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ABSTRACT

We examine the relationship between local public goods, prices, wages, and population in an equilibrium inter-city model. Non-traded production, federal taxes, and imperfect mobility all affect how public goods (or "amenities" more broadly) should be valued from data. Reinterpreting the estimated effects of public infrastructure on prices and wages in Haughwout (2002), we find infrastructure over twice as valuable with our more general model. New estimates based on more years, cities, and data-sets indicate stronger wage and positive population effects of infrastructure. These imply higher values of infrastructure to firms, and also to households if moving costs are substantial.

JEL Classification Codes: H54, H2, H4, J3, R2

Key Words: Infrastructure, public goods, capitalization, valuation, nontraded goods, federal taxation, imperfect mobility.

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1 Introduction

Determining the benefits of public goods is a challenging task. Benefits that accrue to private producers should generate observable income (Eberts and McMillen 1999). Benefits that accrue directly to households through "quality-of-life" improvements are harder to value as their economic impacts are not directly observed. Luckily, the value of such quality-of-life benefits may be inferred through higher housing values when households are mobile (Rudd 2000). However, as we show in this paper, there are several shortcomings with the basic theory that directly maps improvements in public goods to the value of housing.[1] First, public goods may ease housing production or lower local input costs, so that valuable public investments actually *lower* housing values. Second, federal subsidies to housing consumption, as well as taxes on income, will distort price responses to public goods (Albouy 2009). Third, imperfect household mobility may mitigate or even mute price responses altogether. In this case, housing tenants, rather than housing owners, receive some or all of the benefits of a public improvement.

Below, we analyze how public goods (or *amenities* more broadly) in an urban system impact local wages, land values, the prices of housing (or other nontraded goods), and population. Our model is more general than the standard Roback (1982) model as it accounts for nontraded production, like housing; federal taxes, including housing subsidies; and most remarkably, population movements with limited mobility.[2] The role of these three generalizations is demonstrated analytically and in a numerical simulation below. We distinguish improvements according to how much they affect household quality of life versus firm productivity, where, following up on Albouy (2016), we distinguish between trade productivity for firms producing traded output, and home productivity, for nontraded output. Using this more nuanced framework, we reinterpret the estimated effects of public infrastructure on prices and wages by Haughwout (2002), finding infrastructure to be much more valuable. This conclusion is reinforced by new estimates of wage, price, and also population effects, based on more data.

Our theoretical analysis and numerical simulations provide insights about how public goods may impact competitive local labor and housing markets. The simulations predict that housing prices capitalize the benefits of public goods quite differently than land values, making them poor substitutes but useful complements in disentangling the channels through which public goods affect welfare. Also, increases in local wages are likely to overstate increases in trade productivity

[1] The term *capitalization* is often used in this context to refer to changes to land and housing prices, not rents. In practice, these prices are given by the present discounted value of rents. Since discounting is unaltered, *rents*, *values*, and *prices* are used almost interchangeably here.

[2] Nontraded production is discussed in Roback, but is not developed theoretically or used empirically. Taxes are contained in Albouy (2009, 2016), although the analysis and simulations presented here are largely new. The major modeling innovation is that the third item, imperfect mobility, which builds on how Albouy and Stuart (2015) translate structural population relationships using reduced-form elasticities.

due to important wage and tax "multiplier" effects, discussed below. Local wages are predicted to fall with quality-of-life or home-productive improvements, but not by much, especially if mobility is imperfect. Tax distortions cause land values to rise with a quality-of-life improvement much more than a trade-productive one of similar value; yet, housing prices will reflect these in similar proportions, absent immobility. On the other hand, housing prices indeed *fall* with home productivity — while land values rise — although the magnitude depends critically on household mobility. Price decreases are greatest when mobility is modest.[3]

Our reevaluation of infrastructure values calls into question Haughwout's conclusion that infrastructure investments are unlikely to pass a cost-benefit test. While his original model implies that a typical investment returns between 30 and 60 percent of its cost (depending on the estimates), the general model finds that range to be 70-135 percent. Most of these benefits are in quality of life. New estimates, based on more years, cities, and data sets, find more modest (albeit more robust) positive housing price effects, and larger wage effects. Furthermore, infrastructure appears to increase population levels. Together, the estimates imply positive net returns, with large benefits to firms, and some direct benefits to households, particularly if they are imperfectly mobile. The new estimates also indicate that infrastructure has positive fiscal externalities and likely increases nontraded productivity.

2 Previous Literature and Motivation

Our valuation model generalizes the Roback model as it considers labor and technology in nontraded production, accounts for federal fiscal externalities, and demonstrates how to use population changes to better measure quality-of-life improvements and compensate for missing land data. This last innovation is helpful as land values are rare and hard to measure, making it nearly impossible to estimate how public goods raise land values (see Mills 1998; Case 2007).

The idea that land rents capitalize differences in the value of local amenities when all other factors are mobile, has a long history (see, e.g., Ricardo 1817; George 1879; Tiebout 1956; Arnott and Stiglitz 1979; Brueckner 1983). This idea forms the basis of valuation methods using cross-sectional hedonic techniques (e.g., Oates 1969; Rosen 1974), as well as those using more focused identification strategies (e.g., Black 1999; Kline and Moretti 2014a). Since most valuations are conducted with home values, many previous studies may need to be re-examined to consider the generalities raised here. This is particularly true for public goods provided across areas as large as

[3]Rappaport (2008a,b) considers the price effects of changes in various amenities in a quantitative model with nontraded production, but without federal taxes, or immobility, and restricting home productivity and trade productivity to be equal, precluding some important issues raised here. Rappaport's simulations are especially useful for considering nonlinearities for large changes, although they do not provide the same insights provided by the analytical solutions given here.

a metropolitan area.[4]

Nontraded production has long been known to affect income comparisons. Balassa (1964) and Samuelson (1964) first demonstrated how nontraded production complicates incomes and productivity comparisons across countries. Moving from countries to cities, our work bridges the standard Roback model with Tolley's (1974) theory of "wage multipliers," which amplify how amenity values are capitalized into housing costs and wages. We also consider how public goods can improve nontraded production. Indeed, when considering the role public infrastructure, Gruen (2010, p. 2) writes "federal and state expenditures for roads, utilities, drainage, and other improvements" are needed to make vacant land accessible to home builders. Thus, high housing prices may be a misleading marker of public good values when we consider housing production.

Outside of Albouy (2009, 2016), the impact of federal taxes on local prices has largely been ignored. Moreover, those two articles do not consider how federal tax policy may magnify or contract the effect of public goods on housing and land prices. We model and quantify these effects below, and explain a feedback effect through what we name a "tax multiplier." One takeaway is that federal fiscal externalities should be counted when valuing a public good. Furthermore, federal taxes distort local incentives to invest in public goods toward quality-of-life improvements and against productive ones.

While perfect mobility is a powerful assumption, imperfect mobility has received growing attention in estimates of the fiscal impact of local policies, e.g., Busso, Gregory, and Kline (2013) and Suárez Serrato and Zidar (2016). Our framework is the first to incorporate imperfect mobility with either nontraded production or federal taxes. It provides tractable analytical expressions that cover full to zero mobility. It also interestingly divides benefits between local residents, landowners, and the federation as a whole.[5]

3 Prices and Amenities in Equilibrium

3.1 Model Set-up and Notation

Consider a system of cities, indexed by j, that share a homogeneous population of households, N. Households are identical and consume a numeraire traded good, x, and a nontraded home good, y, with local price, p^j. We discuss multiple household and home-good types in Appendices B.1 and

[4]Inside a metro area, effects on wages should largely dissipate, eliminating their impact on housing costs and federal tax payments.

[5]Suárez Serrato and Zidar (2016) estimate a framework with imperfect firm mobility that subdivides gains from local corporate income tax cuts to local residents, land values, and local firms. Their analysis based on establishment counts impose certain restrictions on firm production, such as Cobb-Douglas production.

B.2. [6] Firms produce traded and home goods out of land, capital, and labor. Within a city, factors command the same price in either sector.[7] Land, L, is homogeneous and immobile, and is paid a city-specific price r^j. Capital, K, is supplied elastically at the price $\bar{\imath}$. Households each supply a single unit of labor, earning wage w^j. Revenues from land and capital are collected nationally and rebated as non-labor income, $I + R$; total income, $m^j \equiv I + R + w^j$, varies only with wages. Federal tax payments of $\tau^j(y) = \tau\left(m^j - \delta p^j y\right)$ are net of transfers, and include a deduction at rate δ for nontraded purchases, such as housing. For simplicity, assume net tax payments average to zero; some payments are negative, while all marginal tax rates are positive.

Cities differ in three general "urban attributes": (i) quality of life, Q^j; (ii) trade productivity, A_X^j; and (iii) home productivity, A_Y^j. These attributes depend on a vector of individual amenities, $\mathbf{Z}^j = (Z_1^j, ..., Z_K^j)$, which may include public goods.

3.2 Equilibrium Conditions

We begin with the case where households are fully mobile, so that they receive the same utility, $\bar{u}$, in all (inhabited) cities. This equilibrium maps the three prices (r^j, w^j, p^j) one-to-one with the three attributes (Q^j, A_X^j, A_Y^j), by assuming workers are mobile and firms in both sectors make zero profit. Households preferences are represented by the expenditure function, $e(p^j, u; Q^j)$, which increases in utility, u, and p^j, and decreases in Q^j. Thus, local incomes $m^j = w^j + I + R$ must provide utility $\bar{u}$ after taxes: $e(p^j, \bar{u}; Q^j) = m^j - \tau^j(y)$.

Operating in perfectly competitive markets, firms produce under constant returns to scale; city returns to scale are embedded within the factor-neutral productivities, A_X^j and A_Y^j. The unit cost of producing a traded good is $c_X(r^j, w^j, \bar{\imath}; A_X^j) = c_X(r^j, w^j, \bar{\imath})/A_X^j$ where $c(r, w, i) \equiv c(r, w, i; 1)$. A symmetric definition holds for home-good unit costs, c_Y[8] Firms make zero profits in equilibrium: $c_X(r^j, w^j, \bar{\imath})/A_X^j = 1$, and $c_Y(r^j, w^j, \bar{\imath})/A_Y^j = p^j$.

[6] In practice, p^j is the measured cost of housing services. In an urban system, housing costs may proxy for cost-differences in all locally-provided goods. Non-housing goods, such as haircuts and restaurant meals, are considered to be a composite commodity of traded goods and non-housing home goods, with price p^j. Appendix B.2 shows that if housing is more land-intensive than non-housing home goods, then housing will more strongly reflect amenity values.

[7] Unlike in Glaeser and Gottlieb (2009), where the supply of land in each sector is fixed, and cities exhibit diminishing returns as the supply of residential land expands. The authors also impose Cobb-Douglas production technology and do not account for taxes or non-labor income. See Appendix C.3 for more explanation

[8] Formally, $e(p^j, u; Q^j) \equiv \min_{x,y}\{x + p^j y : U\left(x, y; Q^j\right) \geq u\}$. The single index Q^j assumes that amenities are weakly separable from consumption. The model generalizes to one with heterogeneous workers that supply different fixed amounts of labor if these workers are perfect substitutes in production, have identical homothetic preferences, and earn equal shares of income from labor. Additionally, the mobility condition need not apply to all households, but only a sufficiently large subset of mobile households (Gyourko and Tracy 1989). Appendix B.1 discusses the case with multiple household types with varying preferences and skills. Unit cost is $c_X(r^j, w^j, \bar{\imath}; A_X^j) \equiv \min_{L,N,K}\{r^j L + w^j N + \bar{\imath}K : A_X^j F\left(L, N, K\right) = 1\}$. Appendix B.1 demonstrates that non-neutral productivity differences have similar impacts on relative prices across cities.

3.3 Log-Linearization, Expenditure and Cost-Share Parameters

For analytical purposes, log-linearize the equilibrium equations around the national average, so that for any z, $\hat{z}^j = d\ln z^j = dz^j/\bar{z}$ approximates the percent difference in city j of z, relative to the national geometric average $\bar{z}$. Table 1 summarizes the key parameters, which without superscripts, refer to national averages: "s" is for expenditure shares, "θ'', for cost shares in traded production, and "ϕ'' for cost shares in home production, each with appropriate subscripts. The implied shares of land and labor used for the traded good — given by the parameters λ_L and λ_N — and the tax and deduction rates, τ' and δ, prove to be key. The "chosen" parameterized values shown come from Albouy (2009), reviewed in Appendix C.1.[9] The other columns present values implied by Haughwout (2002); Glaeser and Gottlieb (2009), adjusted for absentee land and capital owners; and Rappaport (2008a,b). The table highlights the simplifications other models often make in regard to home production, federal taxation, and mobility, which we relax in section 5.[10]

The log-linearized equilibrium conditions describe how prices co-vary with city attributes in a spatial equilibrium.[11]

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

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

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

Each equilibrium condition states that the relative value of a city's amenities is measured implicitly

[9] The one exception to this notation is $\hat{Q}^j \equiv -(\partial e/\partial Q)(1/\bar{m})dQ^j$, which is the dollar value of a change in Q^j divided by income. The shares of (gross) expenditures spent on traded goods and home goods are $s_x^j \equiv x^j/m^j$ and $s_y^j \equiv p^j y^j/m^j$; the shares of income received from land, labor, and capital income are $s_R^j \equiv R/m^j$, $s_w^j \equiv w^j/m^j$, and $s_I^j \equiv I/m^j$. For firms, denote the cost-shares of land, labor, and capital in the traded-good sector as $\theta_L^j \equiv r^j L_X^j/X^j$, $\theta_N^j \equiv w^j N_X^j/X^j$ and $\theta_K^j \equiv \bar{\imath} K_X^j/X^j$; denote equivalent cost-shares in the home-good sector as ϕ_L^j, ϕ_N^j, and ϕ_K^j. Finally, denote the shares of land, labor and, capital used to produce traded goods as $\lambda_L^j \equiv L_X^j/L^j$, $\lambda_N^j \equiv N_X^j/N^j$, and $\lambda_K^j \equiv K_X^j/K^j$. Assume home goods are more cost-intensive in land relative to labor than traded goods, both absolutely, $\phi_L^j \geq \theta_L^j$, and relatively, $\phi_L^j/\phi_N^j \geq \theta_L^j/\theta_N^j$, implying $\lambda_L^j \leq \lambda_N^j$. Nationally, the parameters obey the following identities: (i) $s_w + s_I + s_R = 1$; (ii) $\theta_L + \theta_K + \theta_N = 1$; (iii) $\phi_L + \phi_K + \phi_N = 1$; (iv) $s_w = s_x\theta_N + s_y\phi_N$; (v) $s_I = s_x\theta_K + s_y\phi_K$; (vi)$s_R = s_x\theta_L + s_y\phi_L$. (vii) $\lambda_L = s_x\theta_L/s_R$, (viii) $\lambda_N = s_x\theta_N/s_w$.

[10] Other applications with $\phi_L = 1, \lambda_N = \phi_N = 0$ include Shapiro (2006), who proposes $\theta_L = 0.1, \theta_N = 0.75$, and $s_y/s_w = 0.32$, implying $\lambda_L = 0.20$ and $\lambda_N = 1$;Gabriel and Rosenthal (2004) use values implying $\lambda_L = 0.5$ and $\lambda_N = 1$. Kline and Moretti (2014b) take $\theta_N = 0.47$ and $\theta_L = 0.23$. Roback (1982, p.1273) assumes $s_y/s_w = 0.035$, but does not provide other values.

[11] When simply linearized with Shephard's Lemma, the equations are

$$-(\partial e/\partial Q)dQ^j = \bar{y}\cdot dp^j - (1-\tau')\cdot dw^j$$

$$dA_X^j = \overline{(L_X/X)}\cdot dr^j + \overline{(N_X/X)}\cdot dw^j$$

$$\bar{p}\cdot dA_Y^j = \overline{(L_Y/Y)}\cdot dr^j + \overline{(N_Y/Y)}\cdot dw^j - dp^j$$

The first equation is log-linearized by dividing through by $\bar{m}$, and the third, by dividing by $\bar{p}$. As shown by Hochman and Pines (1993), it is the marginal tax rate on wage income that matters.

Table 1: Model Parameters and Possible Values

Parameter	*Notation*	*Chosen values*	*Haughwout**	*Glaeser-Gottlieb**	Rappaport
Non-labor income		rebate	rebate	absent	rebate
Panel A: Values parameterized directly					
Home-goods share	s_y	0.360	0.124	0.200	0.180
Traded-good cost-share of land	θ_L	0.025	0.055	0.100	0.018
Traded-good cost-share of labor	θ_N	0.825	0.856	0.733	0.655
Home-good cost-share of land	ϕ_L	0.233	1.0	0.300	0.350
Home-good cost-share of labor	ϕ_N	0.617	0.0	0.400	0.455
Marginal tax rate on labor	τ'	0.361	0.0	0.0	0.0
Deduction rate for home-goods	δ	0.291	0.0	0.0	0.0
Immobility (see section 5)	ψ	0.0/0.05/∞	0.0	0.0	0.0
Panel B: Parameters derived from theory (see below)					
Income share to labor	s_w	0.750	0.750*	0.667*	0.615
Share of land in traded good	λ_L	0.17	0.28	0.57	0.19
Share of labor in traded good	λ_N	0.70	1.0	0.88	0.87
Wage multiplier	μ_w	1.42	1.0	1.14	1.15
Tax multiplier	μ_τ	1.20	1.0	1.0	1.0

NOTE: Haughwout: s_I is set to get $s_w = 0.750$; Glaeser-Gottlieb: θ_N is set to get $s_w = 0.667$.

by how much households or firms will pay for them. Equation (1a) measures local quality of life from how high the discounted cost-of-living, $(1 - \delta\tau')\, s_y \hat{p}^j$, is relative to after-tax nominal income, $s_w(1-\tau')\hat{w}^j$. Equation (1b) measures local trade productivity, $\hat{A}^j_X$, from how high the labor costs, $\theta_N \hat{w}^j$, and land costs, $\theta_L \hat{r}^j$, are in traded-good production. Equation (1c) measures local home productivity, $\hat{A}^j_Y$, from how high the labor costs, $\phi_N \hat{w}^j$, and land costs, $\phi_L \hat{r}^j$, are in production relative to the home-good price, $\hat{p}^j$.

The equilibrium conditions hold even when the attributes are endogenous, e.g., if they change with population N^j. Due to feedback effects, it can be difficult to isolate the effect of a single public good without a full accounting of amenities. To appreciate the potential complexity of comparative statics, say that $Q^j = Q^j_0 (N^j)^{-\gamma}$ and $A^j_X = A^j_{X0}(N^j)^{\alpha}$, where Q^j_0 and A^j_{X0} are exogenous, and $\gamma \geq 0$ and $\alpha \geq 0$ are congestion and agglomeration parameters. If a city's transportation network improves, then both Q^j_0 and A^j_{X0} rise. These benefits attract new workers, raising N^j. This population increase then reduces $\hat{Q}^j = \hat{Q}^j_0 - \gamma \hat{N}^j$ and further increases $A^j_X = \hat{A}^j_{X0} + \alpha \hat{N}^j$. While we cannot observe these effects separately, we may infer them if we estimate $\hat{N}^j$, and have prior information on γ and α.

4 Price Effects of Amenities with Home Goods and Taxes

4.1 Mathematical Inversion of Equilibrium Conditions

To describe how prices are affected by small changes in local attributes, the system in Equations (2a), (2b), and (2c), below invert the system of Equations in (1a), (1b), and (1c). For comparison, each price differential is multiplied by its income share, so that each equation expresses the change in total land, labor, and home-good values relative to local income. Thus, a 1 percent increase in $s_R \hat{r}^j$ represents an increase in land values of one percent of income. Each attribute is similarly weighted. With these normalizations, we express prices in terms of urban attributes:

$$s_R \hat{r}^j = \frac{l}{m} dr^j = \mu_\tau \left\{ \hat{Q}^j + \left[1 - \tau' \left(\delta + (1-\delta)\mu_w\right)\right] s_x \hat{A}_X^j + \left(1 - \tau'\delta\right) s_y \hat{A}_Y^j \right\} \tag{2a}$$

$$s_w \hat{w}^j = \frac{w}{m} dw^j = \mu_\tau \mu_w \left\{ -\lambda_L \hat{Q}^j + \left(1 - \tau'\delta\right) \left[(1-\lambda_L) s_x \hat{A}_X^j - \lambda_L s_y \hat{A}_Y^j \right] \right\} \tag{2b}$$

$$s_y \hat{p}^j = \frac{y}{m} dp^j = \mu_\tau \mu_w \left\{ (\lambda_N - \lambda_L) \hat{Q}^j + \left(1 - \tau'\right) \left[(1-\lambda_L) s_x \hat{A}_X^j - \lambda_L s_y \hat{A}_Y^j \right] \right\} \tag{2c}$$

$l^j \equiv L^j/N^j$ is the land-to-labor ratio. These expressions depend only on the fractions of land and labor in traded-good λ_L and λ_N, and the tax and discount rates τ' and δ. To build understanding, we collect some parameter into two multipliers: a wage multiplier, μ_w, and a tax multiplier, μ_τ, which are composed of the following parameters.

$$\mu_w \equiv \frac{1}{\lambda_N}, \quad \mu_\tau \equiv \frac{1}{1 - \tau' \left[\delta + (1-\delta) \frac{\lambda_L}{\lambda_N} \right]} \tag{3}$$

Both multipliers are weakly greater than one with normal parameterizations, $\lambda_N \geq 0, \tau' \geq 0$. When home-goods have no labor component ($\lambda_N = 1$), then $\mu_w = 1$; when federal taxes are absent ($\tau' = 0$), then $\mu_\tau = 1$. Both multipliers decrease in λ_N; the tax multiplier increases in τ', δ, and λ_L and equals $(1-\tau')^{-1}$ if $\delta = 1$. Subsection 4.3 explains more.

4.2 Basic Capitalization Effects

Land values are closely related to the total value of amenities, denoted $\Omega(Q, A_X, A_Y)$. The log-difference of this value equals the weighted value of attribute differences: $\hat{\Omega}^j \equiv \hat{Q}^j + s_x \hat{A}_X^j + s_y \hat{A}_Y^j = s_R \hat{r}_*^j$, where the subscript "$*$" denotes differentials with $\tau' = 0$, taken from the solution for land rents (2a). Thus, the last equality expresses the classical result that land values fully capitalize amenity values.[12] With federal taxes, this capitalization result breaks down,

[12] Wihout taxes, the linearized version of (2a) is $\overline{(L/N)} dr^j = -(\partial e/\partial Q) dQ^j + \overline{(X/N)} dA_X^j + \overline{(pY/N)} dA_Y^j = d\Omega^j$. Per capita, $\overline{(L/N)} dr^j$ is the change in land value, $-(\partial e/\partial Q) dQ^j$ is the improvement in quality-of-life per resident,

since local land values also capitalize federal-tax payments, captured in the "tax differential" $d\tau^j/m \equiv \tau' s_w \hat{w}^j - \delta\tau' s_y \hat{p}^j$.[13] The land-rent differential then capitalizes this equilibrium tax differential, i.e., it follows from $s_R \hat{r}^j = s_R \hat{r}^j_* + d\tau^j/m$. Solving for the tax differential:

$$\frac{d\tau^j}{m} = \tau' \mu_\tau \left[(1-\delta)\left(\frac{1-\lambda_L}{\lambda_N} s_x \hat{A}^j_X - \frac{\lambda_L}{\lambda_N} s_y \hat{A}^j_Y \right) - \left(\delta + (1-\delta)\frac{\lambda_L}{\lambda_N} \right) \hat{Q}^j \right] \tag{4}$$

This expression neatly summarizes the results of Albouy (2009): federal taxes increase in trade productivity, and fall in home productivity and quality of life; deductions mitigate tax differences from both kinds of productivity, but magnify for them for quality-of-life.

Abstracting away from taxes, higher land values pass through to lower wages by an amount $-\lambda_L s_R \hat{r}^j$, seen inside the brackets of (2b) for $\hat{Q}^j$ and $\hat{A}^j_X$. With trade productivity, this negative effect through land is outweighed by positive productivity effects, proportional to $s_x \hat{A}^j_X$, modifying the coefficient to $1 - \lambda_L$. A similar pass-through effect applies to home-good prices: lower-paid workers do not accept a lower real wage, unless it is due to a higher quality of life — e.g., $s_y \hat{p}^j_* = s_w \hat{w}^j_* + \hat{Q}^j$. This modifies the coefficient on $\hat{Q}^j$ from $-\lambda_L$ to $(\lambda_N - \lambda_L)$. To better understand this modification, we explain the wage multiplier.

4.3 Wage and Tax Multipliers

The wage multiplier, $\mu_w = 1/\lambda_N$, outside the brackets in Equations (2b) and (2c), is related to one proposed by Tolley (1974). It results from local workers purchasing home goods from other local workers. To derive the multiplier, ignore taxes, and let equilibrium wages without home-good price responses equal $\hat{w}_0$. Since home producers make zero profits and must offer the same wages as traded producers, they must raise prices by ϕ_N times $\hat{w}_0$, meaning $\hat{p}_0 = \phi_N \hat{w}_0$. Yet, since workers are mobile, firms need to compensate them for the increase in cost-of-living of $s_y \phi_N \hat{w}_0$ by $1/s_w$ that amount in wages, leading to a further wage increase of $\hat{w}_1 - \hat{w}_0 = \phi_N (s_y/s_w) \hat{w}_0 = (1-\lambda_N)\hat{w}_0$. This leads to further increases in costs-of-living and feedback effects on wages, given by the sum $\hat{w}_\infty = \sum_{k=0}^{\infty} (\hat{w}_{k+1} - \hat{w}_k) + \hat{w}_0 = \sum_{k=0}^{\infty} (1-\lambda_N)^k \hat{w}_0 = (1/\lambda_N)\hat{w}_0 = \mu_w \hat{w}$. This infinite sum provides a fixed point, $\hat{w}_\infty = \hat{w}_*$, in equilibrium. The more labor is in nontraded production, i.e., the smaller λ_N, the larger the wage multiplier. Operating in symmetry, home-good prices are subject to the same effect. Land prices remain unaffected.

The tax multiplier, μ_w, which multiplies all of the expressions in (2), follows a similar logic.

$\overline{(X/N)} dA^j_X$ and and $\overline{(pY/N)} dA^j_Y$ are the per-capita decrease in tradable and non-tradable costs. The solutions in (2) are derivable from Albouy's (2009) model. The expressions here are more interpretable, relative to income, use factor (not cost) shares, λ, and incorporate δ.

[13] Like the other terms, this differential is normalized to express how much relative to the national average households in a city pay in taxes as a fraction of their income.

For ease, let $\delta = 0$, and consider $\mu_\tau = 1/(1-\tau'\lambda_L/\lambda_N) \geq 1$. A wage differential of $\hat{w}_*$ leads to an additional tax payment of $\tau' s_w \hat{w}_*$. This payment lowers land prices for firms. They pass on these savings to workers by the amount $\lambda_L \tau' s_w \hat{w}_* / s_w = \lambda_L \tau' \hat{w}_*$. This premium is subject to the wage multiplier, causing wages to rise further to $\Delta\hat{w} = (\tau'\lambda_L/\lambda_N)\hat{w}_*$. This full wage increase is then taxed, completing the tax feedback loop. Compounding these effects results in the multiplier $\sum_{k=0}^{\infty} (\tau'\lambda_L/\lambda_N)^k \hat{w}_* = [1/(1-\tau'\lambda_L/\lambda_N)]\hat{w}_* = \mu_\tau \hat{w}_*$. Thus the tax multiplier magnifies any equilibrium wage differences. Furthermore, it impacts land values in addition to home-good prices.

With a deduction, the tax multiplier also integrates how taxes lower home-good prices, which in turn implies a lower deduction amount. Following the previous logic, wages rise by an amount satisfying $s_w \Delta\hat{w}^j = (\lambda_L/\lambda_N)\tau' \left(s_w \hat{w} - \delta s_y \hat{p}^j\right)$. At the same time, prices fall to offset the tax, save the portion that is compensated for via higher wages, meaning $s_y \Delta\hat{p} = -\left(1 - \lambda_L/\lambda_N\right)\tau' \left(s_w \hat{w}_* - \delta s_y \hat{p}_*^j\right)$. This results in a net tax increase of $\tau' \left(s_w \Delta\hat{w} - \delta s_y \Delta\hat{p}\right) = \tau' \left[\delta + (1-\delta)\lambda_L/\lambda_N\right]$. Compounding these tax effects in an infinite sum produces the full tax multiplier. The tax multiplier causes both wage and price differential to expand. Higher taxes beget higher wages, which beget higher taxes. Meanwhile, higher prices beget lower taxes, which beget higher prices. Therefore, the two effects work in tandem.

There are also three direct effects of taxes, seen inside the curly brackets. First, both productivity terms in the price Equation (2c) are reduced immediately by τ'. This occurs since any initial pass-through effects of productivity on wages are immediately subject to taxes, lowering the initial willingness-to-pay for local goods. Second, both productivity effects in the wage equation are reduced by $\delta\tau'$. This accounts for how firms can incorporate the deduction immediately when offering compensation for local cost-of-living. Third, there is a more complex effect on land rents. $\tau' \left[\delta + (1-\delta)\mu_w\right] s_x \hat{A}_X^j + \tau'\delta s_y \hat{A}_Y^j$. The term on home productivity reflects how price decreases lower tax deductions. The more complex term on trade productivity is due to the initial impact of trade productivity on wages, which is multiplied by μ_w, with ensuing effects on deductions given by $\delta\left(\mu_w - 1\right)$.[14]

5 Population and Price Changes with Imperfect Mobility

The model above is predicated on perfect mobility across cities, which are deemed "open." While the case of perfect mobility is a useful benchmark for long-run adjustments, in the short to medium run, mobility is likely to be imperfect. Economists also often work with the other extreme of

[14]Roback (1982, p. 1265) reports a linear analogue to Equation (2c) without taxes in her Equation (9) expressed in derivatives of cost and indirect utility functions. Roback states that the effect of improvements in quality-of-life on home-good prices is ambiguous. It is unambiguous if home goods are relatively land intensive, meaning $\lambda_N > \lambda_L$. This condition underpins Roback's assumption that the determinant in her Equation 9 (Δ^*) is greater than zero.

"closed" cities, with no mobility. In a monocentric city model, Wheaton (1974) and Brueckner (1987) demonstrate that an improvement in transportation infrastructure raises central land and housing values in open cities. Meanwhile, in closed cities, central land values are depressed relative to peripheral values, and infrastructure benefits are shared by workers and landowners. While our analysis ignores the inner structure of cities, below we provide a formulation that captures some of these features and allows for any degree of mobility across cities.[15]

An accepted way to handle imperfect mobility is to assume preferences for location are heterogeneous along an unobserved dimension (e.g., Aura and Davidoff 2008; Kline and Moretti 2014b). Suppose that quality of life for household i in metro j equals the product of a common term and a household-specific term, $Q_i^j = Q^j \zeta_i^j$. In addition, assume that ζ_i^j comes from a Pareto distribution with parameter $1/\psi > 0$, common across metros, and distribution function $F(\zeta_i^j) = 1 - (\underline{\zeta}/\zeta_i^j)^{1/\psi}, \zeta_i^j \geq \underline{\zeta}$. A larger value of ψ corresponds to greater preference heterogeneity; $\psi = 0$ is the baseline value for an open city with perfect household mobility, and as $\psi \to \infty$ the city becomes closed, with perfect immobility. ψ is therefore naturally called the immobility parameter.

For each populated metro, there exists a marginal household, denoted by k, such that $e(p^j, \bar{u}; Q^j \zeta_k^j) = m^j - \tau(m^j)$. Log-linearizing this condition replaces $\hat{Q}^j$ in Equation (1a) with $\hat{Q}^j - \psi \hat{N}^j$, where $\hat{N}^j$ is the population change. In other words, where $\hat{Q}_0^j$ is the quality of life inferred with perfect mobility, $\hat{Q}^j = \hat{Q}_0^j + \psi \hat{N}^j$.[16] The population change depends on a complex structural relationship depending on substitution responses in production and consumption, income effects, and output effects in housing. We take the approach of Albouy and Stuart (2015), of modeling this structural relationship as a reduced-form relationship between population and attribute changes. To do this, first consider the perfectly mobile case of $\psi = 0$. The log-linearized population change is described as

$$\hat{N}_0^j = \varepsilon_0^{N,Q} \hat{Q}^j + \varepsilon_0^{N,A_X} \hat{A}_X^j + \varepsilon_0^{N,A_Y} \hat{A}_Y^j, \tag{5}$$

where $\varepsilon_0^{N,Q}$ is the elasticity of population with respect to quality of life under full mobility; ε_0^{N,A_X} and ε_0^{N,A_Y} are defined similarly. These elasticities are functions of elasticities of substitution, as well as expenditure and cost shares and tax rates. [17]

[15]Both open and closed monocentric cities have perfect mobility within the city

[16]For some presumably large fixed constant $N_{\max}^j$, population density in each metro can be written $N^j = N_{\max}^j \Pr[\zeta_i^j \geq \zeta_k^j] = N_{\max}^j (\underline{\zeta}/\zeta_k^j)^{1/\psi}$. This provides the same basic structure as a discrete choice formulation, e.g. McFadden (1978), Bayer, Ferreira, and McMillan (2007), although it is not as conducive to estimation.

[17]$\hat{L}^j$ brings up the possibility of any changes in land. Therefore, think of $\hat{N}^j - \hat{L}^j$ as describing a change in density, and for now set $\hat{L}^j = 0$.The assumptions of an internally homogeneous open city, exogenous and neutral amenities, and constant returns in the cost and expenditure functions imply that all of the production quantities increase linearly with the quantity of land. If land in a city doubles, labor and capital will enter and also double, so that all prices and per-capita quantities do not change.

For a general level of immobility ψ, we substitute for $\hat{Q}^j - \psi N^j$ and solve for N^j. This implies a reduced-form relationship of

$$\hat{N}^j_\psi = \frac{1}{1+\psi\varepsilon_0^{N,Q}} \underbrace{\left(\varepsilon_0^{N,Q}\hat{Q}^j + \varepsilon_0^{N,A_X}\hat{A}^j_X + \varepsilon_0^{N,A_Y}\hat{A}^j_Y\right)}_{\hat{N}^j_0} \tag{6a}$$

$$= \varepsilon_\psi^{N,Q} Q^j + \varepsilon_\psi^{N,A_X}\hat{A}^j_X + \varepsilon_\psi^{N,A_Y}\hat{A}^j_Y \tag{6b}$$

Heterogeneous tastes from ψ dampen mobility — as seen in the multiplier $\left(1+\psi\varepsilon_0^{N,Q}\right)^{-1}$ — since firms need to pay incoming migrants an increasing schedule of after-tax real wages to have them overcome their increasing distaste to live in city j.[18]

With values ψ and $\varepsilon_0^{N,Q}, \varepsilon_0^{N,A_X}, \varepsilon_0^{N,A_Y}$ all of the predictions can be reformulated. Furthermore, the equations in (2) can then be rewritten with the substitution $\hat{Q}^j - \psi\hat{N}^j$ for $\hat{Q}^j$. Besides amending the quality-of-life change, the tax differential and land capitalization effects are now

$$\frac{d\tau^j_\psi}{m} = \frac{d\tau^j}{m} + (\mu_\tau - 1)\psi\hat{N}^j \tag{7}$$

$$s_R\hat{r}^j_\psi + \psi\hat{N}^j_\psi = s_R\hat{r}^j_* - \frac{d\tau^j_\psi}{m} \tag{8}$$

The first expression amends the tax differential from Equation (4). It adds the term $(\mu_\tau - 1)\psi\hat{N}^j$ to account for the tax on the real-wage premium offered to income workers. The second expression (8) states that benefits from amenities in $s_R\hat{r}^j_*$ net of tax effects in $d\tau^j_\psi/m$, on the right, are shared between capitalization effects in $s_R\hat{r}^j$ and benefits to inframarginal households in $\psi\hat{N}^j$. This latter amount also depends on ψ and the actual population change we observe.[19] Overall, imperfect mobility reduces the capitalization responses in wages and prices needed to equilibrate cities in proportion to the population change observed.

The previous capitalization formulae in (2) are modified by the following subtractions for land

[18]The comparative statics with imperfect mobility are indistinguishable from congestion effects: ψ and γ are interchangeable. The welfare implications are different as infra-marginal residents share the value of local amenities with land-owners. The increase in real income is given by $s_w(1-\tau)d\hat{w}^j - s_y d\hat{p}^j = \psi\hat{N}^j = -s_R d\hat{r}^j$, where "d" denotes price changes between actual and full mobility. As with most closed-city models, the main challenge in putting into operation the assumption of imperfect mobility is specifying the baseline level of population that deviations $\hat{N}^j$ are taken from, as a baseline of equal density may not be appropriate.

[19]Estimates of $\hat{A}^j_X$ and $\hat{A}^j_Y$ from $\hat{w}^j, \hat{p}^j$, and $\hat{N}^j$ do not depend on ψ.

values and home prices, and an addition for wages:

$$s_R\hat{r}^j_\psi = s_R\hat{r}^j - \psi\frac{\mu_\tau}{1+\psi\varepsilon_0^{N,Q}}\hat{N}^j_0 \tag{9a}$$

$$s_w\hat{w}^j_\psi = s_w\hat{w}^j + \psi\frac{\mu_\tau\mu_w\lambda_L}{1+\psi\varepsilon_0^{N,Q}}\hat{N}^j_0 \tag{9b}$$

$$s_y\hat{p}^j_\psi = s_p\hat{p}^j - \psi\frac{\mu_\tau\mu_w\left(\lambda_N-\lambda_L\right)}{1+\psi\varepsilon_0^{N,Q}}\hat{N}^j_0 \tag{9c}$$

With immobility, wages are reduced less by quality of life, are increased more by trade productivity, and are also boosted by home productivity. Home-good values capitalize quality-of-life and home-productive amenities less, as locals benefit more from them. Most importantly, home productivity has a greater effect in reducing local home-good prices. No matter what the value of ψ the inferred values of A_X and A_Y are unaffected, conditional on observing $\hat{N}^j$.[20]

A useful feature of the model is the limiting case of complete immobility. This occurs in the limit with $\psi \to \infty$. At this extreme, quality-of-life benefits are not seen in prices or population at all; benefits are internalized completely by existing residents. Productive amenities still affect prices, but their benefits are in proportion to the structural elasticities under perfect mobility according to the ratios, $\varepsilon_0^{N,A_X}/\varepsilon_0^{N,Q}$, and $\varepsilon_0^{N,A_Y}/\varepsilon_0^{N,Q}$, respectively. Curiously, the collection

[20]The solutions for the case of imperfect mobility come from manipulating Equation (6a) to show

$$\hat{Q}^j - \psi\hat{N}^j = \frac{1}{1+\psi\varepsilon_0^{N,Q}}\left(\hat{Q}^j - \psi\varepsilon_0^{N,A_X}\hat{A}^j_X - \psi\varepsilon_0^{N,A_Y}\hat{A}^j_Y\right) \tag{10}$$

The full formulas for the capitalization effects incorporating immobility are

$$s_R\hat{r}^j = \mu_\tau\left\{\frac{\varepsilon_\psi^{N,Q}}{\varepsilon_0^{N,Q}}\hat{Q}^j + \left[1-\tau'\left(\delta+(1-\delta)\mu_w\right) - \frac{\psi\varepsilon_\psi^{N,A_X}}{s_x}\right]s_x\hat{A}^j_X + \left[1-\tau'\delta - \frac{\psi\varepsilon_\psi^{N,A_Y}}{s_y}\right]s_y\hat{A}^j_Y\right\} \tag{11a}$$

$$\begin{aligned} s_w\hat{w}^j =& \mu_\tau\mu_w\left\{-\lambda_L\frac{\varepsilon_\psi^{N,Q}}{\varepsilon_0^{N,Q}}\hat{Q}^j + \left[\left(1-\tau'\delta\right)\left(1-\lambda_L\right) + \lambda_L\frac{\psi\varepsilon_\psi^{N,A_X}}{s_x}\right]s_x\hat{A}^j_X\right. \\ &\left. +\lambda_L\left[\frac{\psi\varepsilon_\psi^{N,A_Y}}{s_y} - \left(1-\tau'\delta\right)\hat{A}^j_Y\right]\right\} \end{aligned} \tag{11b}$$

$$\begin{aligned} s_y\hat{p}^j =& \mu_\tau\mu_w\left\{\left(\lambda_N-\lambda_L\right)\frac{\varepsilon_\psi^{N,Q}}{\varepsilon_0^{N,Q}}\hat{Q}^j + \left[\left(1-\tau'\right)\left(1-\lambda_L\right) - \left(\lambda_N-\lambda_L\right)\frac{\psi\varepsilon_\psi^{N,A_X}}{s_x}\right]s_x\hat{A}^j_X\right. \\ &\left. - \left[\left(1-\tau'\right)\lambda_L + \left(\lambda_N-\lambda_L\right)\frac{\psi\varepsilon_\psi^{N,A_Y}}{s_y}\right]s_y\hat{A}^j_Y\right\} \end{aligned} \tag{11c}$$

In the limit,as $\psi \to 0$, the elasticity coefficients become

$$\frac{\varepsilon_\psi^{N,Q}}{\varepsilon_0^{N,Q}} \to 0, \quad \psi\varepsilon_\psi^{N,A_X} \to \frac{\varepsilon_0^{N,A_X}}{\varepsilon_0^{N,Q}}, \quad \psi\varepsilon_\psi^{N,A_Y} \to \frac{\varepsilon_0^{N,A_Y}}{\varepsilon_0^{N,Q}},$$

of parameters in these reduced-form elasticities describing frictionless mobility are pertinent to understanding price responses with no mobility.

6 Simulated Impact of Public Goods on Prices and Populations

Simulating the above capitalization results using hard numbers helps to build intuition and understand the magnitudes of the predictions. Our simulation applies the values in table 1, meant to represent a typical city, to Equations (2) and (9). Table 2 reports how a $1 dollar increase in the value of a local attribute is capitalized into local prices. To highlight the importance of federal taxes and nontraded production, the coefficients in panel A eliminate taxes and the wage multiplier by altering the parameterization so that $\tau' = 0$ and $\lambda_N = 1$, while holding λ_L constant. Panel B re-introduces only the wage multiplier, with a value of $\mu_w = 1/\lambda_N = 1.42$. Panel C then cumulatively adds federal taxes on wages at a rate of $\tau' = 0.36$, leading to a tax multiplier of 1.09; panel D adds refinements for housing tax benefits and state taxes, which raises the tax multiplier to 1.17. While the first four panels assume perfect mobility, $\psi = 0$, panels E and F consider the case of partial mobility with $\psi = 0.05$, and perfect immobility, with $\psi \to \infty$.

The first rows of panel A and B demonstrate that, without taxes, land rents capitalize the full value of amenities. In panel A, 83 percent of quality-of-life values are capitalized into higher home-good prices, with the remaining 17 percent in lower wages. In panel B, the effect on wages grows relative to prices. With trade productivity, the wage multiplier effect plays an important role: home-good prices go from mirroring 83 percent of their value in A, and to 119 percent in B. Naturally, these price changes are fully offset by equally valued wage increases. Even with the wage-multiplier effect, home productivity only modestly decreases home-good prices by 23 percent of their value; this too is offset with lower wages.

Federal taxes change some of the capitalization effects substantially. While panel C covers the case of a simple wage tax, panel D offers a more realistic case to focus on. Here we see land rents capitalize only 63 percent of the value of trade productivity, while the federal government expropriates the remaining 37 percent. Meanwhile, the federal government implicitly subsidizes quality-of-life amenities at a rate of 19 percent, and home-productive amenities at a rate of 8 percent. A local government maximizing land rents has twice the incentive to provide public goods to households than to traded-good producers.

Through the tax multiplier, wage differentials are amplified by 9 percent. In total, wages then capitalize quality-of-life amenities by $0.27 on the dollar. This low figure undermines studies (e.g., Moore 1998) that try to value quality-of-life amenities using nominal wages alone. For trade productivity, wages reflect an even higher 128 percent, indicating that wage-only measures of productivity — often seen in the agglomeration literature — can overstate differences in total

Table 2: Simulated Effect of Attributes on Prices

	Attribute/ type of amenity:	Value increase from a one-dollar attribute increase: Quality of life	Trade product.	Home product.
Panel A: No Wage Multiplier; Federal Taxes Neutral				
Land rents*	$s_R\hat{r}^j$	1.00	1.00	1.00
Wages	$s_w\hat{w}^j$	-0.17	0.83	-0.17
Home-good prices	$s_y\hat{p}^j$	0.83	0.83	-0.17
Population	$\hat{N}^j$	5.52	4.54	7.80
Panel B: Wage Multiplier; Federal Taxes Neutral				
Land rents*	$s_R\hat{r}^j$	1.00	1.00	1.00
Wages	$s_w\hat{w}^j$	-0.23	1.19	-0.23
Home-good prices	$s_y\hat{p}^j$	0.77	1.19	-0.23
Population	$\hat{N}^j$	7.09	5.81	7.54
Panel C: parameterization with Wage Multiplier & Federal Taxes				
Land rents*	$s_R\hat{r}^j$	1.09	0.53	1.09
Wages	$s_w\hat{w}^j$	-0.25	1.30	-0.25
Home-good prices	$s_y\hat{p}^j$	0.84	0.83	-0.16
Fed. Tax Payment*	$d\tau^j/\bar{m}$	-0.09	0.47	-0.09
Population	$\hat{N}^j$	8.28	3.15	8.06
Panel D: Wage Multiplier, Fed. Taxes with Housing Benefits				
Land rents*	$s_R\hat{r}^j$	1.18	0.63	1.07
Wages	$s_w\hat{w}^j$	-0.27	1.28	-0.24
Home-good prices	$s_y\hat{p}^j$	0.92	0.91	-0.17
Fed. tax payment*	$d\tau^j/\bar{m}$	-0.18	0.37	-0.07
Population	$\hat{N}^j$	8.17	3.38	8.01
Panel E: Wage Mult., Taxes/Benefits, and Imperfect Mobility ($\psi = 0.05$)				
Land rents*	$s_R\hat{r}^j$	0.84	0.48	0.73
Wages	$s_w\hat{w}^j$	-0.19	1.31	-0.17
Home-good prices	$s_y\hat{p}^j$	0.65	0.79	-0.43
Fed. tax payment*	$d\tau^j/\bar{m}$	-0.13	0.40	-0.02
Population	$\hat{N}^j$	5.80	2.40	5.69
Local resident gains*	$\psi\hat{N}^j$	0.29	0.12	0.28
Panel F: Wage Mult., Fed. Taxes/Benefits, and No Mobility ($\psi = \infty$)				
Land rents*	$s_R\hat{r}^j$	0.00	0.13	-0.10
Wages	$s_w\hat{w}^j$	0.00	1.39	0.02
Home-good prices	$s_y\hat{p}^j$	0.00	0.52	-1.08
Fed. tax Payment*	$d\tau^j/\bar{m}$	0.00	0.45	0.12
Population	$\hat{N}^j$	0.00	0.00	0.00
Local resident gains*	$\psi\hat{N}^j$	1.00	0.41	0.98

NOTE: Based on (2) with parameterization in table 1. Panel A sets $\lambda_N = 1$, but keeps $\lambda_L = 0.17$. * indicates final incidence, with values summing to 1.00.

factor productivity. [21]

For home-good prices, taxes increase the capitalization of quality-of-life to 90 percent and decrease that of productivity to 92 percent. Home-good prices capitalize the value of quality-of-life and trade productivity differences more accurately than land rents considered in isolation. Home productivity remains hard to detect with any land data.

The results for imperfect mobility are shown in panel E, with a value of $\psi = 0.05$, reduce population responses by 30 percent. Benefits are now divided between land-owners, federal revenues, and local residents. Land values capitalize local improvements by about 30 percent. Wages are less affected by attributes, except for trade productivity. Home-good prices become less responsive to quality of life and trade productivity; instead, residents gain directly more from these improvements, as their real wages rise. Home-good prices drop by 43 percent by the value of home productivity: a much larger pass-through than before.

With perfect immobility in panel E ($\psi \to \infty$), the results are more stark. Quality-of-life gains have no effect on anything. Trade productivity raises wages by more than 40 percent over their value, as mobile capital inflows boost labor productivity. These gains are taken back partly in home-good prices from a standard "cost disease." Nonetheless, local residents receive two-fifths of the gains; land-owners receive less than a seventh, and the federal government receives the most. Improvements in home productivity provide benefits mainly in the form of lower home-good prices, reflecting them almost one-for one. Interestingly, this does have tax consequences, as tax-benefits for housing are lower, making land-owners slightly *worse* off. Still, existing residents come away with most of the benefits.

An important take away from this analysis is that when households are immobile, high housing prices reflect not so much quality-of-life and trade productivity (employment) benefits, as much as low productivity in housing. This insight helps to reconcile seemingly opposing views that high housing prices reflect either desirable locations or limits in housing supply.

7 Inferring Values with Limited Data

7.1 Using Housing Costs and Wages Alone

Most of the time, researchers estimating the value of public goods do not have access to adequate and reliable land value data. With only data on wages and home-good (or housing) prices, $\hat{Q}^j$

[21] Rappaport (2008b) finds a capitalization effect of quality of life on wages similar to the one here without taxes, as his calibration implies similar values of λ_L. For other amenities his results differ as λ_N and τ' play more of a role.

is still uniquely identified, but the two productivities, $\hat{A}_X^j$ and $\hat{A}_Y^j$, are not.[22] The difficulty of distinguishing trade and home productivity can be seen by combining Equations (1b) and (1c), and eliminating $\hat{r}^j$, leading to

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

The two productivity terms are collinear: each changes wages and housing-cost in the same proportion in opposite directions. Two possible shortcuts come to mind: 1) simply ignore $\hat{A}_Y^j$, as most researchers have; or 2) assume $\hat{A}_Y^j = \hat{A}_X^j$, as do a few. While convenient, these assumptions may engender erroneous conclusions. Furthermore, they run contrary to evidence in Albouy and Ehrlich (2016) using actual land values across U.S. cities, that productivity in the housing sector is highly variable, i.e., not zero, and quite different from trade productivity (and, in fact, negatively correlated with it). [23]

Solving for differences in total amenity values in terms of wages and home-good prices only, we obtain the expression:

$$\hat{\Omega}^j = \frac{1}{1-\lambda_L}\left\{\left[1-(1-\lambda_L)\delta\tau'\right]s_y\hat{p}^j + \left[\tau'(1-\lambda_L)-(1-\lambda_N)\right]s_w\hat{w}^j + s_y\hat{A}_Y^j\right\}. \tag{13}$$

This measure is increasing in home expenditures, $s_y\hat{p}^j$, and accounts for land used in the traded sector multiplying by $1/(1-\lambda_L)$, discounting for the deduction. The bracketed term associated with wages is of ambiguous sign: high wages signal high federal-tax revenues, but also high labor costs in housing. The measure also misses differences in home productivity by $1/(1-\lambda_L)$ of their value. Even if we give up on measuring the value of home productivity, the value of the remaining amenities is still biased by $\hat{A}_Y^j$: $\hat{\Omega}^j - s_y\hat{A}_Y^j = \hat{Q}^j + s_x\hat{A}_X^j - [\lambda_L/(1-\lambda_L)]s_y\hat{A}_Y^j$.

[22]Rearranging the zero-profit condition for home-good producers (1c) demonstrates how land rents may be inferred from housing costs, notwithstanding unobserved productivity:

$$\hat{r}^j = \frac{1}{\phi_L}\left(\hat{p}^j - \phi_N\hat{w}^j\right) + \frac{1}{\phi_L}\hat{A}_Y^j$$

This follows Muth (1969), except for the inclusion of unobserved home productivity.

[23]To aid intuition, consider two extreme cases. In the first case, traded goods are made without land, i.e. $\theta_L = 0$. Then, trade productivity is proportional the wage level, $\hat{A}_X^j = \theta_N\hat{w}^j$. This may be a reasonable approximation if θ_L is small, but not if the variation in $\hat{r}^j$ is much larger than $\hat{w}^j$. In the second case, the cost shares in both sectors are the same, i.e. $\theta_L = \phi_L$, and $\theta_N = \phi_N$. Then,$\hat{A}_X^j - \hat{A}_Y^j = \hat{p}^j$ as the input costs are the same in each sector: home-good prices may be used to infer input costs in tradables only insofar as home productivity remains constant.

7.2 Incorporating Population Data

Without land-value data, researchers can look to other data sources to deal with nontraded production. Fortunately, data on local population levels are as common as land values are rare. The intuition behind using population data is that cities that are efficient in providing nontraded goods should be able to support a larger population than cities that are not as efficient, but otherwise equal.

Combining Equation (1a) and the analog of Equation (6b) for population yields the following expression, which says that "excess population" (or density) not explained by quality-of-life, on the left, must be explained by either trade or home productivity, on the right:

$$\hat{N}^j - \varepsilon_{\psi}^{N,Q} \underbrace{[s_y \hat{p}^j - s_w(1-\tau)\hat{w}^j + \psi \hat{N}^j]}_{\hat{Q}^j} = \varepsilon_{\psi}^{N,A_X} \hat{A}_X^j + \varepsilon_{\psi}^{N,A_Y} \hat{A}_Y^j. \tag{14}$$

While immobility appears to complicate this equation, it actually simplifies to

$$\hat{N}^j - \varepsilon_{0}^{N,Q} \underbrace{[s_y \hat{p}^j - s_w(1-\tau)\hat{w}^j]}_{\hat{Q}_0^j} = \varepsilon_{0}^{N,A_X} \hat{A}_X^j + \varepsilon_{0}^{N,A_Y} \hat{A}_Y^j. \tag{15}$$

which is independent of ψ. Equations (12) and (15) are exactly identified, so that the inferred amenities *perfectly predict* population. Inverting this system, as we show in Appendix A.3, allows A_X^j and A_Y^j to be inferred separately from wage, price, and population data. The total value differential, $\hat{\Omega}^j$, is then composed of the sum $s_x \hat{A}_X^j + s_y \hat{A}_Y^j$ from this calculation, plus ${\hat{Q}_0}^j$ inferred from prices and wages, and the immobility term $\psi \hat{N}^j$

The difficulty of using this procedure is that it depends on population elasticities, which are not known as well as the simple cost, expenditure, and tax parameters listed in Table 1. These reduced-form elasticities depend on more "structural" parameters, including these parameters, as well as those describing immobility and substitution elasticities of substitution and immobility. However, Albouy and Stuart (2015) do make a case for certain numerical values of these parameters appear to explain local labor and housing supply elasticities, and in particular, population density differences across metro area. We use these values below.[24]

[24]Long-run densities do appear to be consistent with the assumption of perfect mobility, $\psi = 0$, which appears sensible. Many researchers simply assume Cobb-Douglas production, which implies large reduced-form elasticities. For comparison we take Glaeser and Gottlieb (2009). We note four differences with our model. First, while we assume income is rebated back to workers, they assume it accrues to absentee owners. In a general equilibrium model, this creates some ambiguity around the share spent on nontraded goods the value of amenities to households relative to firms. Second, they assume that traded and nontraded (housing) sector each has an "immobile capital" input, similar to land, that cannot move between sectors within a city. This creates diminishing returns in nominal wages when the supply of (residential) land grows. See Appendix C.3 for detail on our re-parameterization of their model.

7.3 Inferring Benefits to Households and Firms by Different models.

We now summarize the general problem of inferring the benefits of public improvements to households and firms using parameterized simulations in Table 3

Empty cells imply that the data presented in the column are not used or are unavailable in the methodology, and therefore do not convey information about whether there was an amenity improvement of that type. For instance, neither land rents nor population are needed to estimate quality of life, assuming preferences are homogeneous, since urban households are assumed to consume land only indirectly.

If land data are available, then inference works ideally. In panel A, trade and home productivity are inferred from cost-share weighted input costs; with home goods, these costs are considered relative to the output price. The total value of amenities involves examining land values in proportion to its income share of 10 percent. Wages and home-good prices serve only to measure the value of tax externalities from higher wages, minus deductions for home goods.

Without land data, the numbers in panel B show how to infer amenity values, assuming home productivity is the same everywhere, i.e., $\hat{A}_Y^j = 0$. Housing costs help to infer trade productivity, although the measure relies mostly on wages, with a slightly smaller coefficient than in A. The total value of amenities now depends strongly on housing values and only weakly on wages: this occurs from competing tax and housing cost effects almost canceling out.

Haughwout's inference technique, shown in panel C, is similar to panel B in its limitations, but more restrictive by equating housing with land. It is like the model of panel A in Table 2, but using Haughwout's values in Table 1. On quality of life, it shows a much weaker effect of prices and stronger negative effect of wages. Trade productivity also depends more on wages, mainly as the traded sector is a larger share of output. The total value depends only on housing prices, and weakly, as they are being taken literally as land values. Here wages serve only to identify benefits to households as opposed to firms.

The results in panel D present how to use population data to identify and refine estimates of both trade productivity and home productivity, using the formula solved for in Appendix A.3. Trade productivity uses almost no weight on housing costs, using population primarily to identify land values. Home productivity estimates rely even more on population numbers, and negatively on home values, much as in the ideal case. Total value figures rely strongly on the wage and population, and essentially not at all on housing prices. The shift from relying exclusively on housing prices to not at all, when population numbers are available, represents a dramatic shift from the current literature. Conditioning on wages and population, housing values serve almost exclusively to identify quality-of-life amenities from dis-amenities in home production.

Results in panel E present results from raising the immobility parameter ψ to 0.05. Since the mobility parameters does not affect the productivity estimates, this just raises the quality-of-life

Table 3: Inferred Amenity Values from Prices and Population

		Attribute increase from a one log point change in			
	Price or quantity:	Land value $\hat{r}$	Housing cost $\hat{p}$	Wage $\hat{w}$	Pop-ulation $\hat{N}$
Panel A: Chosen Price Model: Ideal Data					
Household QOL	$\hat{Q}^j$		0.325	-0.499	
Firm: Trade prod.	$s_x \hat{A}_X^j$	0.016		0.550	
Firm: Home prod.	$s_y \hat{A}_Y^j$	0.083	-0.36	0.231	
Total value	$\hat{\Omega}^j$	0.100	-0.035	0.280	
Panel B: Chosen Price Model: Housing Costs and Wages Only (A^j **constant)**					
Household QOL	$\hat{Q}^j$		0.325	-0.499	
Firm: Trade prod.	$s_x \hat{A}_X^j$		0.069	0.506	
Firm: Home prod.	$s_y \hat{A}_Y^j$				
Total value	$\hat{\Omega}^j$		0.394	0.007	
Panel C: Haughwout (2002) Price Model: Housing Costs and Wages Only					
Household QOL	$\hat{Q}^j$		0.124	-0.75	
Firm: Trad prod.	$s_x \hat{A}_X^j$		0.048	0.750	
Firm: Home prod.	$s_y \hat{A}_Y^j$				
Total value	$\hat{\Omega}^j$		0.172	0.00	
Panel D: Chosen Price and Population Model, Perfect Mobility ($\psi = 0$)					
Household QOL	$\hat{Q}^j$		0.325	-0.499	
Firm: Trade prod.	$s_x \hat{A}_X^j$		0.005	0.558	0.022
Firm: Home prod.	$s_y \hat{A}_Y^j$		-0.333	0.274	0.115
Total value	$\hat{\Omega}^j$		-0.003	0.333	0.138
Panel E: Chosen Price and Population Model, Imperfect Mobility ($\psi = 0.05$)					
Household QOL	$\hat{Q}^j$		0.325	-0.499	0.050
Firm: Trade prod.	$s_x \hat{A}_X^j$		0.005	0.558	0.022
Firm: Home prod.	$s_y \hat{A}_Y^j$		-0.333	0.274	0.115
Total value	$\hat{\Omega}^j$		-0.003	0.333	0.188

NOTE: Panels A, B, D, and E use chosen values in Table 1. Panel C uses values from Haughwout column.

and total-value estimates by ψ times the population change, $\hat{N}^j$.

8 The Value of Urban Infrastructure

Haughwout (2002) estimates the marginal benefit of public capital investments using housing-cost and wage data from 1971 to 1992 for a sample of 36 large US cities. The public capital stock for these cities includes roads, parks, sewer systems, and public buildings. When valued by Haughwout and Inman's (1996) perpetual inventory technique, this infrastructure had a depreciated value of $428 billion in the year 2000. Financing is taken as external (i.e., state and federal). However, if financing is internal, then the implied values would be larger.

In the next subsection, we reconsider the value of infrastructure using Haughwout's estimates of how this infrastructure changes wages and housing prices, based on our general model. We then present estimates based on a similar panel covering more cities and years, using similar pooled ordinary least squares (OLS) estimates and those with city and year indicators, or "fixed effects" (FE). [25]

8.1 Reinterpreting Haughwout's Estimates

Haughwout follows the standard Roback model that equates housing values with land values. Thus, he uses a housing-value differential as a land-value differential, yet he multiplies it by the average value of urban land to estimate the effect of public infrastructure on land values. This reduction of the zero-profit condition (1c) to $\hat{p}^j = \hat{r}^j$ assumes that home goods are not produced — as in Haughwout and Inman (2001) — and leaves out wage multiplier effects. It also does not account for federal tax effects.

The original Haughwout (2002) estimates of the effect of public infrastructure on housing costs and wages are presented in columns 1 and 2 of Table 4. The regression estimates in panel A are based on repeated cross-sections that control for natural amenities, including climate, and local taxes and services; the less precise estimates in panel B control for state and year effects. The inferred values of a dollar of public infrastructure are in column 5, with columns 3 and 4 separating the values for households and firms. In panel A, public infrastructure is valued at 60 cents per dollar of cost, with 39 cents going to households and 21 cents going to firms. The values in panel B is only 30 cents on the dollar, representing a 39-cent gain to households and a 9-cent

[25] While space precludes offering a full literature review, we noted that Gramlich (1994) provides. Aschauer (1989) present income-based estimates of infrastructure which are disputed by Holtz-Eakin (1994). Fernald (1999) and Duranton and Turner (2012) consider other methods to consider the growth impacts of highways in particular. See Glaeser and Gottlieb (2008) fora larger discussion of the impact of local investments.

Table 4: The Value of Public Infrastructure Based on the Original Haughwout Estimates

Effect of a 1 std. dev. increase in public infrastructure on log			Value per dollar of infrastructure			
Housing cost	Wages	Valuation	Household QOL	Firm tr. prod.	Total value	Federal revenue
(1)	(2)	procedure	(3)	(4)	(5)	(6)
Panel A: Pooled Estimates with Controls						
		Haughwout	0.39	0.21	0.60	
0.23	0.003		(0.06)	(0.04)	(0.07)	
(0.02)	(0.002)					
		Revised	1.09	0.26	1.35	-0.11
			(0.18)	(0.04)	(0.18)	(0.02)
Panel B: Panel Estimates with City and Year Fixed Effects						
		Haughwout	0.39	-0.09	0.30	
0.12	-0.016		(0.10)	(0.10)	(0.15)	
(0.05)	(0.009)					
		Revised	0.70	0.00	0.70	-0.13
			(0.31)	(0.21)	(0.29)	(0.06)

Source: Estimates taken from rows 2 and 4 of Table 4 in Haughwout (2002), covering 33 cities from 1974 to 1992. Haughwout valuation based on Panel C of Table 3; Revised from panel B. Per-dollar values obtained by multiplying values by 14.93, the ratio of the present value of income flows to the valued infrastructure (with a std. dev of $ 4,640 million in 1997$).

loss to firms.[26]

The revised estimates of the value of public infrastructure shown in each panel, use the same regression estimates, but recalculate the values using the coefficients in panel B of Table 3, as opposed to panel C. The revised values are considerably larger: in panel A the marginal value of a dollar of public infrastructure is $1.35, which may passes a cost-benefit test provided the marginal cost of public funds is sufficiently low. In panel B, the estimate is $0.70 — all to households — still falling short of even the $1.00 benchmark, albeit it cannot be ruled out statistically. Endogeneity concerns aside, the "Iron Law of Econometrics" (Hausman 2001) implies that estimates are likely highly attenuated given the errors in measuring infrastructure. Furthermore, they ignore spillover effects to suburban residents.[27]

8.2 Estimates from a Longer, Wider, and Deeper Panel of Cities

In the pursuit of updating Haughwout's estimates, we construct a longer panel of infrastructure stocks from 1974 to 2011, doubling the sample length. We increase the number of central cities in

[26] Our parameterization of the Haughwout (2002) model is explained in Appendix C.2.

[27] This effect is especially true locally, as local wages do not rise. Also note that because home productivity effects are unobserved, it is hard to know how these bias the estimates. If public infrastructure improves home productivity, which seems likely, then the revised estimates are too low.

the sample from 31 to 55, and include New York City. We also expand the range of data sources used to estimate housing-cost and wage differences to include not only the American Housing Survey (AHS), but also the Current Population Survey (CPS), and the Census (Decennial in 1980, 1990, and 2000; American Community Survey in 2005 and 2011) from Ruggles et al. (2004). One manner in which we differ from Haughwout is that we combine benefits to renting households to owner-occupied ones, merging the two in a "housing cost" index, described in Appendix D.

We estimate the same specifications as Haughwout, focusing on his full elasticity (log-log) model. This specification uses total infrastructure without normalizing for population size.[28] One challenge we face is that we are unable to replicate Haughwout's findings exactly. Furthermore, his standard errors do not adjust for clustering effects by city. Our calculations — based on our own data — suggest they may have been too small.[29]

Our wage and housing-cost estimates presented in Table 8.2 are rather different from those in 4, The wage estimates are considerably greater: 0.21 in the pooled OLS, as opposed to 0.003; 0.77 with FE, as opposed to -0.16. This may have to do with the much higher quality of wage data in the CPS, ACS and the Census, relative to the AHS. Our housing-cost effects are slightly more modest: 0.12 vs 0.23 in the pooled OLS; 0.11 vs 0.12 with city and year effects.

Our estimates are less precise, although that appears to be due to the clustering of the standard errors, which cluster not only by state, but also rather conservatively by year. These standard errors are roughly double the size of un-clustered, albeit robust, ones. Still, all of the wage and housing cost estimates are statistically different from zero at a size of 6 percent.

The value of public infrastructure to households and firms is again inferred from the coefficients in Panel B of Table 3. In the pooled OLS, the implied benefits to households are a bit weaker; for firms they are modest, yet larger than before. With fixed effects, only the benefits to firms are detected, but they are considerable. Furthermore, federal taxes now recoup almost half of infrastructure's total value. On the whole, the valuations in A and B are more modest than the reinterpreted estimates in Table 4, yet they cannot rule out the hypothesis that infrastructure investments generate a dollar of benefits for each dollar of cost.

8.3 Incorporating Population Changes and Home-Good Production

As mentioned earlier, estimates based on prices alone ignore information from population changes. These may be particularly informative about home productivity changes, and if households have

[28] We consider alternative specifications using the transformation $g = G^{\alpha}$, where $\alpha \in [0, 1]$ is a generalized congestion parameter. We find, like Haughwout, that values of $\alpha > 0$ lead to worse fits of the data most of the time.

[29] We did consider several variables that might serve as instruments for infrastructure investments, primarily political ones such as those from Atlas et al. (1995) and Albouy (2013) None of our candidate variables proved to be sufficiently relevant when trying to accommodate for stocks of infrastructure. See Cellini, Ferriera, and Rothstein (2010) for a more successful attempt for school infrastructure.

Table 5: The Value of Public Infrastructure Based on New Price Estimates

Effect of a 1 std. dev. increase in public infrastructure on log			Value per dollar of infrastructure			
Housing cost	Wages	Valuation	Household QOL	Firm tr. prod.	Total value	Federal revenue
(1)	(2)	procedure	(3)	(4)	(5)	(6)
Panel A: Pooled OLS Estimates with Controls						
0.12	0.021	Revised	0.44	0.28	0.73	0.02
(0.03)	(0.007)		(0.17)	(0.06)	(0.19)	(0.03)
Panel B: Panel Estimates with City and Year Fixed Effects						
0.11	0.077	Revised	-0.07	0.69	0.62	0.27
(0.06)	(0.023)		(0.32)	(0.18)	(0.33)	(0.10)

Source: Housing-cost and wage estimates from years 1974 to 2011 for 55 cities combining AHS, CPS, Census, and ACS data. Standard errors are clustered by city and year. See Appendix D for more.

some immobility, quality-of-life changes. This valuation procedures draws on panels 4 and 5 of Table 3 Recall, this method generally infers higher productivity and overall value from wage and population changes; conditional on population, high housing costs no longer signal total value, just in what form it takes.[30]

The population numbers may be the most difficult to interpret as causal, since endogeneity concerns are that investments may be based on predicted population patterns. Nevertheless, they do appear to be positively related with infrastructure. The pooled OLS numbers imply a population elasticity of 0.72; the FE, just 0.39. Both are positive and statistically and economically significant.

The results for welfare now are considerably more positive. Because of the large population effect, the pooled OLS estimates suggest a large benefit for firm producing nontraded goods. The net result is a $1.58 return per dollar spent, almost half through home productivity. This result underscores the need to account for nontraded goods, and how misleading results may be if those factors are ignored. The FE results show a somewhat smaller valuation tilted towards higher home productivity.

With moderate immobility, the case for quality-of-life benefits also rises. With a $\psi > 0$, existing residents have not seen the pecuniary and non-pecuniary benefits of infrastructure completely offset by housing costs. The resulting valuation more comfortably passes the cost-benefit test, even in cases where the the marginal cost of public funds is considerably above one.

While our estimates are far from conclusive, at a minimum this illustration reveals how important valuation methods are; moreover, that they are sensitive to modeling assumptions. Even the

[30]When considering changes in population, it is important to note that in the early part of the sample, most central cities saw a decline in population. In the latter part of the sample, a number of cities saw a considerable resurgence in population, particularly cities in the "sun belt" as opposed to the "rust belt."

Table 6: The Value of Public Infrastructure with Price and Population Estimates

Effect of a 1 std. dev. increase in public Infrastructure on log				Value per dollar of infrastructure			
Housing cost	Wages	Population	Mobility assumption	Household QOL	Firm tr. prod	Firm Home pr.	Total value
(1)	(2)	(3)		(4)	(5)	(6)	(7)
Panel A: Pooled OLS Estimates with Controls							
			Perfect	0.44	0.42	0.71	1.58
0.12	0.021	0.72	$\psi = 0.00$	(0.17)	(0.06)	(0.18)	(0.08)
(0.03)	(0.007)	(0.04)					
			Imperfect	0.98	0.42	0.71	2.12
			$\psi = 0.05$	(0.17)	(0.06)	(0.18)	(0.09)
Panel B: Panel Estimates with City and Year Effects							
			Perfect	-0.07	0.77	0.46	1.17
0.11	0.077	0.39	$\psi = 0.00$	(0.32)	(0.19)	(0.31)	(0.15)
(0.06)	(0.023)	(0.04)					
			Imperfect	0.22	0.77	0.46	1.46
			$\psi = 0.05$	(0.33)	(0.19)	(0.31)	(0.15)

Population estimates for central cities. See 8.2 for details

best estimates of the impact of public infrastructure on prices and population, if not interpreted properly, could lead to misleading results. For a topic as important as public investment, this has important policy implications.[31]

9 Conclusion

This paper highlights how the standard urban model of wages and housing values may be inadequate for valuing of public goods. Valuations can be made more accurate by accounting for nontraded production and federal taxes. In practice, these additions more than double our value of public infrastructure based on previous estimates. Valuations may be improved further by accounting for population changes, particularly if mobility is imperfect. Our appraisal of infrastructure is much greater when population changes are accounted for. Fortunately, data on wages, housing values, and population should be available in many instances to evaluate local projects.

It is remarkable how wages, housing values, land values, and population numbers convey different but complementary information. Moreover, the conventional wisdom that the full value of public goods is captured in land values, e.g., Brueckner (1983) may be misguided. Land values do not capture federal tax externalities, nor the net benefits received by local residents when mo-

[31] Appendix D also considers results around commuting times, spillover effects to suburbs and other metro areas, and the sensitivity of results to large cities

bility is imperfect. Simulations suggest that these housing costs may serve mainly to distinguish improvements in quality-of-life reductions in nontraded productivity. Thus, if housing prices in a city rise while its population and incomes remain constant, this indicates that improvements in quality of life are being negated by diminishing productivity in the housing sector.

Finally, this paper sheds light on the actual value of infrastructure. The estimates here find that housing costs, wages, and populations all increase with infrastructure investments. While the estimates are not conclusive, the positive results for housing do reinforce Haughwout's original estimates. The stronger positive wage estimates based on CPS data, combined with the novel population estimates, evoke the older literature that focused on the contribution of infrastructure to output. The inferred values indicate that infrastructure investments may indeed be worthwhile for central cities, even without spillovers to the suburbs. Some of these benefits may accrue directly by local residents because of imperfect mobility. Furthermore, infrastructure investments seem to have substantial fiscal externalities, which help to justify federal subsidies for infrastructure. Lastly, infrastructure services may help to keep housing costs from rising, even as it engenders urban population growth.

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Appendix

A Additional Proofs and Details

A.1 Derivation of Tax Differential

With the definition of the tax deduction, the mobility condition (1a) becomes:

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

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

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

substituting these conditions into the tax differential formula, solving recursively:

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

The tax multiplier now includes a second mechanism: higher prices lead to greater deductions, lowering taxes, and increasing prices further. It also softens the wage component of the multiplier, by softening higher living costs. Thus, the tax multiplier is increasing in δ, and attains a maximum value of $1/(1-\tau')$ when $\delta = 1$. Substituting in $\hat{w}^j_*$ and $\hat{p}^j_*$ from (2b) and (2c) with $\tau' = 0$, gives the tax differential in Equation (4) in terms of the attributes.

A.2 State Taxes

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

$$\frac{d\tau^j}{m} = \tau'\left(s_w\hat{w}^j - \delta\tau' s_y\hat{p}^j\right) + \tau'_S[s_w(\hat{w}^j - \hat{w}^S) - \delta_S s_y(\hat{p}^j - \hat{p}^S)], \tag{A.1}$$

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

A.3 Inferring Trade and Home Productivity with Population Data

As derived in Albouy and Stuart (2015), solving Equations (12) and (15) identifies each productivity from observable differentials $\hat{N}_*^j$, $\hat{w}^j$, and $\hat{p}^j$:

$$\hat{A}_X^j = \frac{\theta_L[\hat{N}^j - \varepsilon^{N,Q}(s_y p^j - s_w(1-\tau)w^j)] + \phi_L \varepsilon^{N,A_Y}[\frac{\theta_L}{\phi_L}p^j + (\theta_N - \phi_N \frac{\theta_L}{\phi_L})w^j]}{\theta_L \varepsilon^{N,A_X} + \phi_L \varepsilon^{N,AY}} \tag{A.2a}$$

$$\hat{A}_Y^j = \frac{\phi_L[\hat{N}^j - \varepsilon^{N,Q}(s_y p^j - s_w(1-\tau)w^j)] - \phi_L \varepsilon^{N,A_X}[\frac{\theta_L}{\phi_L}p^j + (\theta_N - \phi_N \frac{\theta_L}{\phi_L})w^j]}{\theta_L \varepsilon^{N,A_X} + \phi_L \varepsilon^{N,AY}} \tag{A.2b}$$

High excess population and high inferred costs imply high trade productivity. Low inferred costs and high excess population imply high home productivity, with the latter effect stronger as $\phi_L > \theta_L$.

B Theoretical Extensions

B.1 Multiple Household Types

For simplicity, ignore federal taxes and assume there are two types of fully mobile households, referred to as "a" and "b." The most interesting case is when some members of each type live in every city. The mobility conditions for each type are

$$e_a(p, w_a, u; Q_a) = 0$$
$$e_b(p, w_b, u; Q_b) = 0$$

I generalize the two zero-profit conditions with unit-cost functions that have factor-specific productivity components.

$$c_X(w_a/A_{Xa}, w_b/A_{Xb}, r/A_{XL}, \bar{\imath}/A_{XL}) = 1$$
$$c_Y(w_a/A_{Ya}, w_b/A_{Yb}, r/A_{YL}, \bar{\imath}/A_{YK}) = p$$

The terms A_{Xa} and A_{Xb} give the relative productivity of each worker type in the city. Log-linearizing these equations:

$$s_{ya}\hat{p} - s_{wa}\hat{w}_a = \hat{Q}_a$$
$$s_{yb}\hat{p} - s_{wb}\hat{w}_b = \hat{Q}_b$$
$$\theta_{Na}\hat{w}_a + \theta_{Nb}\hat{w}_b + \theta_L\hat{r} = \hat{A}_X$$
$$\phi_{Na}\hat{w}_a + \phi_{Nb}\hat{w}_b + \phi_L\hat{r} = \hat{A}_Y$$

where θ denotes the cost-shares of each factor, and $\theta_a\hat{A}_{Xa} + \theta_b\hat{A}_{Xb} + \theta_L\hat{A}_{XL} + \theta_K\hat{A}_{XK} \equiv \hat{A}_X$ and $\phi_a\hat{A}_{Ya} + \phi_b\hat{A}_{Yb} + \phi_L\hat{A}_{YL} + \phi_K\hat{A}_{YK} \equiv \hat{A}_Y$. The additivity of these effects proves that differences in productivity have the same first-order effects on prices regardless of the factor they augment directly when weighted by the cost-share of that factor.

Let the share of total income accruing to type a worker be $\mu_a = N_a m_a/(N_a m_a + N_b m_b)$, with the other share $\mu_b = 1 - \mu_a$, and define the following income-weighted averages

$$\begin{aligned}
&s_y \equiv \mu_a s_{ya} + \mu_b s_{yb},\ s_x \equiv 1 - s_y,\ \varsigma_y \equiv \mu_a s_{ya}/s_y \\
&\hat{Q} \equiv \mu_a \hat{Q}_a + \mu_b \hat{Q}_b,\ s_w \equiv \mu_a s_{wa} + \mu_b s_{wb},\ \hat{w} \equiv \mu_a \frac{s_{wa}}{s_w}\hat{w}_a + \mu_b \frac{s_{wb}}{s_w}\hat{w}_b \\
&\lambda_a = \frac{s_x\theta_{Na}}{s_x\theta_{Na} + s_y\phi_{Na}},\ \lambda_b = \frac{s_x\theta_{Nb}}{s_x\theta_{Nb} + s_y\phi_{Nb}},\ \lambda_N \equiv \frac{1}{s_y}\left[s_{ya}\mu_a\lambda_a + s_{yb}\mu_b\lambda_b\right]
\end{aligned}$$

Then it is possible to show that the following capitalization formulas hold.

$$\begin{aligned}
s_R\hat{r} &= \hat{Q} + s_x\hat{A}_X + s_y\hat{A}_Y \\
s_w\hat{w} &= -\frac{\lambda_L}{\lambda_N}\hat{Q} + \frac{1-\lambda_L}{\lambda_N}s_x\hat{A}_X - \frac{\lambda_L}{\lambda_N}s_y\hat{A}_Y + \left[\left(\frac{\lambda_a}{\lambda_N} - 1\right)\mu_a\hat{Q}_a + \left(\frac{\lambda_b}{\lambda_N} - 1\right)\mu_b\hat{Q}_b\right] \\
s_y\hat{p} &= \frac{\lambda_N - \lambda_L}{\lambda_N}\hat{Q} + \frac{1-\lambda_L}{\lambda_N}s_x\hat{A}_X - \frac{\lambda_L}{\lambda_N}s_y\hat{A}_Y + \left[\left(\frac{\lambda_a}{\lambda_N} - 1\right)\mu_a\hat{Q}_a + \left(\frac{\lambda_b}{\lambda_N} - 1\right)\mu_b\hat{Q}_b\right]
\end{aligned}$$

Except for the terms in square brackets, ”[]”, these terms are otherwise identical to equations (2) without taxes. The bracketed term explains that wage and housing-cost differences increase in the quality-of-life of the labor type that is relatively more represented in the traded-good sector, or decreasing in the quality-of-life of the labor type more represented in the home-good sector. The wage of a-types resembles the average wage except that it is lower in places a-types prefer relative to b-types.

$$\left[\frac{s_y}{s_{ya}}\right] s_{wa}\hat{w}_a = -\frac{\lambda_L}{\lambda_N}\hat{Q} + \frac{1-\lambda_L}{\lambda_N}s_x\hat{A}_X - \frac{\lambda_L}{\lambda_N}s_y\hat{A}_Y + \left[\frac{\lambda_b}{\lambda_N}\left(\hat{Q} - \frac{s_y}{s_{ya}}\hat{Q}_a\right)\right]$$

The model assumes that both types of households live in each city. This assumption is easier to maintain if the type of labor they supply are imperfect substitutes in production.

Factor-specific productivity differences do have first-order effects on quantities in the model. For example, in the case where partial elasticities of substitution across factors within sectors are equal, the relative employment of a-types relative to b-types is

$$\hat{N}_a - \hat{N}_b = -\sigma_X\left(\hat{w}_a - \hat{w}_b\right) + \left(\sigma_X - 1\right)\left(\hat{A}_{Xa} - \hat{A}_{Xb}\right)$$

B.2 Multiple Home Goods

Suppose now that there is one type of household but two types of goods, 1 and 2, e.g., housing versus local services. Beeson and Eberts (1989) consider this situation but do not solve for it completely. The four equilibrium conditions, using obvious definitions, are written

$$\begin{aligned} e(p_1, p_2, u)/Q &= m \\ c_X(w, r, \bar{\imath})/A_X &= 1 \\ c_{Y1}(w, r, \bar{\imath})/A_{Y1} &= p_1 \\ c_{Y2}(w, r, \bar{\imath})/A_{Y2} &= p_2 \end{aligned}$$

Log-linearizing these equations produces

$$\begin{aligned} s_{y1}\hat{p}_1 + s_{y2}\hat{p}_2 - s_w\hat{w} &= \hat{Q} \\ \theta_N\hat{w} + \theta_L\hat{r} &= \hat{A}_X \\ \phi_{N1}\hat{w} + \phi_{L1}\hat{r} - \hat{p}_1 &= \hat{A}_{Y1} \\ \phi_{N2}\hat{w} + \phi_{L2}\hat{r} - \hat{p}_2 &= \hat{A}_{Y2} \end{aligned}$$

If we define an aggregate shares, prices, and home productivity appropriately

$$\begin{aligned} s_y \equiv s_{y1} + s_{y2}.\ \phi_L \equiv \frac{s_{y1}}{s_y}\phi_{L1} + \frac{s_{y2}}{s_y}\phi_{L2} \\ \hat{p} \equiv \frac{s_{y1}}{s_y}\hat{p}_1 + \frac{s_{y2}}{s_y}\hat{p}_2,\ \hat{A}_Y \equiv \frac{s_{y1}}{s_y}\hat{A}_{Y1} + \frac{s_{y2}}{s_y}\hat{A}_{Y2}, \end{aligned}$$

then the main results generalize:

$$\begin{aligned} s_R\hat{r} &= \hat{Q} + s_x\hat{A}_X + s_y\hat{A}_Y \\ s_w\hat{w} &= -\frac{\lambda_L}{\lambda_N}\hat{Q} + \frac{1-\lambda_L}{\lambda_N}s_x\hat{A}_X - \frac{\lambda_L}{\lambda_N}s_y\hat{A}_Y \\ s_y\hat{p} &= \frac{\lambda_N - \lambda_L}{\lambda_N}\hat{Q} + \frac{1-\lambda_L}{\lambda_N}s_x\hat{A}_X - \frac{\lambda_L}{\lambda_N}s_y\hat{A}_Y \end{aligned}$$

Now a question is whether using a local price index based on only one home-good price, e.g. the one for residential housing, $\hat{p}_1$, may be biased relative to using a more balanced local price index, $\hat{p}$.[32] Weighted by the relevant total expenditure share, the bias is given by

$$\begin{aligned} s_y(\hat{p}_1 - \hat{p}) = {} & \frac{1}{\lambda_N}\left[\lambda_N\left(1-\lambda_L\right)\left(\phi_{L1}/\phi_L - 1\right) - \lambda_L\left(1-\lambda_N\right)\left(\phi_{N1}/\phi_N - 1\right)\right]\left(\hat{Q} + s_{y2}\hat{A}_{Y2}\right) \\ & + \frac{1-\lambda_L}{\lambda_N}\left[\lambda_N\left(\phi_{L1}/\phi_L - 1\right) + \left(1-\lambda_N\right)\left(\phi_{N1}/\phi_N - 1\right)\right]s_x\hat{A}_X \\ & + \left\{\frac{1}{\lambda_N}\left[\lambda_N\left(1-\lambda_L\right)\left(\phi_{L1}/\phi_L - 1\right) - \lambda_L\left(1-\lambda_N\right)\left(\phi_{N1}/\phi_N - 1\right)\right] - \left[\frac{s_y - s_{y1}}{s_{y1}}\right]\right\}s_{y1}\hat{A}_{Y1} \end{aligned}$$

[32] Without loss of generality, the capitalization into a specific home-good is determined by $s_{y1}\hat{p}_1 = \left(\frac{\lambda_N-\lambda_L}{\lambda_N} - \left[\lambda_{L2} - \lambda_{N2}\frac{\lambda_L}{\lambda_N}\right]\right)\left(\hat{Q} + s_{y2}\hat{A}_{Y2}\right) + \left(\frac{1-\lambda_L}{\lambda_N} - \left[\lambda_{L2} + \lambda_{N2}\frac{1-\lambda_L}{\lambda_N}\right]\right)s_x\hat{A}_X + \left(-\frac{\lambda_L}{\lambda_N} - \left[\lambda_{L2} - \lambda_{N2}\frac{\lambda_L}{\lambda_N}\right]\right)s_{y1}\hat{A}_{Y1}$

If the cost structure of both home goods are the same, i.e., if $\phi_{L1} = \phi_L$ and $\phi_{N1} = \phi_N$, then this collapses to $-(s_y - s_{y1})\hat{A}_{Y1}$, i.e., the price index is only biased up in cities relatively productive in the first home good. When the first home good is more land intensive and less labor intensive than the second, i.e. if $\phi_{L1} > \phi_L$ and $\phi_{N1} < \phi_{N2}$ then an index based on the first home good will more strongly capitalize differences in $\hat{A}_X$. In this case, the first good capitalizes differences in $\hat{Q}$, $\hat{A}_{Y1}$, and $\hat{A}_{Y2}$ more strongly when $(1/\lambda_L - 1)(\phi_{L1}/\phi_L - 1) > (1/\lambda_N - 1)(\phi_{N1}/\phi_N - 1)$. This condition is expected to hold as λ_L is probably much smaller than λ_N. In the extreme case, where the second good has the same factor proportions as the traded good, i.e., $\phi_{L2} = \theta_L$ and $\phi_{N2} = \theta_N$, $\hat{p}_2 = \hat{A}_X - \hat{A}_{Y2}$, its price only capitalizes differences in its own productivity. Most capitalization occurs in the first good.

The distinction between home goods and traded goods is somewhat artificial, as most goods are a mixture of both. The key distinction being how land and labor-intensive the goods are. The broader the definition of home goods, the larger is the effective share s_y, but the closer the cost shares ϕ_L and ϕ_N are to θ_L and θ_N. The capitalization effects on land are unchanged so long as s_R remains the same. The capitalization of Q and A_Y will also be the same, so long as the ratio λ_L/λ_N remains constant. The only substantial change are for A_X in wages and prices: as the definition of home goods expands, $(1 - \lambda_L)/\lambda_N$ gets larger, increasing the capitalization of A_X.

C parameterization

C.1 Chosen Values

The basic parameter values are taken from Albouy (2009, 2016). Perhaps most notable is the income share to wages of 75 percent, taken from Krueger (1999), and the share of income to land of 10 percent. The reduced-form population elasticities are given and explained in Albouy and Stuart (2015), which appear to explain local labor and market and housing supply elasticities, as well as density differences across metro areas. For the immobility parameter, we consider a value of $\psi = 0.05$ based loosely on values suggested by Notowidigo's (2013) estimates.

C.2 Haughwout (2002)

To recover the proper weights, we examined the numbers from Haughwout's Table 4 together with some accounting in Note 9. A regression of "land price per acre" on "land price elasticity" produces a value of an acre of land of \$95,672. Similarly, the present-value of a worker's wage is \$145,805 (\$ 8,848 annually at a discount rate of 6 %).

Since the model equates land and housing, $\phi_L = 1, \phi_K = \phi_N = 0$. This leaves three effective parameters free, s_y, θ_L, θ_K. Regressions on willingness to pay are also helpful: for firms, the productivity equation gives 35,010×(land price per acre) + 356,350×(PV wages per worker); for households, the quality of life equation gives 90,050*(land price per acre) - 356,350*(PV wages per worker); in total value, 125,060*(land price per acre). From this we infer that the typical city has 356,350 workers, 35,010 acres devoted to firms, and 90,050 acres devoted to households - a split of 28 to 72 percent. Acreage in an average city is 125,060, or 192.3 square miles, consistent with Haughwout's Table 2. Thus, the total value of land is \$11.96 billion. The results also imply there are 2.85 workers per acre, or 6.51 inhabitants per acre (Table 2). For the entire city, the present value of the wage bill is $51.96 billion.

Thus, the acreage results imply $\lambda_L = 0.280 = (1 - s_y)\theta_L/[s_y + (1 - s_y)\theta_L]$. $\lambda_L = 0.280 = (1 - s_y)\theta_L/s_R$. Each value of the wage bill to land $s_R/s_w = 0.2301$. Putting these two expressions together $s_R = 0.2301 s_w = (1 - s_y)\theta_L/(0.280)$ or $(1 - s_y)\theta_L = 0.064428 s_w$ Finally, this leaves the parameter $s_I = (1 - s_y)\theta_I$ free. Since the chosen value for s_w is 0.75, we benchmark the other parameters to be comparable to Haughwout's figures. Through accounting identities, this then fixes s_I. Thus, the implicit parameterization is then $s_y = 0.124, s_R = 0.173, \theta_L = 0.055, \theta_N = 0.856$. Total income, Nm, is equal to the wage bill $51.96 billion divided by 0.75, or $69.28 billion.

Taking a value $s_w < 0.75$, in the Haughwout calibration leads to a larger total income and larger inferred values in the revised estimates. If the shares of income from land are set equal, so that $s_R = 0.1$ in Haughwout's model, this produces a total income value of $119,965 million, creating revised estimates that are an additional 72 percent higher. To be conservative, and since land values are likely to be a larger source of income in central cities, these higher values are not presented.

C.3 Glaeser and Gottlieb (2009)

The mapping between our model and Glaeser and Gottlieb cannot be perfect, since theirs effectively assumes absentee property and owners and that land in traded and nontraded production are separate. Nevertheless, for this parameterization, we make use of several quotes

- "Labor's share in total output $[1 - \alpha]$ may be two-thirds."
- "We need a parameter estimate for $1 - \beta$, such as 0.3, the average share of household spending on housing."
- "One estimate of the share of nontraded capital, $\alpha\gamma$, in production might be 0.1"
- "approximately 30 percent of housing costs are associated with land and permitting across the United States... This suggests values of 0.4 for labor costs and 0.3 for traded capital."

We assume that the absentee owners consume only traded goods. Thus the effective home good share is $s_y = (2/3)(3/10) = 1/5$. For labor to receive 2/3 of income, we must then set $\theta_N = 11/15$. Then $s_w = (1 - s_y)\theta_N + s_y\phi_N = (4/5)(11/15) + (1/5)(2/5) = 2/3$. The rest then falls into place through accounting identities.[33]

C.4 Rappaport

The parameter values taken from Rappaport (2008a, b) are taken from his baseline calibration in Table 3 of Rappaport (2008b). Note, that our model differs from his in that he models leisure, and integrates quality-of-life, using CES aggregators.

[33] If owners are not truly "absentee," then one option is simply to rebate the money back. Based on the cost shares, labor receives 54 of income: $s'_w = (1 - s'_y)\theta_N + s'_y\phi_N = 0.7(0.733) + 0.3(0.4) = 0.54$. This leaves 46 percent of income from these workers to go to capital (30) and land (16), which must go somewhere by general equilibrium.

Table 7: List of Cities

City	Census and ACS	CPS	AHS National	AHS Metro
Akron, OH	1980, 1990, 2000, 2005-2011	1976-2013	1974-1981, 1983-2011B, 1996	
Albuquerque, NM	1980, 1990, 2000, 2005-2011	1995-2013	1974-1981, 1983-2011B, 1996	
Atlanta, GA	1980, 1990, 2000, 2005-2011	1975-2013	1974-1981, 1983-2011B, 1996	1975, 1978, 1982, 1987, 1991, 1996, 2004
Austin, TX	1980, 1990, 2000, 2005-2012	1985-2013	1974-1981, 1983-2011B, 1996	
Bakersfield, CA	1980, 1990, 2000, 2005-2011	1985-2013	1974-1981, 1983-2011B, 1996	
Baltimore, MD	1980, 1990, 2000, 2005-2012	1975-2013	1974-1981, 1983-2011B, 1996	1976, 1979, 1983, 1987, 1991, 1998, 2007
Baton Rouge, LA	1980, 1990, 2000, 2005-2012	1985-2013	1974-1981, 1983-2011B, 1996	
Birmingham, AL	1980, 1990, 2000, 2005-2011	1976-2013	1974-1981, 1983-2011B, 1996	1976, 1980, 1984, 1988, 1992, 1998
Boston, MA	1980, 1990, 2000, 2005-2012	1975-2013	1974-1981, 1983-2011B, 1996	1974, 1977, 1981, 1985, 1989, 1993, 1998, 2007
Buffalo, NY	1980, 1990, 2000, 2005-2011	1975-2013	1974-1981, 1983, 1996, 2011	1976, 1979, 1984, 1988, 1994, 2002
Chattanooga, TN	1980, 1990, 2000, 2005-2012	1985-2013	1974-1981, 1983-2011B, 1996	
Chicago, IL	1980, 1990, 2000, 2005-2012	1975-2013	1974-1981, 1983-2011B, 1996	1975, 1979, 1983, 1987, 1991
Cincinnati, OH	1980, 1990, 2000, 2005-2011	1975-2013	1974-1981, 1983-2011B, 1996	1975, 1978, 1982, 1986, 1990, 1998
Cleveland, OH	1980, 1990, 2000, 2005-2011	1975-2013	1974-1981, 1983-2011B, 1996	1976, 1979, 1984, 1988, 1992, 1996, 2004
Colorado Springs, CO	1980, 1990, 2000, 2005-2011	1995-2013	1985-2011B, 1996	1975, 1978
Columbus, OH	1980, 1990, 2000, 2005-2012	1976-2013	1974-1981, 1983-2011B, 1996	1975, 1978, 1982, 1987, 1991, 1995, 2002
Corpus Christi, TX	1980, 1990, 2000, 2005-2012	2004-2013	1974-1981, 1983-2011B, 1996	

Dallas, TX	1980, 1990, 2000, 2005-2012	1975-2013	1974-1981, 1983-2011B, 1996	1974, 1977, 1981, 1985, 1989, 1994, 2002
Denver, CO	1980, 1990, 2000, 2005-2012	1975-2013	1974-1981, 1983-2011B, 1996	1976, 1979, 1983, 1986, 1990, 1995, 2004
Des Moines, IA	1980, 1990, 2000, 2005-2012	1985-2013	1974-1981, 1983-2011B, 1996	
Detroit, MI	1980, 1990, 2000, 2005-2011	1975-2013	1974-1981, 1983-2011B, 1996	1974, 1977, 1981, 1985, 1989, 1993
El Paso, TX	1980, 1990, 2000, 2005-2012	2004-2013	1974-1981, 1983-2011B, 1996	
Fort Lauderdale, FL	1980, 1990, 2000, 2005-2011	1985-2003	1974-1981, 1983-2011B, 1996	
Fort Wayne, IN	1980, 1990, 2000, 2005-2012	1985-2013	1974-1981, 1983-2011B, 1996	
Fort Worth, TX	1980, 1990, 2000, 2005-2012	1975-2013	1974-1981, 1983-2011B, 1996	1974, 1977, 1981, 1985, 1989, 1994, 2002
Fresno, CA	1980, 1990, 2000, 2005-2011	1985-2013	1974-1981, 1983-2011B, 1996	
Grand Rapids, MI	1980, 1990, 2000, 2005-2012	1985-2013	1974-1981, 1983-2011B, 1996	1976, 1980
Greensboro, NC	1980, 1990, 2000, 2005-2011	1976-2013	1974-1981, 1983-2011B, 1996	
Houston, TX	1980, 1990, 2000, 2005-2012	1975-2013	1974-1981, 1983-2011B, 1996	1976, 1979, 1983, 1987, 1991, 1998, 2007
Indianapolis, IN	1980, 1990, 2000, 2005-2012	1975-2013	1974-1981, 1983-2011B, 1996	1976, 1980, 1984, 1988, 1992, 1996, 2004
Jacksonville, FL	1980, 1990, 2000, 2005-2012	1985-2013	1974-1981, 1983-2011B, 1996	
Jersey City, NJ	1980, 1990, 2000, 2005-2012	1985-2003, 2005-2013	1974-1981, 1983-2011B, 1996	
Kansas City, MO	1980, 1990, 2000, 2005-2012	1975-2013	1974-1981, 1983-2011B, 1996	1975, 1978, 1982, 1986, 1990, 1995, 2002
Knoxville, TN	1980, 1990, 2000, 2005-2012	1985-2013	1974-1981, 1983-2011B, 1996	
Las Vegas, NV	1980, 1990, 2000, 2005-2011	1985-2003	1974-1981, 1983-2011B, 1996	1976, 1979
Lexington, KY	1980, 2000, 2005-2012	1985-2013	1985-2011B, 1996	
Little Rock, AR	1980, 1990, 2000, 2005-2012	1985-2013	1974-1981, 1983-2011B, 1996	
Los Angeles, CA	1980, 1990, 2000, 2005-2011	1975-2013	1974-1981, 1983-2011B, 1996	1974, 1977, 1980, 1985, 1989

Madison, WI	1980, 1990, 2000, 2005-2011	1985-2013	1974-1981, 1983-2011B, 1996	1975, 1977, 1981
Memphis, TN	1980, 1990, 2000, 2005-2011	1985-2013	1974-1981, 1983-2011B, 1996	1974, 1977, 1980, 1984, 1988, 1992, 1996, 2004
Miami, FL	1980, 1990, 2000, 2005-2011	1975-2013	1974-1981, 1983-2011B, 1996	1975, 1979, 1983, 1986, 1990, 1995, 2002, 2007
Milwaukee, WI	1980, 1990, 2000, 2005-2011	1975-2013	1974-1981, 1983-2011B, 1996	1975, 1979, 1984, 1988, 1994, 2002
Minneapolis, MN	1980, 1990, 2000, 2005-2012	1975-2013	1974-1981, 1983-2011B, 1996	1974, 1977, 1981, 1985, 1989, 1993, 1998, 2007
Mobile, AL	1980, 1990, 2000, 2005-2012	1985-2013	1974-1981, 1983-2011B, 1996	
Modesto, CA	1980, 1990, 2000, 2005-2012	1985-2013	1985-2011B, 1996	
Montgomery, AL	1980, 1990, 2000, 2005-2012	1995-2013	1985-2011B, 1996	
Nashville, TN	1980, 1990, 2000, 2005-2011	1985-2013	1974-1981, 1983-2011B, 1996	
New Orleans, LA	1980, 1990, 2000, 2005-2011	1975-2013	1974-1981, 1983-2011B, 1996	1975, 1978, 1982, 1986, 1990, 1995, 2004, 2009
New York, NY	1980, 1990, 2000, 2005-2012	1975-2013	1974-1981, 1983-2011B, 1996	1976, 1980, 1983, 1987, 1991
Newark, NJ	1980, 1990, 2000, 2005-2012	1975-2003, 2005-2013	1974-1981, 1983-2011B, 1996	1974, 1977, 1981, 1987, 1991
Oakland, CA	1980, 1990, 2000, 2005-2011	1985-2003, 2005-2013	1985-2011B, 1996	1998
Oklahoma City, OK	1980, 1990, 2000, 2005-2012	1985-2013	1974-1981, 1983-2011B, 1996	1976, 1980, 1984, 1988, 1992, 1996, 2004
Omaha, NE	1980, 1990, 2000, 2005-2012	1985-2013	1974-1981, 1983-2011B, 1996	1976, 1979
Orlando, FL	1980, 1990, 2000, 2005-2011	1985-2013	1974-1981, 1983-2011B, 1996	1974, 1977, 1981
Philadelphia, PA	1980, 1990, 2000, 2005-2011	1975-2013	1974-1981, 1983-2011B, 1996	1975, 1978, 1982, 1985, 1989

Phoenix, AZ	1980, 1990, 2000, 2005-2012	1975, 1985-2013	1974-1981, 1983-2011B, 1996	1974, 1977, 1981, 1985, 1989, 1994, 2002
Pittsburgh, PA	1980, 1990, 2000, 2005-2012	1975-2013	1974-1981, 1983-2011B, 1996	1974, 1977, 1981, 1986, 1990, 1995, 2004
Portland, OR	1980, 1990, 2000, 2005-2012	1975-2013	1974-1981, 1983, 1996, 2011	1975, 1979, 1983, 1986, 1990, 1995, 2002
Providence, RI	1980, 1990, 2000, 2005-2011	1985-2013	1974-1981, 1983-2011B, 1996	1976, 1980, 1984, 1988, 1992, 1998
Raleigh, NC	1980, 1990, 2000, 2005-2011	1985-2013	1985-2011B, 1996	1976, 1979
Rochester, NY	1980, 1990, 2000, 2005-2012	1976-2013	1974-1981, 1983-2011B, 1996	1975, 1978, 1982, 1986, 1990, 1998
Rockford, IL	1980, 1990, 2000, 2005-2011	1985-2013	1974-1981, 1983-2007B, 1996, 2011	
Sacramento, CA	1980, 1990, 2000, 2005-2011	1976-2013	1974-1981, 1983-2011B, 1996	1976, 1980, 1983, 1996, 2004
Salt Lake City, UT	1980, 1990, 2000, 2005-2011	1985-2013	1974-1981, 1983-2011B, 1996	1974, 1977, 1980, 1984, 1988, 1992, 1998
San Antonio, TX	1980, 1990, 2000, 2005-2011	1985-2013	1974-1981, 1983-2011B, 1996	1975, 1978, 1982, 1986, 1990, 1995, 2004
San Diego, CA	1980, 1990, 2000, 2005-2012	1975-2013	1974-1981, 1983-2011B, 1996	1975, 1978, 1982, 1987, 1991, 1994, 2002
San Francisco, CA	1980, 1990, 2000, 2005-2011	1975-2013	1974-1981, 1983-2011B, 1996	1975, 1978, 1982, 1985, 1989, 1993, 1998
San Jose, CA	1980, 1990, 2000, 2005-2011	1975-2004	1974-1981, 1983-2011B, 1996	1984, 1988, 1993, 1998
Santa Ana, CA	1980, 1990, 2000, 2005-2012	1975-2003, 2005-2013	1974-1981, 1983-2011B, 1996	1974, 1977, 1981, 1986, 1990, 1994, 2002
Santa Rosa, CA	1980, 1990, 2000, 2005-2011	1985-2013	1985-2011B, 1996	
Seattle, WA	1980, 1990, 2000, 2005-2011	1975-2013	1974-1981, 1983-2011B, 1996	1976, 1979, 1983, 1987, 1991, 1996, 2004, 2009
Shreveport, LA	1980, 1990, 2000, 2005-2012	1995-2013	1974-1981, 1983-2011B, 1996	

Spokane, WA	1980, 1990, 2000, 2005-2011	1985-2013	1974-1981, 1983-2011B, 1996	1974, 1977, 1981
Springfield, MA	1980, 1990, 2000, 2005-2012	1985-2013	1974-1981, 1983-2011B, 1996	1975, 1978
St. Louis, MO	1980, 1990, 2000, 2005-2012	1975-2013	1974-1981, 1983-2011B, 1996	1976, 1980, 1983, 1987, 1991, 1996, 2004
Stockton, CA	1980, 1990, 2000, 2005-2012	1985-2013	1974-1981, 1983-2011B, 1996	
Tacoma, WA	1980, 1990, 2000, 2005-2011	1985-2003	1974-1981, 1983-2011B, 1996	1974, 1977, 1981
Tampa, FL	1980, 1990, 2000, 2005-2011	1975-2013	1974-1981, 1983-2011B, 1996	1985, 1989, 1993, 1998, 2007
Toledo, OH	1980, 1990, 2000, 2005-2011	1985-2013	1974-1981, 1983-2011B, 1996	
Tucson, AZ	1980, 1990, 2000, 2005-2012	1985-2013	1974-1981, 1983-2011B, 1996	
Tulsa, OK	1980, 1990, 2000, 2005-2011	1985-2013	1974-1981, 1983-2011B, 1996	
Virginia Beach, VA	1980, 1990, 2000, 2005-2011	1976-2013	1974-1981, 1983-2011B, 1996	
Wichita, KS	1980, 1990, 2000, 2005-2011	1985-2013	1974-1981, 1983-2011B, 1996	1974, 1977, 1981
Worcester, MA	1980, 1990, 2000, 2005-2011	1985-2013	1974-1981, 1983-2011B, 1996	

1. The data sets are Census of Population and American Community Survey (Census and ACS), Current Population Survey (CPS), American Housing Survey (AHS), National and Metropolitan Surveys. 2. Suffix “B” for year ranges indicates biannual frequency.

D Data and Estimation

Below we discuss issues with the data. With the exception of our instrumental variables strategy, we largely follow Haughwout's (2002) choice of variables wherever possible, and adopt some of his notation as well. However, by collecting data for primary central cities of 84 U.S. metropolitan areas from 1974 to 2011, we vastly expand on the data sets previously used in the literature. In order to construct housing price and wage differentials, we use microdata from the Current Population Survey (CPS), Census of Population, and American Housing Survey (AHS). The city infrastructure variable, our main independent variable, is built using the surveys of government finances 1905-2011. While our data sets include information on the residents and their housing within each central city at each cross section, measures of infrastructure are variable only across cities. For each of the samples, Table D below shows the years each city is available. Table 8 provides detailed information on the variables used from each data set and Table 9 provides some summary statistics.

We use all available data sources to get the most accurate estimates of wage and housing price differentials in the first stage. We estimate housing price differentials for owners and renters using AHS, and Census of Population. Wage differentials are estimated for 17- to 55-year-old heads of households who are fully employed using all three data sets, including CPS. The variables controlled for in the first stage are different, however, we control for data set by year interactions in the second stage to combine our estimates.[34]

D.1 Infrastructure Stocks

The infrastructure measures are created using the surveys of city finances beginning in 1905, and cover multiple types of infrastructure and accounting methods. The replacement value of public capital in place is estimated by applying the perpetual inventory technique to get gross-of-depreciation capital investment flows from 1905 to the present. Similar to Haughwout (2002), we divide capital investment into three different types: 1) construction, 2) land and existing structures (L&ES), and 3) equipment when possible.[35] However, the survey of city finances does not allow us to distinguish among the three types of capital spending. We can identify total investment spending, total construction, total non-construction spending, and general investment spending.

Equipment is only separately identifiable in the unit level data sets, which are currently only available in years 1943–1950, 1987–1992, and 1995–2011. In other years, we will have construction and other capital outlays, which include equipment and land and existing structures. Given that the rates of depreciation for the latter two categories are significantly different, we impute the

[34]See Table 8 for a full list of control variables for each data set.

[35]Construction: Production, additions, replacements, or major structural alterations to fixed works, undertaken either on a contractual basis by private contractors or through a governments own staff. Purchase of Land and Existing Structures: Acquisition of these assets as such by outright purchase; payments on capital lease-purchase agreements or installment purchase contracts; costs associated with eminent domain (including purchase of rights-of-way); and tax or special assessment foreclosure. Purchase of Equipment: Purchase and installation of apparatus, furnishings, motor vehicles, office equipment, and the like having a life expectancy of more than five years. Other Than Construction: This object category represents the combined definitions for "Purchase of Land and Existing Structures" plus "Purchase of Equipment." We construct state and local infrastructure stocks following the perpetual inventory approach as used by Haughwout and Inman (1996) and Haughwout. Similarly, we use depreciation rate of 0.11 for equipment, 0.0182 for construction, and 0.01638 for land and existing structures.

equipment expenditures in other years. We use the average historical shares of equipment, and land and existing structures to create appropriate shares.

The most thorough and accurate capital series we could construct was patched together from several sources and are as follows. For 1987–1992 and 1995–2011, we construct the exact spending by all American city and state governments on different types of capital in different sectors. For 1993–1994, only the total spending and construction numbers are known exactly. The L&ES and equipment numbers were created by taking city-specific historical averages from 1987–1992 and 1995–2011 and applying those to the non-construction spending. For 1951–1986, construction and total spending numbers are exact for all cities; non-construction spending is allocated into L&ES and equipment in the same way that 1993 and 1994 was. The shares of the L&ES and equipment in general expenditures are applied to total expenditure minus construction to get total L&ES and equipment.

Finally, prior to 1951 data are available only for spending in larger cities, starting in 1905.[36]. It is impossible to distinguish between construction, L&ES and equipment for 1943–1950. So the shares of the different types of capital in capital outlays are taken and applied to total expenditure. Finally, we interpolate the missing data points in our data set to impute the capital outlays for the years before each city first appears in our data set.

We also construct a series of state infrastructure stocks via Census Bureau state government investment data. When doing so, we do not double count city infrastructure spending because individual government units complete the Census surveys, and the state government does not report city government spending. Of course, state governments invest in cities, so the local infrastructure stock does not actually represent an estimate of the total infrastructure stock present within a city; the local infrastructure stock is an estimate of the infrastructure stock created by local government. The data are available from years 1942-2011 [37]. Before 1950, the government investment data are available bi-annually. We create an annual investment measure by averaging the adjacent non-missing years.[38]

Figure 1 plots the four central variables — housing-cost differentials, wage-differentials, population, and infrastructure stocks — for our four largest central cities: New York, Los Angeles, Chicago, and Houston.

D.2 Amenity Controls

We use several variables to control for city characteristics not captured by infrastucture. The rate of violent crimes per 100,000 residents, which we call the crime rate, is taken from the Uniform Crime Report (UCR) published by the FBI.[39] For the handful of months with missing data, we use the previous month's value. There are a few cases where the crime rate is implausibly zero, e.g. Oakland 1995, Cincinnati 1997 and Baltimore 1999, which we attribute to missing data.

Haughwout uses both state and city level income and sales tax rates from Significant Features of Fiscal Federalism published by the Advisory Commission on Intergovernmental Relations. Unfor-

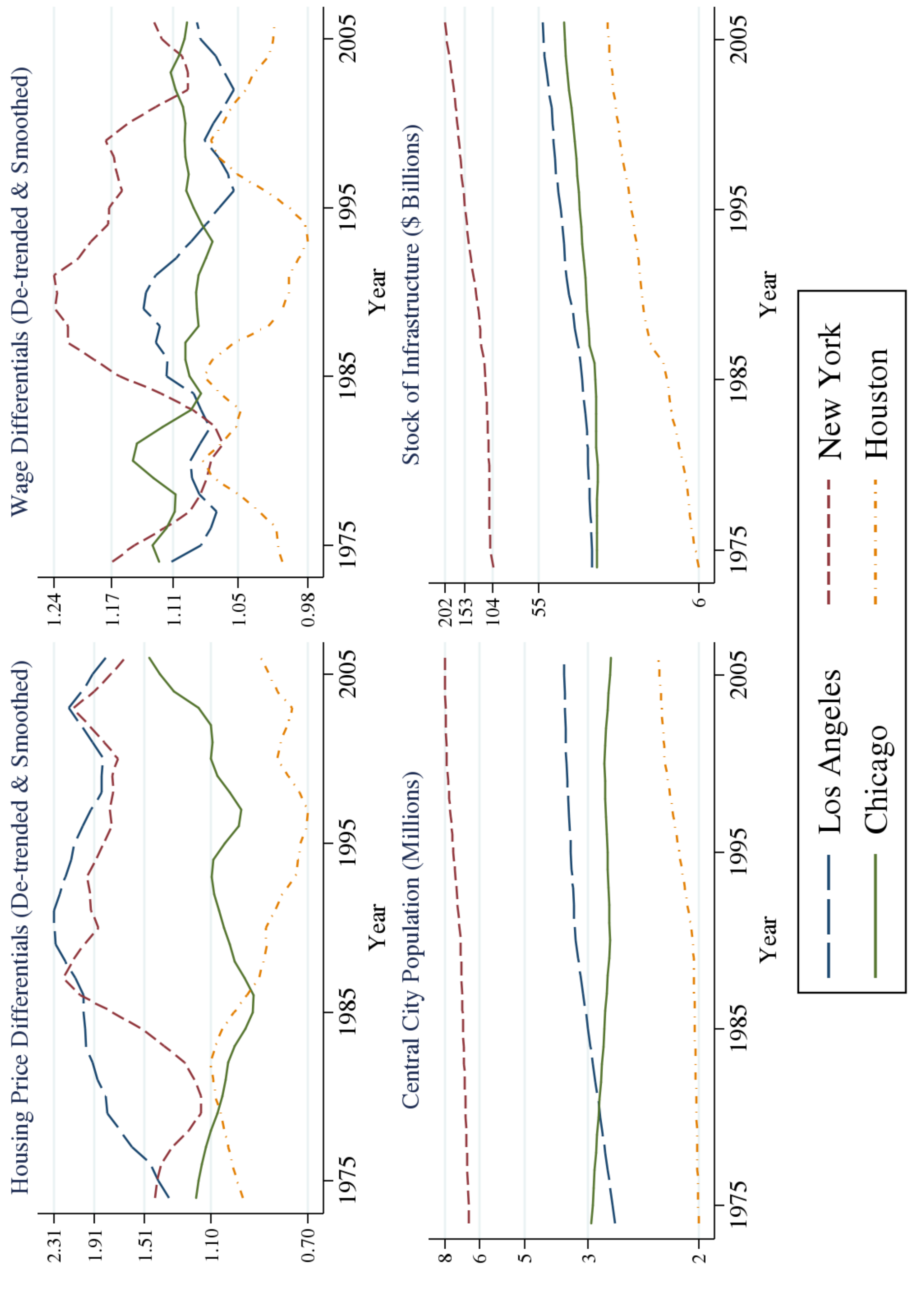
[36] Compendium of Government Finances and Historical Statistics on State and Local Governmental (1905-1951) is not digitized. So, we manually enter the data from PDF files.

[37] Data for Alaska and Hawaii are available beginning in 1959, the year in which they became states. Data for Washington D.C. is available beginning in 1951, the year in which it was first surveyed.

[38] For example, if year t data are missing, we construct $LG_{j,t} = (LG_{j,t-1} + LG_{j,t+1})/2$.

[39] We obtained the UCR series from Justin McCrarys website, http://emlab.berkeley.edu/ jmccrary/UCR/.

Figure 1: Price, Wage, Population and Infrastructure Values for the Four Largest Central Cities



tunately, this Commission is now defunct. We are not aware of a centralized database of city-level income and sales taxes. As a result, we do not have city level income or sales tax rates. We have data on the top state income tax rate, bottom state income tax rate, and state sales tax rate.[40]

Three variables that describe cities climate amenities are mean annual heating days, mean annual cooling days and mean annual rainfall. We obtained these data from the National Climatic Data Center and smoothed out effects of weather anomalies by using 10-year averages. Data for both 1980–1989 and 1990–1999 are available.

We obtain city level student to full-time teacher equivalent ratios from the Department of Education Common Core of Data. There are some issues with this data. First, several years are missing: 1981, 1979, 1977, 1976. Second, there are mistakes in some of the older files, as some pupil-teacher rates are unreasonably high or low. To account for this, we drop the outliers and use MA-3 smoothing and interpolation to impute these cases. Finally, for years 1973-1975, only the number of full-time teachers and part-time teachers was published. Hence, we assume that a part-time teacher is equivalent to 0.5 of a full-time teacher in those surveys and calculate the full-time teacher equivalent ratio by hand.

Table 8: Descriptions, Levels of Variation, and Sources for Key Variables

Dependent variables: vary by house (i), region (j) and time (t).
Source: American Housing Survey, Decennial Census. 1974-2011
1. HV, House and land value, continuous.
Source: American Housing Survey, Decennial Census, and Consumer Population Survey, 1974-2011
2. W, Annual wages and salaries, head of household, continuous.

HQ vector: house quality controls, vary by house (i), region (j) and time (t).
Source (a): American Housing Survey, 1974-2011
1. No. of bathrooms: polychotomous, 1, 1.5, 2, 2.51
2. No. of bedrooms: polychotomous, 1, 2, 3, 4, 5, 61
3. Basement: dichotomous, 0-1
4. Condominium: dichotomous, 0-1
5. Central air conditioning: dichotomous, 0-1
6. Detached unit: dichotomous, 0-1
7. Garage present: dichotomous, 0-1 [41]
8. Age of house: continuous
9. No. of other rooms: continuous (=total rooms-bedrooms-bathrooms)
10. Public sewerage hookup: dichotomous, 0-1
11. Heating equipment: polychotomous (warm air, electric, steam, other)
12. House quality rating: polychotomous (excellent, good, fair, poor)

[40] We thank Nathan Seegert for providing us with this data, which he compiled from The Book of the States and other sources, as described in Seegert (2012).

[41] Age of the house is computed as a function of when the house is reported to have been built. Those data are reported in interval form. The midpoint of the interval is used as the year of construction. When bottom coding is relevant (for old homes), the house is assumed to have been built during the bottom code year.

Table 8: Descriptions, Levels of Variation, and Sources for Key Variables

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13. Central city indicator: dichotomous, 0-1

Source (b): Decennial Census and American Community Survey, 1980, 1990, 2000, and 2005-2011
1. No. of rooms: polychotomous, N/A, 1, 2, ... , 9, and 10+
2. Condominium: dichotomous, 0-1
3. Number of units in structure: polychotomous, Mobile home or trailer, 2 family building, 3-4 family building, 5-9 family building, One unit- unspecified type, 10+ units in structure (CPS)
4. Heating equipment: polychotomous (warm air, electric, steam, other)
5. Commercial use: dichotomous, 0-1
6. Acreage: polychotomous, N/A, less than 1, 1-9, and 10+ acres
7. Built year: polychotomous, Before 1940, 1940-49, 1950-49, ..., 2000+
8. Complete Plumbing: dichotomous, 0-1
9. Own Kitchen: dichotomous, 0-1
10. Interaction of the above with ownership status.

HC vector: head of household human capital controls, vary by house (i), region (j), and time (t).
Source (a): American Housing Survey, 1974-2011
1. Age: continuous
2. Education: polychotomous (no school, elementary, some HS, HS graduate, some college, College graduate, graduate school)
3. Married: dichotomous, 0-1
4. White: dichotomous, 0-1
5. Hispanic: dichotomous, 0-1

Source (b) & (c): Decennial Census and American Community Survey, 1980, 1990, 2000, and 2005-2011 & Current Population Survey, 1974-2011
1. Educational: polychotomous with 12 categories
2. A quartic in potential experience, and potential experience interacted with years of education, continuous
3. Industry at the one-digit level (1950 classification): polychotomous with 9 categories
4. Employment at the one-digit level (1950 classification): polychotomous with 12 categories
5. Marital status, polychotomous (married, divorced, widowed, separated)
6. Veteran status, dichotomous, 0-1; and veteran status interacted with age
7. Minority status, polychotomous (Black, Hispanic, Asian, Native American, and other)
8. Immigrant status, years since immigration, and immigrant status interacted with black, Hispanic, Asian, and other. (Not in CPS)
9. English proficiency, polychotomous (none, poor, or well) (Not in CPS)

STS and **LTS:** local and state tax and service vectors, vary by region (j) and year (t).

Table 8: Descriptions, Levels of Variation, and Sources for Key Variables

Sources: Government Finances (GF) series (Census a, various years); Signicant Features of Fiscal Federalism (ACIR, various years); US Bureau of the Census, 1974-1991; Digest of Educational Statistics (DES), (Department of Education, various years); Uniform Crime Reports (UCR), (FBI, various years).
1. Mean city effective property tax rate: continuous, Source: AHS
2. State income tax rate: continuous
3. State sales tax rate: continuous [42]
4. Serious crimes per 100 000 population: continuous, UCR
5. Student-teacher ratio in city schools: continuous, Department of Education Common Core of Data
6. City infrastructure stock: Continuous, GF and authors' calculations
7. State infrastructure stock: continuous, GF and authors' calculations

A: unproduced amenities, vary by region (j).
Source: US Bureau of the Census (1980-2000 Avg.)) and authors' calculations.
1. Coastal status: dichotomous, 0-1, authors' calculations
2. Mean annual rainfall: continuous
3. Mean annual heating degree days: continuous
4. Mean cooling degree days: continuous

E Estimation

We use a two-level hierachical linear model to determine whether city infrastructure can account for any of the variance in land prices and wages across cities and over time. At the first level we estimate rent and wage the city fixed effects after controlling for housing quality and human capital variables. This enables us to compare homogeneous units of observations over time and space.

E.1 Stage 1: Housing-Cost, Wage, and Population Differentials

The first-stage regression equations are:

$$\ln HV_{i,j,t} = \alpha_1 HQ_{i,j,t} + \alpha_{2,j,t} C_j T_t + \epsilon_{i,j,t} \quad \text{(A.6)}$$
$$\ln W_{i,j,t} = \beta_1 HC_{i,j,t} + \beta_{2,j,t} C_j T_t + \mu_{i,j,t} \quad \text{(A.7)}$$
$$\ln Pop_{j,t} = \zeta_0 + \zeta_{2,j,t} C_j T_t + \theta_{j,t} \quad \text{(A.8)}$$

where i indexes individual observations, j indexes cities, t indexes years, HV is self-reported house value, HQ are house quality controls, W is annual wage, HC are human capital controls,

[42] We thank Nathan Seegert for providing us with this data, which he compiled from The Book of the States and other sources, as described in Seegert (2012).

C and T are city and time dummies, and ϵ and μ are standard residual terms. We are interested in the coefficients $\alpha_{2,j,t}$ and $\beta_{2,j,t}$, which we take as composition-adjusted housing prices and wages. $\zeta_{2,j,t}$ indicates population differentials.

Consistent estimation of these coefficients requires that housing quality and worker quality do not vary systematically across cities. All regressions are estimated by OLS and weighted using AHS, CPS, and Census of sample size weights[43].

E.2 Level 2: Estimating the Effect of Infrastructure

The second stage of the estimation strategy involves examining whether the variance in composition-adjusted prices can be accounted for by a vector of climate characteristics (A_j), local and state marginal income tax rates, violent crime rate, and student-teacher ratio ($LTS_{j,t}$, $STS_{j,t}$), version $k \in \{1, \ldots, 5\}$ of local infrastructure stock ($LG^k_{j,t}$), and the state infrastructure stock ($SG_{j,t}$) [44].

The regression equations are

$$\hat{\alpha}_{2,d,j,t} = \gamma_1 A_j + \gamma_2 LTS_{j,t} + \gamma_3 STS_{j,t} + \gamma_4 LG^k_{j,t} + \gamma_5 SG_{j,t} + \gamma_6 L_{j,2000} + \nu_{j,t} \tag{A.9}$$

$$\hat{\beta}_{2,d,j,t} = \delta_1 A_j + \delta_2 LTS_{j,t} + \delta_3 STS_{j,t} + \delta_4 LG^k_{j,t} + \delta_5 SG_{j,t} + \delta_6 L_{j,2000} + \eta_{j,t} \tag{A.10}$$

$$\hat{\zeta}_{2,j,t} = \phi_1 A_j + \phi_2 LTS_{j,t} + \phi_3 STS_{j,t} + \phi_4 LG^k_{j,t} + \phi_5 SG_{j,t} + \phi_6 L_{j,2000} + \xi_{j,t} \tag{A.11}$$

where $\hat{\alpha}_{2,d,j,t}$ and $\hat{\beta}_{2,d,j,t}$ are the estimated housing quality adjusted house values and human capital adjusted wages for sample d, city j, time t respectively; and $\hat{\zeta}_{2,j,t}$ are the population differentials.

We estimate these regressions using pooled OLS and with city and year fixed effects. Since we use the prices from three different data sets, we include data set indicator variables in OLS estimates and use year by data set indicators instead of year indicators in city and year fixed effect regressions.

We estimate wage and rent elasticity of local infrastructure from A.9 and A.10 and estimate average willingness to pay for infrastructure by households and firms using the formulas from the theoretical model.

F Supplementary Results and Robustness

In this section we present further results focused on the relationship between infrastructure and commuting time, and intra-MSA and inter-MSA spillover effects. At the end, we check the sensitivity of our results to exclusion of different cities.

1. Transportation Costs and Commuting Time. Higher investment in city infrastructure can reduce the transportation costs, and facilitates commuting. In this section, we investigate the magnitude of such a relationship. As shown in Table 10 below, this is particularly relevant for our sample because highways and transportation utilities compose 19.5% of total capital outlays in our cities. Since we readily have such composition for years after 1950, we can't construct

[43] In Particular, we use the square root of average annual sample size which are 1.00, 1.29, 11.13, and 13.74 for National and Metro samples of AHS, Census of Population, and CPS, respectively.

[44] See Table 8 for a complete list of the variables used in each of these categories.

highway and transportation infrastructure stock measures. However, we can test whether the stock of infrastructure is facilitating the commuting between the employment and residential locations.

We estimate commuting time differentials using the same Census of Population and AHS samples used for wages, applying the methodology of Albouy and Lue (2015). We regress the square root of commuting time on the same controls used for the wage equation. The differential is then constructed using $\hat{CT}_j = 2\mu_j^{CT}/\sqrt{\bar{CT}}$ where $\sqrt{\bar{CT}}$ is the average of square-root commuting time[45].

In the second stage, we then regress the commuting time differentials on stocks of infrastructure and the same other control variables used for wage, rent, and population regressions. Table 11 shows the regression coefficients for different specifications for central cities and suburbs.

2. The Effect of Central City Infrastructure on Suburbs Not only higher levels of infrastructure in central cities benefits the residence of them, but also the residence of nearby suburbs may benefit from it. Since the available investment data does not fully cover the suburbs of metropolitan areas, we cannot calculate the infrastructure stocks for the suburbs and how those stocks react to central city investments. However, we test the presence of intra-MSA spillover effects by investigating whether higher central city infrastructure has spillover effects on the suburbs. We can do so by estimating the relationship between central city infrastructure and the welfare and productivity of the suburbs.

In our regressions, the infrastructure measures of the suburbs are the missing variable. Consequently, we are overestimating the direct effect of central city infrastructure on the suburbs if suburban infrastructure stocks are positively co-moving with the central city stocks. On the other hand, if the central city infrastructure crowds out suburban investments, we are underestimating the direct effects. This is straightforward from the omitted variable bias formula in linear regression.

Table 12 shows positive and statistically significant effects of central city infrastructure on suburban wage and housing price differentials.

3. Sensitivity of the Results to large cities In this section we show how sensitive the main results are to removing certain cities in our sample. We do this by estimating the main second stage results while excluding each city from the sample. Repeating this exercise 84 times, we present the average coefficients and p-values in Table 13 below.

The log-log specification estimates are fairly robust to exclusion of different cities from our sample. This is consistent with precision of these estimates presented earlier. Reassuringly, if we treat the range of these estimates as alternative confidence bands, our conclusions will be similar to those drawn from the confidence bands of the full sample estimates.

[45]We use square root since Albouy and Lue (2015) found that it fits the data better, and as it accommodates reports of zero commuting time

Table 9: Summary Statistics

	(1) Mean	(2) Std. Dev.
Census Housing cost differential	-0.14	0.51
Census HCD: Owners	-0.18	0.51
Census Wage Differential	-0.07	0.11
National AHS Housing cost differential	-0.61	0.69
National AHS HCD: Owners	-0.18	0.44
National AHS Wage Differential	-0.08	0.20
Metro AHS Housing cost differential	-0.58	0.63
Metro AHS HCD: Owners	0.17	0.43
Metro AHS Wage Differential	-0.14	0.49
All AHS Housing cost differential	-0.58	0.68
All AHS HCD: Owners	-0.13	0.44
All AHS Wage Differential	-0.08	0.21
CPS Wage Differential	-0.02	0.11
Central City Population (Log of thousands)	12.86	0.77
Central City Infrastructure Stock ($Billions)	7.44	17.76
Avg. Annual Precipitation	37.78	14.50
Avg. Cooling Degree Days in 65	1,389	946
Avg. Heating Degree Days in 65	4,125	2,059
City on Sea	0.34	0.47
City on Lake	0.10	0.30
Student/Teacher Ratio	18.04	4.42
Top Inc. Tax Rate	5.28	3.87
Bottom Inc. Tax Rate	1.75	1.69
State and Local Sales Tax Rate	4.96	1.29
State Infrastructure Stock ($Billions)	65	47.86
# Violent Crimes per 100K	1,121	636

Source: Difference sources listed in Table (8), 1980-2011. There are 85 distinct cities in our sample.

Table 10: Component shares of investment

Variable	Mean	Std. Dev.	Min	Max	Obs
Total Educ-Cap Outlay (% of total)	3.867	11.371	0	98.946	3,471
Gen Pub Bldg-Cap Out (% of total)	1.909	4.869	0	72.146	3,471
Total Hospital-Cap Out (% of total)	0.650	3.107	0	61.747	3,471
Total Highways-Cap Out (% of total)	18.576	14.81	0	90.658	3,471
Hous & Com-Cap Outlay (% of total)	7.182	12.698	0	100	3,471
Parks & Rec-Cap Outlay (% of total)	5.896	8.703	0	67.703	3,471
Sanitation-Cap Out (% of total)	7.197	9.864	0	91.601	3,471
Sewerage-Cap Outlay (% of total)	8.886	10.644	0	81.057	3,471
General NEC-Cap Out (% of total)	24.866	19.484	0	100	3,471
Liquor Stores-Cap Out (% of total)	0.002	0.143	0	8.401	3,471
Total Util-Cap Outlay (% of total)	20.969	20.986	0	99.529	3,471
Water Util-Cap Outlay (% of total)	14.566	15.391	0	92.705	3,471
Elec Util-Cap Outlay (% of total)	5.037	14.649	0	86.354	3,471
Gas Util-Cap Outlay (% of total)	0.451	2.366	0	47.786	3,471
Transit Util-Cap Outlay (% of total)	0.914	3.379	0	46.1	3,471

Calculated using the data from City Government Finances 1950-2006 for our sample of cities.

Table 11: The relationship between Infrastructure Stocks and Commuting time

Model	City and Year & Fixed Effects?	Commuting Time, Central Cities	Commuting Time, Suburbs
Log	N	0.182***	0.138***
		(0.019)	(0.017)
Log	C,Y	0.083**	0.044
		(0.034)	(0.027)

* p<0.10, ** p<0.05, *** p<0.01

Table 12: Central City and Suburban Elasticities

Model	City and Year Fixed Effects?	Housing Price Elasticity		Wage Elasticity		Population Elasticity	
		Central City	Suburb	Central City	Suburb	Central City	Suburb
Log	N	0.123***	0.137***	0.020***	0.025***	0.020***	0.475***
		(0.032)	(0.030)	(0.005)	(0.005)	(0.005)	(0.063)
Log	C, Y	0.105*	-0.068	0.076***	0.048**	0.386***	0.422***
		(0.060)	(0.063)	(0.023)	(0.020)	(0.071)	(0.083)

1. * p<0.10, ** p<0.05, *** p<0.01

2. In column 2, "N" indicates no fixed effects and "C,Y", city and year fixed effects.

Table 13: City Exclusion Robustness Log Specification

Variable	Mean	Std. Dev.	Min	Max
Housing cost				
Coefficient	0.106	0.007	0.085	0.124
P-Value	0.086	0.021	0.044	0.159
Wage				
Coefficient	0.077	0.003	0.069	0.086
P-Value	0.001	0.000	0.000	0.003
Place Population (Log)				
Coefficient	0.386	0.009	0.347	0.407
P-Value	0.000	0.000	0.000	0.000