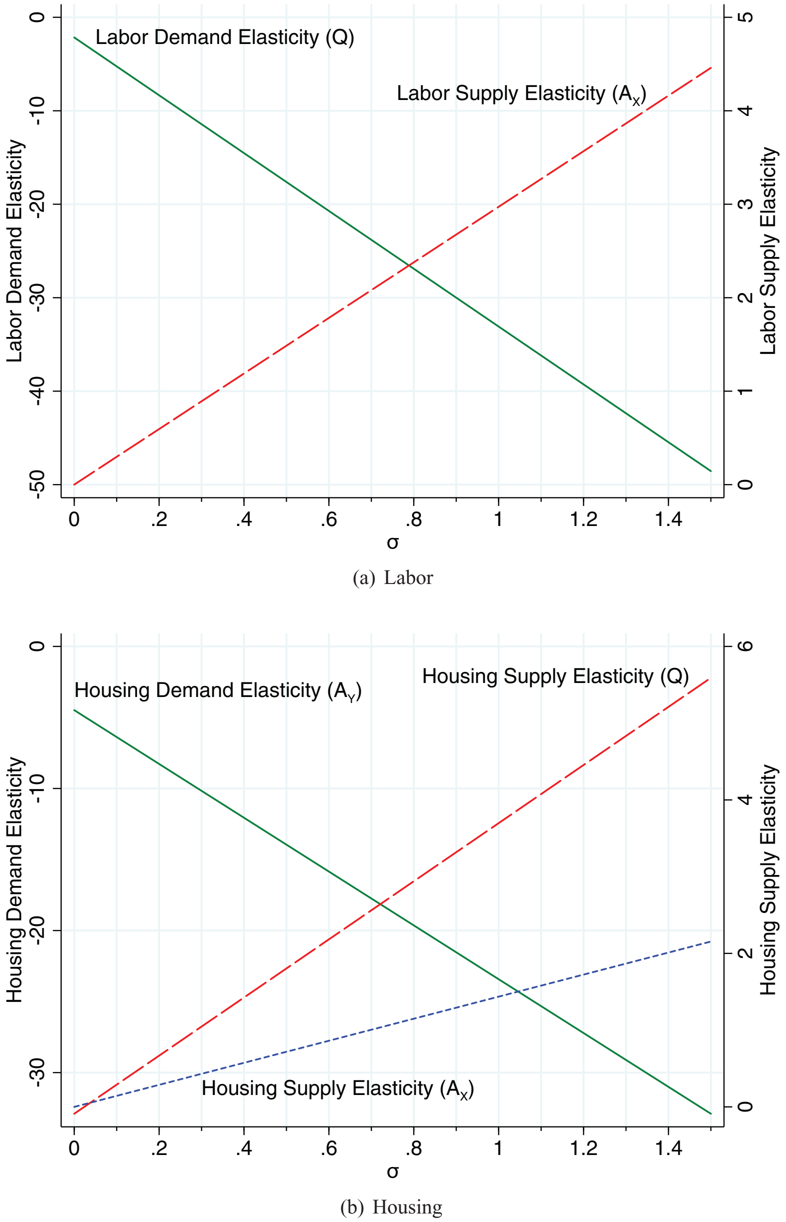
These equal 2.44 and 0.96 when $\sigma_D = \sigma_X = \sigma_Y = 0.667$ and $\varepsilon_{L,r} = 0$. The two formulae point out that the magnitude of a housing supply elasticity depends on the demand shock. Both

[14] A number of papers estimate the relationship between immigration-induced (total) labor supply changes and (average) wage changes, which is the closest empirical analog to $(\partial\hat{N}/\partial\hat{w})|_{\hat{A}_X,\hat{A}_Y}$. Results from such regressions vary widely, as discussed by Borjas (1999).

If demand for the traded good is not perfectly elastic, as in a model with heterogeneous traded output, then the elasticity of labor demand will be lower. To illustrate this in a partial equilibrium setting, let demand for the local traded good be $\hat{X}^j = -\eta\hat{p}_X^j$ where p_X^j is its price, formerly fixed. Let land supply for traded-good firms be provided in a segmented market by $\hat{L}_X^j = \hat{L}_{0X}^j + \varepsilon_X\hat{r}_X^j$. From the equations governing the firm—(1b), (3a), and (3b)—one can derive a general form of Marshall's Rule for labor demand in the trade sector. It includes additional terms of trade productivity and the land endowment:

$$\hat{N}_X^j = \frac{-[\sigma_X(\eta+\varepsilon_X) + \theta_N\varepsilon_X(\eta-\sigma_X) - \theta_K(\eta-\sigma_X)\sigma_X]\hat{w}^j + (\eta-1)(\sigma_X+\varepsilon_X)\hat{A}_X^j + (\eta-\sigma_X)\theta_L\hat{L}_{0X}^j}{\eta\theta_L + \sigma_X(1-\theta_L) + \varepsilon_X}.$$

The coefficient on wages increases with η, meaning labor demand is more elastic when product demand is elastic. If we take $\varepsilon_X = 1$ (see Table 6 below), then a commonly estimated value of $\eta = 4$ (e.g., from Suárez Serrato and Zidar, 2016) produces a labor demand elasticity of -3.2, whereas $\eta = \infty$ produces a an elasticity of -22. We also see that wages here rise with the endowment of land, comparable to a fixed capital, as in Glaeser and Gottlieb (2008) or Hsieh and Moretti (2019).



(a) Labor

(b) Housing

NOTES: Panel (a) displays $\partial\hat{N}/\partial\hat{w}$, where the change in both density and wages is due to a change in the indicated amenity, as a function of the substitution elasticity $\sigma_D = \sigma_X = \sigma_Y \equiv \sigma$. Panel (b) displays similar results for the elasticity of housing with respect to housing prices.

FIGURE 1

RELATIONSHIP BETWEEN LABOR AND HOUSING GENERAL EQUILIBRIUM ELASTICITIES AND SUBSTITUTION POSSIBILITIES [COLOR FIGURE CAN BE VIEWED AT WILEYONLINELIBRARY.COM]

elasticities have large coefficients on σ_Y, from housing being produced more densely on the intensive margin. Supply also depends strongly on the extensive margin, through $\varepsilon_{L,r}$. Subtly, it depends on the intensive margin through σ_X: as land released from the traded sector moves to the home sector, workers demand more land. The elasticities also incorporate small reductions in demand from rising prices, seen in the negative constant and coefficient on σ_D.

The predicted values of the supply elasticities are consistent with the range of estimates seen in Green et al. (2005) and Saiz (2010) for different cities. However, those estimates vary considerably across metros, from what their authors argue are differences in geography or regulatory constraints. This suggests that these constraints affect either the intensive or extensive margin of housing supply by altering the parameter values of σ_Y or $\varepsilon_{L,r}$ across metros.[15]

A shift in supply due to home productivity could arguably identify a metro-level housing demand curve. In the neoclassical model, home productivity increases the amount of housing much more than it lowers prices:

$$\left.\frac{\partial \hat{Y}}{\partial \hat{p}}\right|_{\hat{Q},\hat{A}_X} = \frac{\partial \hat{Y}/\partial \hat{A}_Y}{\partial \hat{p}/\partial \hat{A}_Y} = -4.48 - 0.13\sigma_D - 3.69\sigma_X - 15.12\sigma_Y - 22.37\varepsilon_{L,r}$$

When $\sigma_D = \sigma_X = \sigma_Y = 0.667$ and $\varepsilon_{L,r} = 0$, this is -17.12. This large magnitude rests heavily on households having homogeneous tastes for locations. If so, improvements to housing productivity increase the quantity of housing much more than they lower prices.

Panel B of Figure 1 illustrates how general equilibrium elasticities of housing supply and demand vary with elasticities of substitution in consumption and production. As elasticities of substitution increase, the difference between housing supply elasticities identified by quality of life and trade productivity grows.

5. THE RELATIONSHIP BETWEEN DENSITY, PRICES, AND AMENITIES

5.1. *Data.* We now apply the neoclassical model empirically to see if it can predict population levels. We examine cities in the continental United States, defined at the Metropolitan Statistical Area (MSA) level using 1999 Office of Management and Budget consolidated definitions (e.g., San Francisco is combined with Oakland and San Jose), of which there are 274. We use the 5% sample of the 2000 United States Census from Ruggles et al. (2004) to calculate wage and housing price differentials, controlling for relevant covariates (see Online Appendix F for details). Metro level population densities are shown in Figure 2. We construct these as the population-weighted average of density in each urban area. We use MSA population weights throughout.

Figure 3 displays kernel density estimates of wages, housing prices, and population density across MSAs. Population density varies by an order of magnitude more than wages and prices. This basic fact is reflected in our amenity estimates below.

5.2. *Predicting and Explaining Population Density.* We first consider how well the model predicts population density using price information alone. As in Albouy (2016), we use estimates of $\hat{Q}^j$ and $\hat{A}_X^j$ based on $\hat{w}^j$ and $\hat{p}^j$, from Equations (1a) and (12), and assume $\hat{A}_Y^j = 0$. Thus, predicted population density is simply $\varepsilon_{N_*,Q}\hat{Q}^j + \varepsilon_{N_*,A_X}\hat{A}_X^j$, approximated by $8.18\hat{Q}^j +$

[15] Consider a typical partial equilibrium setting of home good supply with exogenous wages, but where we let land values be set endogenously by the zero-profit condition (1c). For simplicity, also assume that home and traded good land markets are segmented. Thus, residential land is given by $\hat{L}_Y^j = \hat{L}_{0Y}^j + \varepsilon_Y \hat{r}_Y^j$. Then the supply of housing increases with prices, productivity, and land endowments, while it falls with wages:

$$\hat{Y}^j = \frac{\sigma_Y(1-\phi_L)+\varepsilon_Y}{\phi_L}\hat{p}^j - (\sigma_Y+\varepsilon_Y)\frac{\phi_N}{\phi_L}\hat{w}^j + \left[1+\frac{\sigma_Y(1-\phi_L)+\varepsilon_Y}{\phi_L}\right]\hat{A}_Y^j + \hat{L}_{0Y}^j$$

Parametrized, $\hat{Y} = (2.2+4.3\varepsilon_Y)\hat{p}^j - (1.8+2.6\varepsilon_Y)\hat{w}^j + (3.2+4.3\varepsilon_Y)\hat{A}_Y^j$. The base coefficient of 2.2 on $\hat{p}^j$ is similar to estimates in the literature. The formula also highlights the separate role of an extensive margin through land supply in ε_Y and $\hat{L}_{0Y}^j$, as well as productivity in $\hat{A}_Y^j$ in determining supply. Local wages, $\hat{w}^j$, play a particular role as $\hat{Q}^j$ and $\hat{A}_Y^j$ lower wages, while $\hat{A}_X^j$ raises them. Thus, omitting wages from an elasticity regression could create an omitted variable bias in estimating the structural parameters, either up or down, depending on the origin of the price change. Furthermore, with heterogeneous preferences (Subsection 2.5), the total elasticity, net of demand, is lower.

Note that even without modeling local labor inputs, $\phi_N = 0$, we cannot reduce the supply relationship between home-good prices and population as $\hat{Q}^j$ is present in (21).

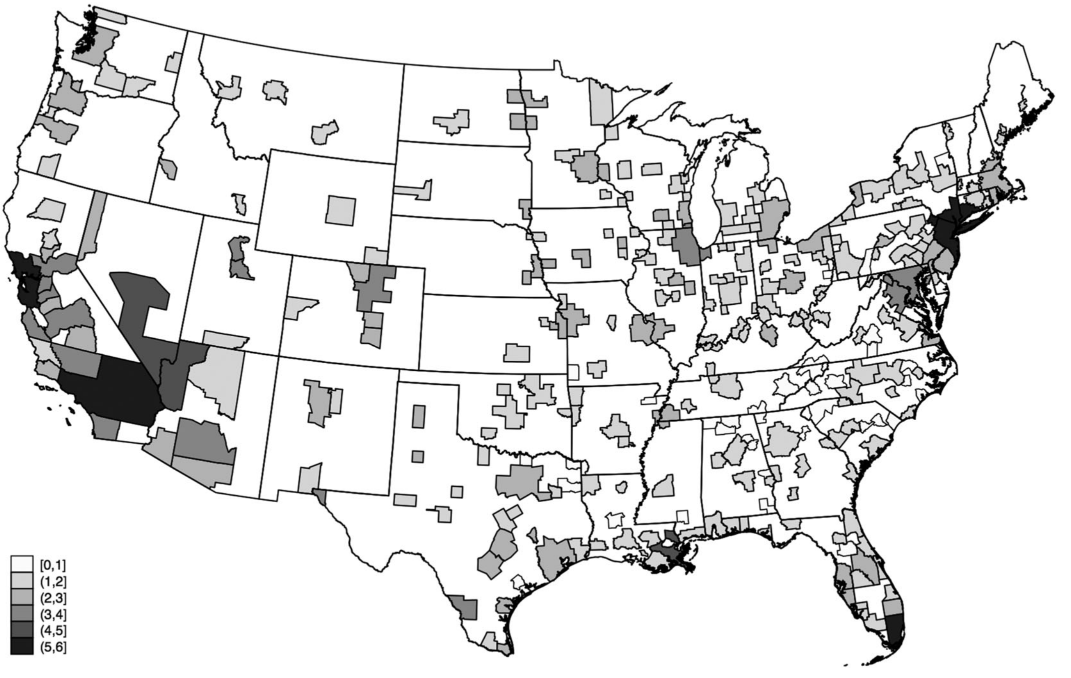
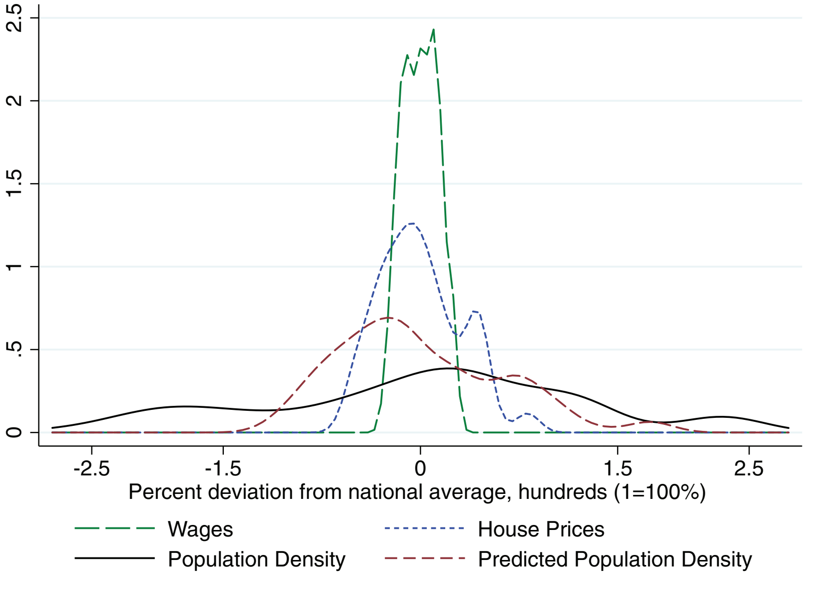


FIGURE 2

METROPOLITAN POPULATION DENSITY, THOUSANDS PER SQUARE MILE, 2000



NOTES: Predicted population density, calculated under the assumption of equal home-productivity across metros, depends only on wages and housing prices.

FIGURE 3

DISTRIBUTION OF WAGES, HOUSE PRICES, AND POPULATION DENSITY, 2000 [COLOR FIGURE CAN BE VIEWED AT WILEYONLINELIBRARY.COM]

$2.16\hat{A}_X^j \approx 2.89\hat{p}^j - 2.37\hat{w}^j$. The prediction error for each city is then $\xi^j = \hat{N}_*^j - \varepsilon_{N_*,Q}\hat{Q}^j - \varepsilon_{N_*,A_X}\hat{A}_X^j$.[16]

Figure 4 plots actual and predicted density against each other for each of the 274 metros, along with a 45° line. Overall, 49% of density variation is explained by this restricted neoclassical model, which, to reiterate, does not estimate a single parameter.[17] This model does underpredict density for a number of large, relatively old cities—such as New York, Chicago, and Philadelphia—as well as large Texan metros—including Houston, Dallas, and Austin. It overpredicts density for a number of metros in California and Florida, including San Francisco and Naples. Figure 3 shows that in general, the model predicts a more compressed density distribution than is observed, even though the reduced-form elasticities are quite high.

To see if other elasticities of substitution provide better fits, we consider how well other combinations of σ_D, σ_X, and σ_Y predict density under certain restrictions. Figure 5 graphs the variance of the prediction error, $\mathrm{Var}(\xi^j)$, as a function of these elasticities. If $\sigma_D = \sigma_X = \sigma_Y = \sigma$, $\mathrm{Var}(\xi^j)$ is minimized at $\sigma = 0.7$, close to the value of 0.667 from the pre-set parametrization. The common Cobb–Douglas case $\sigma = 1$ fits notably worse. Fixing $\sigma_X = 0.667$ reduces $\mathrm{Var}(\xi^j)$ for all other values of $\sigma_D = \sigma_Y$. Fixing both $\sigma_D = \sigma_X = 0.667$, as in the lowest curve, reduces $\mathrm{Var}(\xi^j)$ by roughly the same amount. $\mathrm{Var}(\xi^j)$ is reduced the most by setting $\sigma_Y = 0.667$. This underlines how responses in the home sector are key for understanding how population density varies.[18]

5.3. *Using Density to Estimate Trade and Home Productivity.* We next relax the restriction that home productivity is constant ($\hat{A}_Y^j = 0$) and use density data to separately identify trade and home productivity, as described in Subsection 2.4. Panel A of Figure 6 displays our measures of inferred cost and excess density for MSAs. They are estimated from the left-hand sides of Equations (12) and (13) under the parametrization with $\sigma_D = \sigma_X = \sigma_Y = 0.667$. The figure includes iso-productivity lines for each of the traded and home sectors at average levels of productivity, $\hat{A}_X^j = 0$ and $\hat{A}_Y^j = 0$.

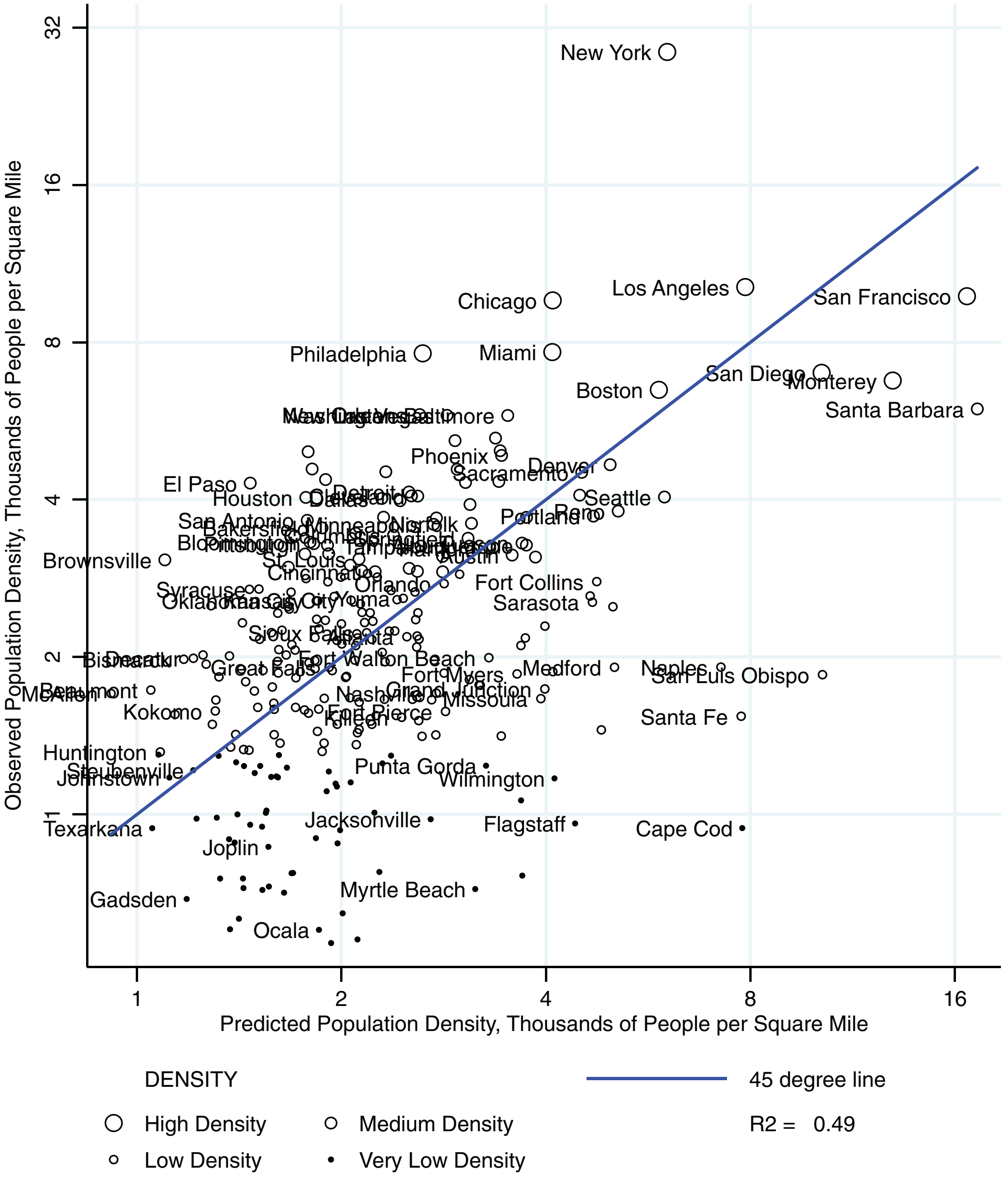
To visualize the productivity estimates, first consider the downward-sloping iso-trade-productivity line, along which cities have average trade productivity. Above and to the right of this line, cities have high inferred costs, together with considerable excess density. This indicates they have above-average trade productivity. Second, consider the upward-sloping iso-home-productivity line. Above and to the left of it, cities have high excess density, with low inferred costs. This indicates high home productivity. Vertical deviations from this second line are equal to the prediction error ξ^j in Subsection 5.2. Since the first line is almost vertical, and the second almost horizontal, excess density—or prediction error for N_*^j—affects home productivity measures much more than trade productivity ones. Note that the slopes of either line rise with the substitution elasticities, as productivity has a greater impact on excess density.

Panel B of Figure 6 graphs trade and home productivity directly, through a change in coordinates of Panel A. Examining each quadrant in turn, Chicago and Philadelphia have high levels of both trade and home productivity, whereas New York is the most productive overall. San Francisco has the highest trade productivity but low home productivity. San Antonio has low

[16] Slight differences stem from state taxes. Note an unrestricted regression of log density on wages and housing costs (naturally) produces a higher R^2 of $0.72 > 0.47$, with $\hat{N}_*^j = 4.40\hat{w}^j + 0.90\hat{p}^j + e^j = 0.63\hat{Q}^j + 6.26\hat{A}_X^j + e^j$. The value of 0.63 is much lower than the parametrized value of $\varepsilon_{N,Q}$, 8.18, whereas the value of 6.26 is larger than ε_{N,A_X}. The two parameters in this regression cannot identify three separate substitution elasticities. But if the elasticities are constrained equal, $\sigma_D = \sigma_X = \sigma_Y = \sigma$, then the constrained regression produces values similar to the parameterization: $\hat{N}_*^j = 8.57\hat{Q}^j + 2.30\hat{A}_X^j + e^j$, implying $\sigma = 0.68$.

[17] We assess model fit by reporting the square of a linear correlation coefficient, from a linear fit with an imposed slope of one.

[18] As described in Online Appendix E.3, our parameterization of the share parameters explains a significantly higher fraction of the cross-metro variance in population density than alternatives.



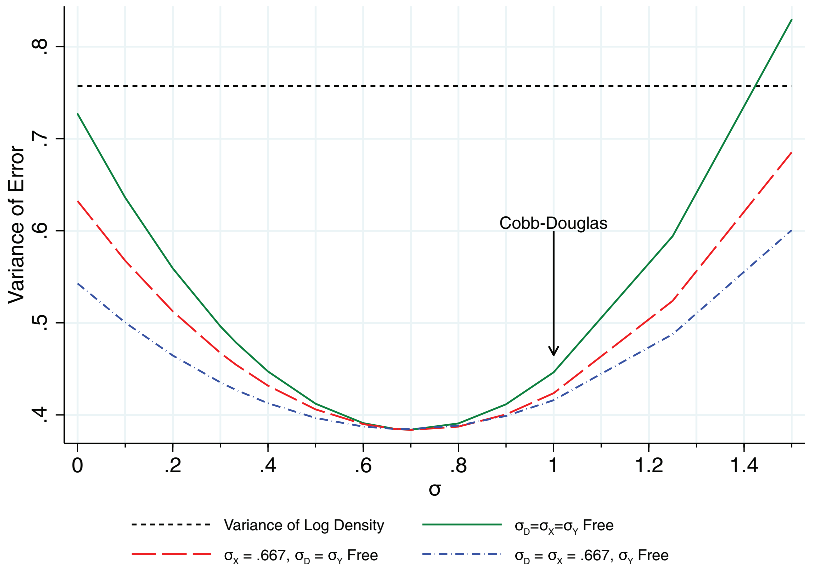
NOTES: See text for estimation details. High density metros have population density that exceeds the national average by 80%, medium density metros are between the national average and 80%. Low density and very low density metros are defined symmetrically.

FIGURE 4

ACTUAL AND PREDICTED POPULATION DENSITY, 2000 [COLOR FIGURE CAN BE VIEWED AT WILEYONLINELIBRARY.COM]

trade productivity and high home productivity. Santa Fe and Myrtle Beach are unproductive in both sectors.[19]

[19] Panel B of Figure 6 also includes isoclines for excess density and inferred costs, which correspond to the axes in Panel A. If quality of life is held constant, trade productivity and home productivity must move in opposite directions to keep population density constant. Similarly, home productivity must rise faster than trade productivity to keep inferred costs constant.



NOTES: We evaluate the variance for σ equal to 0, 0.1, 0.2, 0.3, 0.333, 0.4, 0.5, 0.6, 0.667, 0.7, 0.8, 0.9, 1, 1.25, and 1.5.

FIGURE 5

VARIANCE OF ERROR IN FITTING POPULATION DENSITY USING QUALITY OF LIFE AND TRADE PRODUCTIVITY, AS FUNCTION OF SUBSTITUTION ELASTICITIES [COLOR FIGURE CAN BE VIEWED AT WILEYONLINELIBRARY.COM]

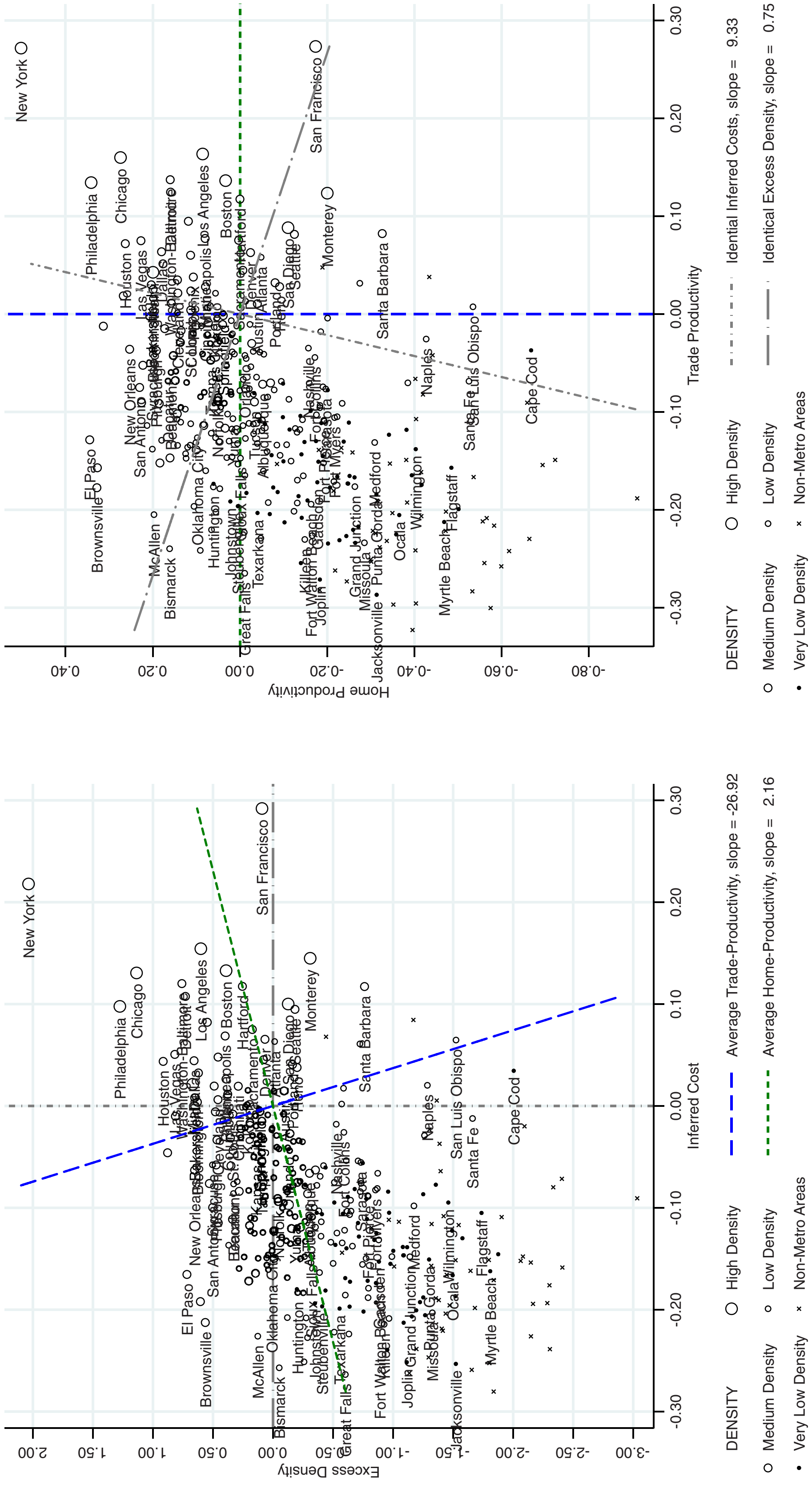
These home productivity estimates deserve several comments. First, they reflect density much more than prices.[20] Second, higher values of σ_Y raise their sensitivity to prices relative to density. Third, home productivity is highest in large, older cities.

This third phenomenon may be due to the static assumptions of the neoclassical model, which can introduce various specification errors. Indeed, the cores of these cities were built prior to World War I, when most land-use regulations were absent, intra-city transport costs were higher, and European immigration was at its peak. These factors caused housing to be built at high densities, which have largely endured.[21] The high excess density in these cities may also be an enduring legacy of these cities having relatively higher trade productivity and quality of life in earlier times. These relative advantages fell with the decline of manufacturing and the rise of air conditioning (Glaeser and Tobio, 2008). Yet durable housing and moving costs have prevented populations from adjusting fully to the neoclassical baseline. These speculations warrant further investigation in models incorporating such dynamic mechanisms.[22]

[20] According to the parametrization in Online Appendix Table A.2, $\hat{A}_Y^j = 0.32\hat{N}_*^j + 0.73\hat{w}^j - 0.93\hat{p}^j$, which largely reflects density since density varies so greatly and housing prices and wages are positively correlated. Trade productivity is $\hat{A}_X^j = 0.03\hat{N}_*^j + 0.84\hat{w}^j + 0.01\hat{p}^j$. Quality of life depends only on the price measures: $\hat{Q}^j = -0.48\hat{w}^j + 0.32\hat{p}^j$. Land values reflect all three measures, $\hat{r}^j = 1.37\hat{N}_*^j + 0.49\hat{w}^j + 0.32\hat{p}^j$, although density is key.

[21] Consistent with this explanation, Table A.9 shows that 59% of the variation in home productivity is explained by four variables: the Wharton Residential Land Use Regulatory Index (WRLURI), average slope of land, log infrastructure stock as of 1980 from Albouy and Farahani (2017), and the share of housing units in 1980 that were built before 1940.

[22] Albouy and Ehrlich (2018) use data on land values to infer productivity in the housing sector, which comprises most of the nontraded sector. Although 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, instead of 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 to strict residential land use regulations, which typically grandfather preexisting buildings.



(a) Excess Density and Inferred Cost Estimates

(b) Trade and Home Productivity Estimates

FIGURE 6

RESULTS OF PARAMETRIZED MODEL, 2000 [COLOR FIGURE CAN BE VIEWED AT WILEYONLINELIBRARY.COM]

NOTES: See note to Figure 4 for metro density definitions.

To summarize the data and findings, Table 4 presents estimates of population density, wages, housing costs, inferred land values, and amenity differentials for a selected sample of metropolitan areas. Online Appendix Table A.3 contains a full list of metropolitan and nonmetropolitan areas and compares trade productivity estimates that make use of density with those that do not (i.e., based on inferred costs only).

5.4. *City-Specific Elasticities of Substitution.* Because geographic and regulatory environments are heterogeneous, housing producers' ability to substitute between land, labor and capital may vary considerably. This heterogeneity is interesting in its own right, and it can impact the model's predictions. We model heterogeneity across metros by assuming that σ_Y^j is a linear function of I^j, the Wharton Residential Land Use Regulatory Index (WRLURI) from Gyourko et al. (2008); S^j, the average slope of land from Albouy et al. (2016b); and v^j, a residual: $\sigma_Y^j = \sigma_{Y0} + \sigma_{YI} I^j + \sigma_{YS} S^j + v^j$. We normalize I^j and S^j to have mean zero and standard deviation one.[23] Similarly, we assume that home productivity is given by a linear function: $\hat{A}_Y^j = a_I I^j + a_S S^j + u^j$. As shown in Online Appendix G, these assumptions yield the following equation:

$$\begin{aligned}(23)\qquad \hat{N}_e^j = {} & \sigma_{Y0}\hat{G}^j + \sigma_{YI} I^j \hat{G}^j + \sigma_{YS} S^j \hat{G}^j + a^I(k_1 + \sigma_{Y0}k_2) I^j + a_S(k_1 + \sigma_{Y0}k_2) S^j \\ & + \sigma_{YI} a_I k_2 (I^j)^2 + \sigma_{YS} a_S k_2 (S^j)^2 + (\sigma_{YI} a_S + \sigma_{YS} a_I) k_2 I^j S^j + e^j,\end{aligned}$$

where $\hat{N}_e^j \equiv \hat{N}_*^j - 1.00\hat{p}^j + 0.79\hat{w}^j$ is density explained by all but σ_Y^j and $\hat{A}_Y^j$, $\hat{G}^j \equiv 2.82\hat{p}^j - 2.37\hat{w}^j$ captures observable demand shifts from $\hat{Q}^j$ and $\hat{A}_X^j$, k_1, and k_2 are known positive constants, and e^j is a residual. Nonlinear least squares provides the parameter estimates under orthogonality conditions for u^j and v^j discussed in Online Appendix G.

The estimator here differs from alternative approaches in several ways. First, it is identified by level differences in population, not changes. Second, as implied by (22a) and (22b), it handles demand shifts asymmetrically, putting more weight on quality of life than trade productivity. Third, it accounts for *all* demand shifts, absent specification error. This eliminates the need for instrumenting demand shifts (e.g., with January temperature or Bartik employment shocks) that are ostensibly exogenous to supply.

An important concern is that I^j and S^j are correlated with unobserved supply shifters in u^j or v^j. As a way of testing the specification, the model provides three overidentifying restrictions. The linear reduced-form equation of (23) has eight terms $\{\hat{G}^j, I^j, S^j, I^j\hat{G}^j, S^j\hat{G}^j, I^jS^j, (I^j)^2, (S^j)^2\}$, with coefficients that depend nonlinearly on the five structural parameters, $\{\sigma_{Y0}, \sigma_{YI}, \sigma_{YS}, a_I, a_S\}$.

The data fail to reject the implied structural restrictions of the model ($p = 0.62$), providing support for the estimates of Equation (23), shown in Table 5. The baseline estimate of σ_{Y0} in column 1 is 0.69, again close to the preset value. The results in column 2, which restricts $\hat{A}_Y^j = 0$, imply (intuitively) that σ_Y^j is negatively related to both regulations and average slope: a one-standard-deviation increase reduces the elasticity by 0.16 and 0.30. The predicted elasticities σ_Y^j have a population-weighted mean of 0.89—higher than without the interactions—with a standard deviation of 0.37.[24] This model now explains 61% of the variation in density, as opposed to the 49% from before with a uniform σ_Y. Column 3 holds σ_Y^j constant and lets $\hat{A}_Y^j$ vary: it falls by about 7% with a one-standard-deviation increase in slope. Column 4 presents the full model estimates that resemble those in columns 2 and 3.

The estimates of σ_Y^j imply city-specific elasticities of housing supply according to the formulae from Section 4. We calculate these housing supply elasticities for when they come from shifts in

[23] When these variables are missing, we impute them with the population-weighted mean. The results are robust to just focusing cities with nonmissing variables.

[24] The unweighted mean and standard deviation are 0.94 and 0.45.

TABLE 4
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 $\hat{A}^j_X$	Home Productivity $\hat{A}^j_Y$
New York, Northern New Jersey, Long Island, NY–NJ–CT–PA	2.295	0.217	0.432	3.406	0.032	0.272	0.502
Los Angeles-Riverside-Orange County, CA	1.259	0.134	0.455	1.947	0.080	0.164	0.086
San Francisco-Oakland-San Jose, CA	1.219	0.259	0.818	2.051	0.138	0.273	−0.173
Chicago–Gary–Kenosha, IL–IN–WI	1.200	0.134	0.230	1.791	0.008	0.160	0.274
Miami-Fort Lauderdale, FL	0.973	0.010	0.127	1.373	0.037	0.043	0.200
Philadelphia–Wilmington–Atlantic City, PA–NJ–DE–MD	0.967	0.115	0.062	1.411	−0.038	0.134	0.341
San Diego, CA	0.881	0.061	0.485	1.440	0.123	0.088	−0.110
Salinas (Monterey-Carmel), CA	0.847	0.102	0.602	1.444	0.142	0.124	−0.200
Boston–Worcester–Lawrence, MA–NH–ME–CT	0.806	0.121	0.343	1.279	0.051	0.136	0.033
Santa Barbara–Santa Maria-Lompoc, CA	0.722	0.058	0.666	1.299	0.182	0.082	−0.326
. . .							
Florence, AL	−1.388	−0.132	−0.352	−2.099	−0.047	−0.166	−0.223
Myrtle Beach, SC	−1.392	−0.188	−0.125	−2.025	0.051	−0.212	−0.468
Florence, SC	−1.397	−0.140	−0.336	−2.114	−0.038	−0.173	−0.247
Johnson City–Kingsport–Bristol, TN–VA	−1.408	−0.190	−0.352	−2.148	−0.019	−0.217	−0.272
Gadsden, AL	−1.436	−0.136	−0.422	−2.192	−0.068	−0.172	−0.177
Goldsboro, NC	−1.499	−0.197	−0.288	−2.228	0.003	−0.225	−0.358
Dothan, AL	−1.523	−0.189	−0.404	−2.322	−0.036	−0.220	−0.259
Anniston, AL	−1.569	−0.202	−0.425	−2.398	−0.037	−0.234	−0.264
Ocala, FL	−1.572	−0.170	−0.295	−2.363	−0.009	−0.205	−0.365
Hickory–Morganton–Lenoir, NC	−1.614	−0.135	−0.220	−2.357	−0.004	−0.174	−0.416
Rocky Mount, NC	−1.631	−0.122	−0.241	−2.384	−0.017	−0.165	−0.394
Standard deviation	0.871	0.116	0.282	1.323	0.050	0.129	0.200

NOTES: Table 4 includes the top and bottom ten metropolitan areas ranked by population density. The first three columns are estimated from Census data, whereas the last four columns come from the parametrized model. See text for estimation procedure. Standard deviations are calculated among the 274 continental metropolitan areas using metro population weights. All variables are measured in log differences from the national average.

TABLE 5
THE DETERMINANTS OF SUBSTITUTION POSSIBILITIES AND PRODUCTIVITY IN THE HOME SECTOR

Dependent Variable: Population Density not Explained by Home Sector					
		(1)	(2)	(3)	(4)
Elasticity of Substitution in Home Sector					
Baseline	σ_{Y0}	0.693	0.887	0.865	1.106
		(0.247)	(0.272)	(0.325)	(0.348)
Wharton Land Use Regulatory Index (s.d.)	σ_I		−0.157		−0.184
			(0.127)		(0.112)
Average slope of land (s.d.)	σ_S		−0.296		−0.306
			(0.188)		(0.168)
Housing Productivity					
Wharton Land Use Regulatory Index (s.d.)	a_I			0.014	−0.005
				(0.038)	(0.015)
Average slope of land (s.d.)	a_S			−0.071	−0.068
				(0.018)	(0.023)
Observations		274	274	274	274

NOTES: Table 5 presents results of estimating Equation (23) by nonlinear least squares. Explanatory variables are normalized to have mean zero and standard deviation one. Regressions are weighted by population. Robust standard errors are in parentheses.

trade productivity, under constant geography ($\varepsilon_{L,r} = 0$), setting $\sigma_D = \sigma_X = 0.667$ and σ_Y^j to the predicted value from column 2 of Table 5. A regression of the supply elasticities from Saiz (2010) on these calculated elasticities yields a slope of 1.04 (s.e. 0.19), an intercept of 0.45 (s.e. 0.22), and a correlation coefficient of 0.45. This slope is indistinguishable from one. The intercept is close to the value predicted in Equation (21) from the consumption response, $s_x\sigma_D = 0.43$, as Saiz estimates a population response, instead of a housing one.[25] The similarity is remarkable, given how differently the elasticities are estimated.

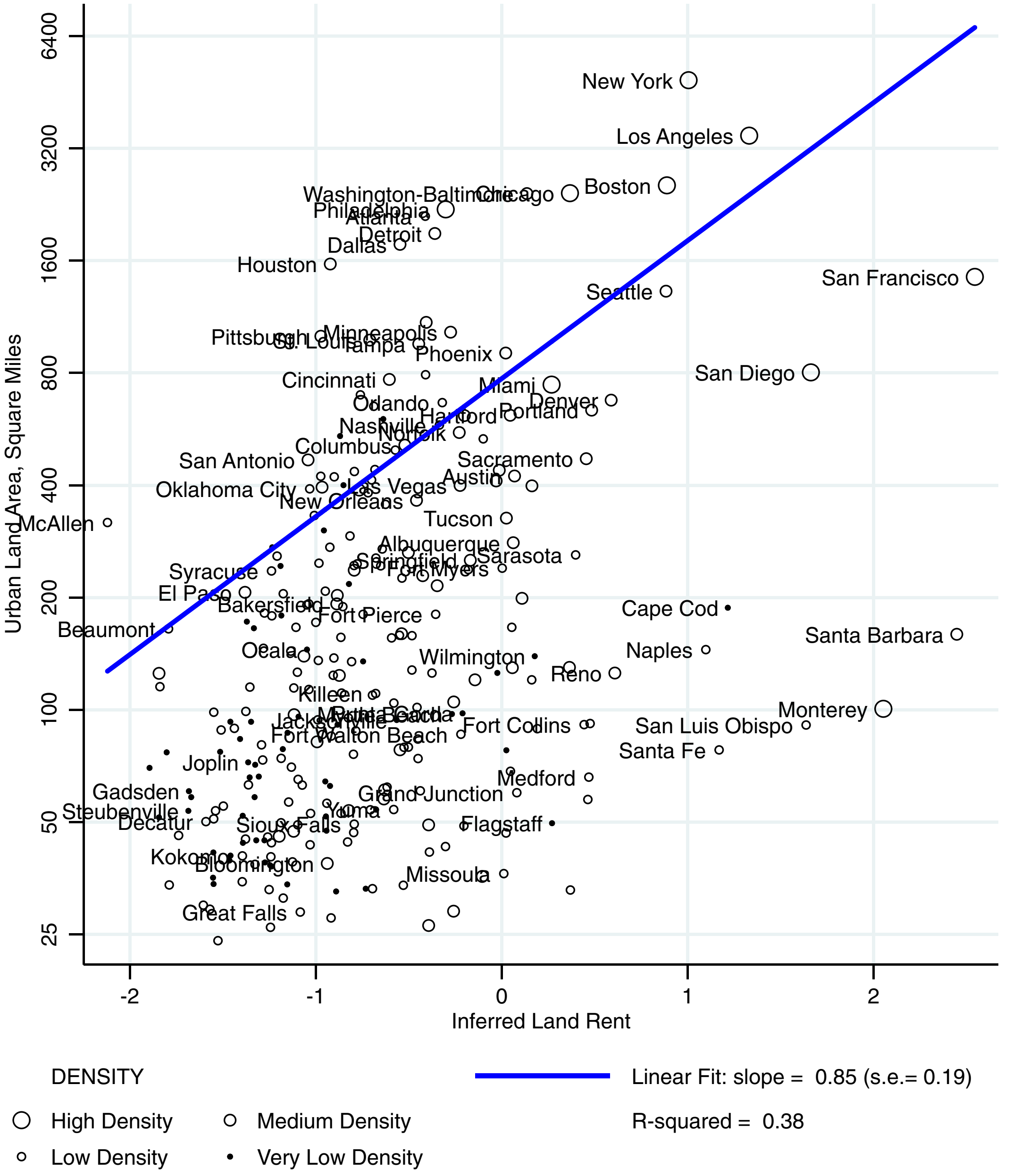
6. LAND AREA AND THE TOTAL POPULATION OF CITIES

The neoclassical model explains density levels across metros fairly well. To explain entire population levels, it must also model land area, which varies tremendously. The original Rosen–Roback model ignores the internal structure of cities and takes its land as homogeneous and fixed. We supplement it with a simple land supply function from Equation (5). Now, this function may vary both in its endowment, $\hat{L}_0^j$, and supply elasticity, $\varepsilon_{L,r}^j$.

To our knowledge, our framework provides the first to estimate both the intensive (density) and extensive (land) margins of urban growth separately. The neoclassical model makes this separation clean, as it uses a unified land market of homogeneous land, with constant returns in urban production. For estimation purposes, take the land supply parameters as linear functions of covariates W^j, with $\hat{L}_0^j = W^j\beta_{L_0} + u^j$ and $\varepsilon_{L,r}^j = \bar{\varepsilon} + W^j\beta_\varepsilon + v^j$. W^j includes I^j, S^j, and also the log land share (i.e., the share which is not water) from Saiz (2010).

We measure land using the square miles in the Census urban area; metropolitan areas, defined by counties, contain a considerable amount of land for nonurban use, which we exclude. Panel A of Figure 7 plots this land area against the inferred land rent from (1c) when $\hat{A}_Y^j = 0$, that is, $\hat{r}^j = (\hat{p}^j - \phi_N\hat{w}^j)/\phi_L$. Since cities are small and open to mobile labor and capital, the demand for land is perfectly elastic at each city's price $\hat{r}^j$. With no other covariates, the regression line traces out a supply curve. The slope equals the supply elasticity, given by $\bar{\varepsilon} = 0.85$; the weighted intercept provides a base land endowment of 773 square miles.

[25] Saiz's empirical strategy examines temporal variation using industrial composition, immigrant enclaves, and sunshine as sources of exogenous variation in demand. By combining quality of life and productivity shifters, the estimates may not be directly comparable, although we suspect that productivity shifters are more important in his analysis.



NOTES: Inferred land rent comes from equation (1c) assuming $\hat{A}_Y^j = 0$. See note to Figure 4 for metro density definitions.

FIGURE 7

URBAN LAND AREA AND INFERRED LAND RENTS [COLOR FIGURE CAN BE VIEWED AT WILEYONLINELIBRARY.COM]

Table 6 reports results from specifications with covariates.[26] A one standard deviation increase in slope lowers the land endowment by over half, whereas a one standard deviation increase in land not covered by water increases it by almost a quarter. In the fully interacted model, the population-weighted average elasticity of land is 1.58 (unweighted mean is 1.47) but is reduced by about 0.25 from a one standard deviation increase in slope or regulation. Although these

[26] Summary statistics are in Online Appendix Table A.4.

TABLE 6
THE DETERMINANTS OF LAND SUPPLY

Dependent Variable: Log Urban Area, Square Miles	(1)	(2)	(3)
Inferred land rent	0.852	1.202	1.468
	(0.190)	(0.210)	(0.142)
Wharton Land Use Regulatory Index (s.d.)		0.073	−0.086
		(0.094)	(0.086)
Average slope of land (s.d.)		−0.610	−0.546
		(0.099)	(0.078)
Log land share (s.d.)		0.240	0.279
		(0.098)	(0.078)
Interaction between inferred land rent and			
Wharton Land Use Regulatory Index (s.d.)			−0.219
			(0.089)
Average slope of land (s.d.)			−0.247
			(0.087)
Log land share (s.d.)			0.069
			(0.117)
Constant	6.650	6.650	6.898
	(0.143)	(0.112)	(0.108)
Observations	274	274	274
R^2	0.377	0.526	0.594

NOTES: Inferred land rent is constructed without using density data. All explanatory variables are normalized to have mean zero and standard deviation one. Regressions are weighted by population. Robust standard errors are in parentheses.

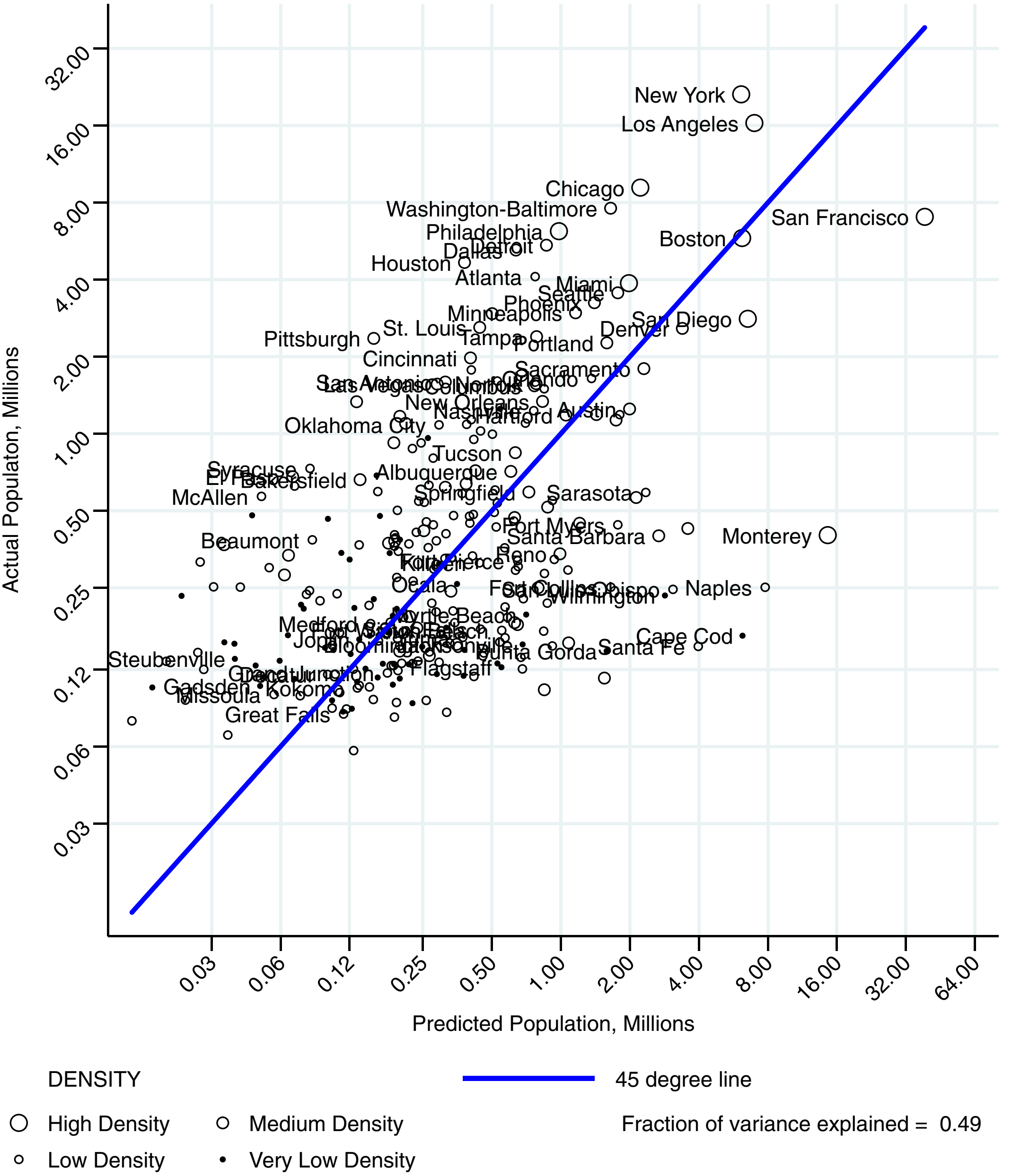
results are not as well identified as those in Table 5, they do accord with intuition, suggesting that the land measure and inferred land rents contain valuable information.

To examine how well the model explains cross-metro population differences, we use Equation (7) to predict the total population differential as the sum of the predicted land differential—equal to $W^j \beta_{L_0} + \bar{\varepsilon}\hat{r}^j$, from column 2 of Table 6—and the simple predicted density differential—conditional on $\hat{p}^j$ and $\hat{w}^j$. Figure 8 plots actual metro population against this prediction. The simple prediction explains 49% of cross-metro population variation, without using data on either density or population. This fit is reasonably successful, as it is based on a model built to value amenities from prices alone. Nevertheless, the model could clearly be improved to incorporate other economic factors.

7. POPULATION DETERMINANTS AND COUNTERFACTUAL EXERCISES

7.1. *Why Do People Live Where They Do?* Here we answer the question of whether people follow jobs, jobs follow people, or both follow housing. To do this, we decompose the variance of cross-metro differences in population due to quality of life, trade productivity, and home productivity. Column 1 of Table 7 begins with a restricted model of density with constant home productivity $\hat{A}_Y = 0$, and substitution elasticities set to $\sigma = 0.667$. Quality of life accounts for nearly half of the explained variance, dominating trade productivity (i.e., inferred costs), even though the latter shows greater cross-sectional variation in value (see Online Appendix Figure A.2). Quality of life and trade productivity are positively correlated.

The decomposition in column 2 lets A_Y vary across metros, so that the entire population density is explained by all three attributes. As before, quality of life dominates trade productivity, yet both are dominated by home productivity. Although all three attributes are important in explaining density, it appears that people and jobs follow housing more than anything else. Because the home productivity estimates are heavily based on density, this conclusion should



NOTES: See note to Figure 4 for metro density definitions.

FIGURE 8

ACTUAL AND PREDICTED POPULATION [COLOR FIGURE CAN BE VIEWED AT WILEYONLINELIBRARY.COM]

be treated cautiously. Nonetheless, it complements the finding that home sector substitution is key in how population responds to amenities.

The decompositions in columns 3 and 4 bring in land supply to account for total population. To keep the accounting tractable, we use the specification from column 2 of Table 6, with a uniform price elasticity of 1.20 for land, and vary land endowments. In column 3, we see quality of life continues to dominate trade productivity, whereas both dominate the land endowment. Finally, column 4 considers the full model for population. As in column 2, home productivity

TABLE 7

FRACTION OF DENSITY AND POPULATION EXPLAINED BY QUALITY OF LIFE, TRADE PRODUCTIVITY, HOME PRODUCTIVITY, AND LAND

		Density		Population	
Variance/Covariance Component	Notation	(1)	(2)	(3)	(4)
Quality of life	$\mathrm{Var}(\varepsilon_{N,Q}\hat{Q})$	0.488	0.225	0.585	0.223
Trade productivity	$\mathrm{Var}(\varepsilon_{N,A_X}\hat{A}_X)$	0.189	0.103	0.315	0.142
Home productivity	$\mathrm{Var}(\varepsilon_{N,A_Y}\hat{A}_Y)$	–	0.438	–	0.393
Land	$\mathrm{Var}(\hat{L}_0)$	–	–	0.167	0.064
Quality of life and trade productivity	$\mathrm{Cov}(\varepsilon_{N,Q}\hat{Q}, \varepsilon_{N,A_X}\hat{A}_X)$	0.323	0.138	0.457	0.161
Quality of life and home productivity	$\mathrm{Cov}(\varepsilon_{N,Q}\hat{Q}, \varepsilon_{N,A_Y}\hat{A}_Y)$	–	−0.141	–	−0.133
Quality of life and land	$\mathrm{Cov}(\varepsilon_{N,Q}\hat{Q}, \hat{L}_0)$	–	–	−0.410	−0.157
Trade and home productivity	$\mathrm{Cov}(\varepsilon_{N,A_X}\hat{A}_X, \varepsilon_{N,A_Y}\hat{A}_Y)$	–	0.237	–	0.263
Trade productivity and land	$\mathrm{Cov}(\varepsilon_{N,A_X}\hat{A}_X, \hat{L}_0)$	–	–	−0.114	−0.036
Home productivity and land	$\mathrm{Cov}(\varepsilon_{N,A_Y}\hat{A}_Y, \hat{L}_0)$	–	–	–	0.078
Total variance of prediction		0.350	0.758	2.190	5.740
Data used to construct attributes					
Wages and housing prices		Yes	Yes	Yes	Yes
Density		No	Yes	No	Yes
Predicted land intercept		No	No	Yes	Yes

NOTES: Predicted land intercepts come from column 2 of Table 6.

dominates quality of life and trade productivity. The largest interaction is the positive one between home and trade productivity.

One stimulating result from this table is that quality of life is negatively related to land and home productivity. Unfortunately, the most attractive areas of the United States are often the most difficult to build on. This appears to stem mainly from two causes. First, coastlines and rugged terrain are associated with higher quality of life (Albouy, 2008), but lower land supply and ability to build densely, as shown above. Second, higher quality of life areas tend to have more land use restrictions, although these do not seem to improve quality of life (Albouy and Ehrlich, 2018).[27]

Online Appendix Table A.5 explores how the results are affected by preference heterogeneity, endogenous amenity feedback, and geographically neutral federal taxation. Incorporating preference heterogeneity makes quality of life relatively more important than trade and home productivity. To some extent, this is mechanical, as Equation (16) infers that quality of life rises with population if there is preference heterogeneity. This also explains why quality of life is positively correlated with home productivity in this model. Incorporating endogenous amenity feedback—where population density decreases quality of life and home productivity while increasing trade productivity—yields similar results, as these forces cancel each other out to some degree. As discussed in more detail in Online Appendix D.7, endogenous amenity feedback and preference heterogeneity have similar (and so, hard to separate) effects in a log-linearized model. On the policy side, if federal taxes were made geographically neutral, trade productivity would determine locations more than quality of life; people would follow jobs more than the opposite.[28]

[27] The equilibrium model ignores that people are gradually moving to areas with nicer weather (Rappaport, 2007; Glaeser and Tobio, 2008).

[28] 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.

TABLE 8

CHANGES IN POPULATION FROM RELAXING LAND USE REGULATIONS

Panel A: Metro-Level

	Home Subs. Elasticity (σ_Y^j)		2000 Population, Mil.	
Main city in MSA	Estimated	Counterfactual	Observed	Counterfactual
San Francisco	0.29	0.42	7.0	8.4
San Diego	0.30	0.47	2.8	3.2
Los Angeles	0.45	0.57	16.4	18.3
Boston	0.71	0.96	5.8	6.2
Seattle	0.11	0.31	3.5	3.7
New York	0.94	0.97	21.2	21.8
Philadelphia	0.89	1.04	6.2	6.3
Miami	1.07	1.21	3.9	3.9
Denver	0.49	0.74	2.6	2.6
Phoenix	0.67	0.84	3.2	3.2
Washington–Baltimore	0.87	0.94	7.6	7.5
Detroit	1.15	1.15	5.5	5.3
St. Louis	1.27	1.27	2.6	2.5
Chicago	1.23	1.23	9.2	8.9
Houston	1.22	1.22	4.7	4.6
Dallas	1.15	1.15	5.2	5.1
Cleveland	1.07	1.07	3.0	2.9
Tampa	1.17	1.17	2.4	2.3
Pittsburgh	0.70	0.71	2.4	2.3
Portland	0.48	0.50	2.3	2.2
Minneapolis	1.02	1.05	3.0	2.9
Atlanta	0.96	0.98	4.1	4.0

Panel B: Change in Regional Dist.

Northeast	1.01
Midwest	0.98
South	0.97
West	1.06

Panel C: Change in Amenity Dist.

Quality of life	0.002
Trade productivity	0.005
Home productivity	0.003
Total value	0.006

NOTES: The counterfactual decreases the WRLURI to the population-weighted mean in metro areas with an above-average WRLURI, thus increasing the home substitution elasticity based on the estimates in column 2 of Table 5. Land supply and amenities are held fixed in the counterfactual.

7.2. *What if Chicago was as Nice as San Diego?* As quality of life is key in determining where people live, consider what would happen if the city with the largest growth potential, Chicago, were given the quality of life of one of America's nicest cities, San Diego. In this counterfactual, Chicago receives none of the attributes that lower San Diego's population. As seen in Table 8, Chicago has an elastic home good sector, with $\sigma_Y = 1.23$, which from (18) implies $\hat{N}_*^j = 12.69\hat{Q}^j$. The difference in quality of life between San Diego and Chicago is 0.12, explained entirely by climate and geography (Albouy, 2008), making it effectively exogenous. Therefore, the model predicts that the population of Chicago would expand by $3.59 (= \exp(12.69 \times 0.12) - 1)$ times. Based on the 2000 numbers, this implies a population of 42 million, double that of New York City![29] A sunny and beautiful city with such great home productivity would likely be full of gleaming skyscrapers, packed with residents. On the other hand, if San Diego's quality of life fell to that of Chicago's, the long-run effect would be less dramatic, as its home good sector is less responsive. With $\sigma_Y = 0.30$, $\hat{N}_*^j = 5.24\hat{Q}^j$, so San Diego's population would fall by 47%, from 2.8 to 1.5 million.

[29] A change of this kind would increase the welfare of the country by reducing the density outside of Chicago. This would create a feedback effect that would lower the population increase by some minor amount given that this population change is around 10% of the national population.

A related thought experiment is to make home productivity in San Diego as high as in Chicago. From (18), the elasticity of population density in San Diego with respect to home productivity is $\hat{N}^j_* = 1.93\hat{A}^j_Y$. As a result, a 0.38 log point increase in home productivity (see Table 4) would increase population in San Diego by 8%. The small response stems from the relatively low elasticity in San Diego's home good sector of 0.3. If this elasticity and home productivity both rise to Chicago's values, then San Diego's population would then grow by $4.24(= \exp(4.36 \times 0.38) - 1)$ times.

7.3. *The Effect of Relaxing Land Use Regulations.* The parametrized model readily permits nationwide counterfactual policy exercises. Given the importance of the home good sector, we focus on the effects of lowering land use regulations in cities for inhabitants with above-average regulation. This exercise is similar to Hsieh and Moretti (2019)—who lower regulations more dramatically—although we examine levels instead of growth.[30] We hold amenities fixed in these counterfactuals.

Table 8 presents results from these counterfactual exercises. In Panel A, column 1 shows the estimated elasticity of substitution in housing, and column 2 shows the counterfactual elasticity when cities with above-average regulation are lowered to the average.[31] Column 3 shows each metro's population in 2000, and column 4 shows the population under the counterfactual. The elasticities in several coastal cities, notably San Francisco, Los Angeles, and San Diego, increase substantially. This permits many more people to take advantage of their amenities. Because population must balance, less attractive cities, such as Detroit, Atlanta, and Dallas, lose residents even without changes in their elasticity. As seen in Panels B and C, the West would gain population from the South and Midwest, and people would live in more amenable and productive places. The increase in the total value of amenities experienced by households would equal 0.6% of GDP.

As discussed in Subsection 2.5, population will respond less to changes in amenities or regulations in the presence of imperfect mobility. The predicted populations presented here most sensibly describe a long-run equilibrium.

8. CONCLUSION

This article studies what the canonical spatial equilibrium model of household location decisions implies for population numbers. Our full characterization flexibly captures interactions between labor and housing markets, workers' preferences, and firms' production technology. Location decisions are determined by quality of life, trade productivity, home productivity, and land. We allow land use regulations and geography to affect both home productivity and substitution possibilities in home good production. We also introduce a novel approach to estimating home productivity, elasticities of substitution in the home good sector, and land supply elasticities.

We find that a restricted model—in which home productivity does not vary across metros—explains half of the observed variation in density and population across metro areas. When we use the structure of the model to jointly estimate quality of life, trade productivity, and home productivity, we find that quality of life is more important than trade productivity in determining household location decisions, and home productivity may be more important than either. We use the model to quantify the effects of relaxing land use regulations, which would increase substitution possibilities in housing production. Households would move to nicer and more productive cities. Population would increase by 6% in the West—driven by increases of 20% in San Francisco, 14% in San Diego, and 12% in Los Angeles—while falling in the Midwest and South.

[30] We lower regulations to the population-weighted average of the WRLURI, whereas Hsieh and Moretti (2019) lower regulations to the median city in their sample. The reduction in WRLURI considered by Hsieh and Moretti is over half a standard deviation lower than our baseline counterfactual.

[31] These rely on the estimates in column 2 of Table 5.

The neoclassical framework accounts for the most basic factors that affect urban life. The version we develop here requires relatively simple data, and thus it could be used to understand location decisions in other periods and countries. It is also remarkably versatile for adding features, such as agglomeration, multiple types of workers, and preference heterogeneity. We hope that this version serves as a unifying framework for future work on the determinants of urban population.

Supporting Information

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Table A.1: Parametrized Relationship between Amenities, Prices, and Quantities, Model Extensions
Table A.2: Relationship between Model-Implied Variables and Data
Table A.3: List of Metropolitan and Non-Metropolitan Areas Ranked by Density
Table A.4: Summary Statistics, Land Supply
Table A.5: Fraction of Population Density Explained by Quality of Life, Trade Productivity, and Home Productivity, Model Extensions
Table A.6: Alternative Parametrizations and the Relationship between Population Density and Amenities
Table A.7: Fraction of Density Explained by Quality of Life, Trade Productivity, and Home Productivity, Alternative Parametrizations
Table A.8: Summary of Changes in Population from Relaxing Land Use Regulations, Alternative Parametrizations
Table A.9: Correlates of Home Productivity
Figure A.1: Quality of Life and Inferred Costs, 2000
Figure A.2: Estimated Amenity Distributions, 2000
Figure A.3: Comparison of Nonlinear and Linear Model

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