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Consumption Amenities and City Crowdedness

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Abstract: Crowdedness varies widely among U.S. cities. A simple, static general equilibrium model suggests that plausible differences in metro areas' consumption amenities can account for much of the observed variation. Under a baseline calibration, differences in amenities valued at 30 percent of average consumption expenditures suffice to support a twenty-fold difference in population density. Empirical results confirm that amenities help support crowdedness and suggest that they are becoming a more important determinant of where people choose to live. But for the moment, local productivity appears to be the more important cause of local crowdedness.

Keywords: Population density, consumption amenities, quality of life, productivity, urban agglomeration

JEL classification: R000, J000, I310

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1 Introduction

Crowdedness varies hugely across U.S. cities. Among metropolitan areas with a population of at least 100,000 in 2000, the most crowded (New York City) had a population density forty-nine times that of the least crowded (Dothan, Alabama). The second-most crowded (Los Angeles) had a population density twenty times that of the least crowded. Moderate differences in cities' total factor productivity can account for such variation (Rappaport, 2006b). In part such productivity variations may arise endogenously as a result of increasing returns to scale. But estimates of the higher productivity *caused* by above-average population density fall considerably short of the higher productivity *required* to support such density. To what extent might consumption amenities make up the difference? More generally, are the quality-of-life differences required to account for the observed range of crowdedness plausible?

To answer these questions, the present paper lays out and calibrates a simple, static general equilibrium model of city crowdedness. Homogenous individuals choose to live and work in one of two local economies. They derive utility from consumption of a traded good, housing, leisure, and a consumption amenity. Firms in each economy produce the traded good and housing using land, capital, and labor. The level of consumption amenities varies exogenously between the two economies. In equilibrium, each economy must offer individuals the same level of utility and provide capital with the same rate of return. The resulting model is a generalization of Rappaport (2006b). It is similar to models in Henderson (1974, 1987, 1988), Haurin (1980), Upton (1981), and Haughwout and Inman (2001). And its equilibrium embeds the compensation for quality-of-life differences that forms the basis of empirical work in Rosen (1979), Roback (1982), Blomquist et al. (1988), Gyourko and Tracy (1989, 1991), Gabriel and Rosenthal (2004), and Chen and Rosenthal (2006).

The paper finds that plausible differences in cities' consumption amenities can, indeed, account for most of the observed variation in crowdedness. Under a baseline calibration, a compensating variation equivalent to 30 percent of average consumption expenditure supports the twenty-fold observed difference in crowdedness between the second-most and least dense metropolitan areas. This is within the range of differentials estimated by Blomquist et al. (1988), Gyourko and Tracy (1991), Gabriel and Rosenthal (2004), and Chen and Rosenthal (2006). Empirical results confirm that variations in consumption amenities help support differences in crowdedness. In particular, density is strongly positively correlated with several subjective rankings of metropolitan-area quality of life. But the positive empirical correlation of wages and density suggests that local productivity is the more important cause of local crowdedness.

The paper proceeds as follows. Section 2 describes the paper's empirical motivation: the wide variations in crowdedness and perceived quality of life across U.S. metro areas. Sections 3 and 4 lay out the model and discuss its calibration. Section 5 describes the model's numerical results, both for a baseline calibration and for several large perturbations to it. It then discusses the implications of allowing productivity and quality of life to themselves endogenously depend on population density. Section 6 presents empirical results that suggest that variations in quality of life indeed help underpin variations in crowdedness but that variations in productivity are a more important cause. A last section briefly concludes.

2 Empirical Motivation

Huge variations in local crowdedness are easy to experience but harder to quantify. One difficulty concerns the correct geographic unit among which to make comparisons. Possibilities include municipalities, counties, metropolitan areas, and states. Another difficulty concerns how to deal with the unequal distribution of population within any geographic unit.

Metropolitan areas are this paper's preferred geographic unit. They are delineated by the Office of Management and Budget to include one or more large municipalities and the suburban areas that surround them. Metro areas best correspond to local economies in the model that follow because they encompass a well-defined labor market in which people both live and work.

Raw population density—total population divided by total land area—is the most straightforward way to measure metro-area crowdedness. It describes density as experienced by the average parcel of metro land. But heterogeneous settlement patterns make using raw density problematic. Metro areas are constructed as the union of one or more whole U.S. counties. Often, large portions of such counties are primarily agricultural or unoccupied. Hence, the density experienced by the average parcel of metro land can be a considerably downward-biased measure of crowdedness for the portion of the metro area where most people actually live.

Average density as experienced by residents is instead used as a preferred measure of metro area crowdedness. It is constructed as a population-weighted average of raw subunit densities (Glaeser and Kahn, 2004; Rappaport 2006b). More specifically, the Census Bureau partitions all U.S. counties into smaller divisions. These county divisions are further partitioned into the portions of any municipalities that lie within them (many municipalities span multiple county divisions) along with any remaining unincorporated area.

The resulting population-weighted average density suggests that metro-area crowdedness in 2000 varied by a multiplicative factor of forty-nine (Table 1). Unsurprisingly, the New York City metropolitan area had the highest density: 18.9 thousand persons per square mile. The next-most crowded metro area, Los Angeles, had a weighted density less than half of this. Among people living in metropolitan areas with population of at least 100,000, the median density was experienced by those living in Omaha. In other words, at least half of individuals experienced density greater than or equal to that of Omaha, and at least half experienced density less than or equal to that of Omaha. An alternative measure of the variation in crowdedness, the raw population density of *municipalities* with population of at least 100,000 in 2000, is characterized by a similar forty-five-fold multiplicative spread.

A second empirical motivation is the perceived wide variation in quality of life across U.S. localities. Again, this is more easily experienced than quantified. Quality of life is meant to connote the total contribution to utility from all local consumption amenities—local attributes that directly affect individuals' utility—not including any offsetting endogenous price response such as lower wages and higher house prices. Popular magazines and numerous books continually evaluate where are the nicest places to live. Top-20 rankings from two of these are shown in Table 2, Panel A. The compensating differential literature, using a more formal theoretical framework, estimates that differences in quality of life are valued at as much as half of median family income. Top-20 rankings from two such studies are shown in Table 2, Panel B. Metro areas' relative quality of life obviously affects demand for where to live and, hence, cross-sectional density.

3 Model

The model uses a static, open-city framework. The world comprises two open economies, one small and one large. The small economy can be interpreted as a locality, a well-defined market for factors and goods. The large economy can be interpreted as the aggregate of numerous other localities. The size distinction reflects relative land areas. An important semantic point is that the small economy may be considerably more crowded than the large economy, in which case it might be interpreted as a "big city."

3.1 Firms

Within each economy ($i = s, l$), perfectly competitive firms employ a constant-returns-to-scale production function that combines land, capital, and labor (D_i, K_i, and L_i) to produce a traded numeraire good and nontraded housing (X_i and H_i). Housing must be consumed in the economy in which is produced. Aggregate production within each economy is given by

$$X_i = \mathrm{A}_X \, D_{X,i}^{\alpha_{X,D}} \, K_{X,i}^{\alpha_{X,K}} \, L_{X,i}^{\alpha_{X,L}} \tag{1}$$

$$H_i = \mathrm{A}_H \left(\eta_{D,KL} D_{H,i}^{\frac{\sigma_{D,KL}-1}{\sigma_{D,KL}}} + \left(1 - \eta_{D,KL}\right) \left(K_{H,i}^{\alpha_{H,K}} L_{H,i}^{\alpha_{H,L}} \right)^{\frac{\sigma_{D,KL}-1}{\sigma_{D,KL}}} \right)^{\frac{\sigma_{D,KL}}{\sigma_{D,KL}-1}} \tag{2}$$

Production of the traded good is Cobb-Douglas. The factor income share parameters are each assumed to be strictly positive with $\alpha_{X,D} + \alpha_{X,K} + \alpha_{X,L} = 1$. Production of housing is characterized by a constant elasticity of substitution (CES) between land and an implicit intermediate product of capital and labor. This elasticity is given by $\sigma_{D,KL}$. The weighting parameter $\eta_{D,KL}$, which lies strictly between 0 and 1, calibrates the relative share of factor income accruing to land. The capital-labor intermediate hybrid good is produced with constant returns to scale: $\alpha_{H,K} + \alpha_{H,L} = 1$. These coefficients determine the division of factor income between capital and labor. Total factor productivity, A_X and A_H, is assumed for now to be exogenous and identical across economies. This will be relaxed in a later section.

Profit maximization by perfectly competitive firms induces demand such that each of the factors is paid its marginal revenue product. Frictionless intersectoral mobility assures intersectoral factor price equalization within each economy. Let p_i give the price of housing in terms of the traded good. The economy-specific returns to land, capital, and labor are respectively given by

$$r_{D,i} \;=\; \partial X_i / \partial D_i \;=\; p_i \, \partial H_i / \partial D_i \tag{3}$$

$$r_{K,i} = \partial X_i / \partial K_i = p_i \, \partial H_i / \partial K_i \tag{4}$$

$$w_i = \partial X_i / \partial L_i = p_i \, \partial H_i / \partial L_i \tag{5}$$

Capital is additionally assumed to be perfectly mobile across economies. Hence its return must be the same in both economies. Because the present framework is static, this identical capital rent is taken as exogenous. In a dynamic neoclassical framework, it would equal the real interest rate plus the rate of capital depreciation.

3.2 Individuals

Individuals derive utility from consumption of the traded good, housing, leisure, and consumption amenities. The utility contribution from the consumption amenities will be referred to as "quality of life." It is assumed to vary exogenously between the two economies, thereby serving as the model's only cause of crowding. More generally, it seems natural to posit that crowding will itself affect quality of life. Allowing for such endogenous quality of life is the subject of a separate section below.

Utility is assumed to take a nested constant elasticity of substitution functional form. Let $\sigma_{a,b}(\cdot)$ be a CES aggregator over a and b:

$$\sigma_{a,b}(a_i, b_i) \equiv \left(\eta_{a,b} \, a_i^{\frac{\sigma_{a,b}-1}{\sigma_{a,b}}} + \left(1 - \eta_{a,b}\right) b_i^{\frac{\sigma_{a,b}-1}{\sigma_{a,b}}} \right)^{\frac{\sigma_{a,b}}{\sigma_{a,b}-1}}$$

Utility in each locality is given by

$$U_i = \sigma_{xhl,q}(\, \sigma_{xh,l}(\, \sigma_{x,h}(x_i, h_i) \, , \, leisure_i) \, , \, quality_i) \tag{6a}$$

The innermost nesting in (6a) is between the traded good and housing. It has elasticity $\sigma_{x,h}$. The middle nesting is between the resulting traded-good-housing composite and leisure. It has elasticity $\sigma_{xh,l}$. The outermost nesting, between the traded-good-housing-leisure composite and quality of life, has elasticity $\sigma_{xhl,q}$. For each of the three nestings, a weighting parameter, η, will be calibrated.

The order of the utility nestings is somewhat arbitrary. One might alternatively assume, for example, that leisure and quality of life are nested together and the resulting composite nested with a traded-good–housing composite. In all, there are 15 possible nestings of the four utility sources.[1] In the special case where the elasticity of substitution is equal across nestings, (6a) simplifies to a standard CES functional form,

$$U_i = \left(\eta_x x_i^{\frac{\sigma-1}{\sigma}} + \eta_h h_i^{\frac{\sigma-1}{\sigma}} + \eta_l leisure_i^{\frac{\sigma-1}{\sigma}} + \eta_q quality_i^{\frac{\sigma-1}{\sigma}}\right)^{\frac{\sigma}{\sigma-1}} \tag{6b}$$

The baseline calibration below is indeed characterized by this specialization. Hence its results do not depend on the order of nesting. With a unitary elasticity of substitution, $\sigma = 1$, (6b) further reduces to Cobb-Douglas utility.

Optimizing behavior by individuals equates the ratio of marginal utility to price *within* each economy. Additionally, individuals' mobility equates utility levels *between* economies.

$$\partial U_i/\partial x_i = \frac{\partial U_i/\partial z_i}{p_i} = \frac{\partial U_i/\partial leisure_i}{w_i} \tag{7}$$

$$U_s = U_l \tag{8}$$

Individuals must satisfy a budget constraint,

$$x_i + p_i h_i \; = \; w_i\,(1 - leisure_i) + nonwage \tag{9}$$

Under the baseline set of assumptions below, non-wage income is assumed to be zero. In this case, capital and land rents can be interpreted as being paid to absentee owners who reside outside of either economy. Under an alternative set of assumptions discussed in the sensitivity analysis, non-wage income is the per-capita sum of all capital and land rents collected in both economies: $nonwage = \sum_i (r_{K,i} K_i + r_{D,i} D_i)/\sum_i N_i$. The variable N_i gives the population of each economy. Note that non-wage income is always assumed to be identical between the two economies.

3.3 Closure

In addition to the profit and utility maximization conditions, several adding up constraints must be met. For each of the economies, the land and labor factor markets and the housing market must clear. And the sum of local populations must equal the exogenously given total

[1] There are $\binom{4}{2}$ innermost nestings times 2 outer nestings for each plus 3 possible combinations of pairwise nestings.

population.

$$D_{X,i} + D_{H,i} = D_i \quad (10)$$

$$L_{X,i} + L_{H,i} = (1 - leisure_i)\, N_i \quad (11)$$

$$h_i\, N_i = H_i \quad (12)$$

$$\sum_i N_i = N \quad (13)$$

When capital and land factor payments are received by residents within the economies, total traded-good consumption across the two economies must also equal total traded-good production, $\sum_i x_i\, N_i = \sum_i X_i$. More generally, total traded consumption will be less than total traded production by the sum of absentee factor payments.

The combined optimization conditions, individual budget constraints, local adding-up constraints, and global adding-up constraint reduce to a nonlinear system of thirteen equations with thirteen unknowns. The absence of any sort of increasing returns to scale, combined with the fixed land supply and decreasing marginal utility, suggests that any solution to this system is unique.

4 Calibration

The primary purpose of the present paper is to gauge the magnitude of the variation in consumption amenities that is required to match the widely varying degree of crowdedness we observe among U.S. cities. In this spirit and to not imply a false level of precision, parameters are set to round values. The numerical results section includes an extensive sensitivity analysis.

To simplify the analysis, the small economy is henceforth assumed to have approximately zero land area. This shuts down any feedback from it to the large economy, which is especially helpful when land and capital factor payments are assumed to be made to individuals within the two-economy system rather than to absentee owners. The large economy serves three functions. First is to calibrate the weighting parameters in the housing production and utility functions. Second is to determine the reservation level of utility that individuals in the small economy must attain. Third is to determine the level of non-wage income when factor payments are recycled.

4.1 Production

The calibration of production requires determining the large-economy factor income share accruing to each of land, capital, and labor in the traded-good and housing sectors. For the housing sector, it also requires determining the elasticity of substitution between land and the capital-labor composite. In addition, the rate of return determining capital intensity needs to be specified. Table 3 summarizes the baseline parameterization as well as alternative values for the sensitivity analysis.

The land share of factor income derived from the production of the traded good is assumed to be 1.6%. This value is a weighted average across a large number of industries using intermediate input shares estimated by Jorgenson, Ho, and Stiroh (2005).[2] It is nearly identical to the 1.5% land share that Ciccone (2002) suggests is reasonable for the manufacturing sector. Sensitivity analysis is conducted for land factor shares equal to 0.4% and 4.8%. One third of remaining factor income is assumed to accrue to capital; two thirds are assumed to accrue to labor (Gollin, 2002). Because traded-good production is Cobb-Douglas, the assumed factor shares will hold in both economies.

Non-Cobb-Douglas production in the housing sector implies that factor income shares differ between the two economies. Numerical results are somewhat sensitive to the assumed land share. Under the baseline parameterization, its large-economy value is set to 35%. This is below a recent estimate that land accounts for approximately 39% of the implicit factor income attributable to aggregate U.S. housing stock (Davis and Heathcote, 2005).[3] Using microeconomic data, several other researchers have found substantially lower land shares. Based on houses sold in the Knoxville metro area, Jackson, Johnson, and Kaserman (1984) estimate that land accounts for 27% of implicit factor income. Based on houses constructed

[2]The industry-specific intermediate input estimates, which are not included in the publication, were kindly provided by the authors.

[3]Davis and Heathcote find that between 1975 and 2004, land accounted for an average of 47% of the sales value of aggregate U.S. housing stock. Adjusting for the fact that structures depreciate but land does not, using the 1.6% rate of structure depreciation suggested by Davis and Heathcote and a 4% required real rate-of-return, gives a 38.8% land factor share.

in new subdivisions of the Portland Oregon metro area, Thorsnes (1997) estimates that it accounts for 17%. But Knoxville is among the least densely populated metro areas. And new subdivisions tend to be located at the edges of metro areas. In both cases, land prices are likely to be below average. If the production elasticity of substitution with land is below one as assumed under the baseline calibration, land's factor share would be below average as well. For the sensitivity analysis, the housing land factor share is assumed to equal 20% and 50%. As with traded-good production, one third of remaining factor income is assumed to accrue to capital; two thirds are assumed to accrue to labor.

The elasticity of substitution between land and non-land inputs, $\sigma_{D,KL}$, is assumed to be 0.75. No clear consensus exists on an appropriate value. A survey by McDonald (1981) reports preferred estimates from twelve different studies ranging from 0.36 to 1.13. Updating this research, Jackson, Johnson, and Kaserman (1984) estimate the elasticity to lie somewhere between 0.5 and 1. More recently, Thorsnes (1997) argues that a unitary elasticity of substitution cannot be rejected. For the sensitivity analysis, $\sigma_{D,KL}$ is assumed to equal 0.5 and 1.

Finally, the rent on the services of capital goods, r_K, is set to 0.08, which implicitly represents the sum of a required annual real return plus an annual allowance for depreciation. However, results are completely insensitive to the parameterization of r_K. This makes sense since the framework has no natural time context.

4.2 Utility

The calibration of the utility function, (6a), requires parameterizing the elasticities of substitution between the traded good and housing, between the resulting two-way composite and leisure, and between the resulting three-way composite and quality of life. In addition, weighting parameters need to be set that determine the large-economy share of consumption spent on housing and the large-economy share of time devoted to leisure.

The elasticity of substitution, $\sigma_{x,h}$, is assumed to equal 0.5. It is calibrated using cross-sectional data on housing prices and the housing share of consumption expenditures. The dots in Figure 1 Panel A plot the latter against the former for 24 large metro areas.[4] The

[4]The housing price measure is an index of the rental price of apartments in professionally-managed properties with five or more units. It is constructed by Torto Wheaton Research based on quarterly surveys. The index adjusts for the number of bedrooms per unit and a property's age, but not for other characteristics such

lines represent the expected housing expenditure share for each of three elasticities of substitution.[5] The line for $\sigma_{x,h}$ equal to 0.50 almost exactly overlays the fitted relationship from a linear regression. This baseline value is close to numerous estimates of the price elasticity of housing demand, the negative of which corresponds to $\sigma_{x,h}$ (Goodman, 1988, 2002; Ermisch, Findlay, and Gibb, 1996; Ionnides and Zabel, 2003). As another source of comparison, some typical open-economy calibrations of the elasticity of substitution between traded and non-traded goods include 0.44 (Mendoza, 1995) and 0.74 (Stockman and Tesar, 1995). For the sensitivity analysis, $\sigma_{x,h}$ is assumed to equal 0.25 and 0.75.

The elasticity of substitution between the traded-good-housing composite and leisure, $\sigma_{xh,leisure}$, is also assumed to equal 0.5. It is calibrated using time diary studies taken in 1965, 1975, 1985, 1993, and 2003 (Robinson and Godbey, 1997; Aguiar and Hurst 2006) and real wage data for each of these years. The bold line in Figure 1 Panel B plots the average share of weekly hours devoted to leisure by non-retired, working-age men. The remaining lines show expected values corresponding to the real wage in each of the above years for $\sigma_{xh,leisure}$ equal to each of 0.25, 0.5, and 1.[6] Calibrating $\sigma_{xh,leisure}$ to equal 0.5 exactly matches the total increase in leisure from 1965 to 2003. The implied elasticity of labor hours with respect to the real wage is consistent with estimates summarized in Pencavel (1986) and Blundell and MaCurdy (1999). Alternative values equal to 0.25 and 1 are used in the sensitivity analysis.

The elasticity parameter between the traded-good-housing-leisure composite and quality of life can be set arbitrarily. While consumption amenities can be valued, they have no inherent quantity unit. As a result, $\sigma_{xhl,quality}$ affects only the level of $quality_s$ required to support a given relative population density, not its valuation. To keep things simple, the base calibration sets $\sigma_{xhl,quality}$ equal to 0.5, thereby simplifying (6a) to its standard CES

as square footage, parking, and location. The inability to control for these implies that the index measures a hybrid of housing rental prices and housing rental expenditures. Because of substitution, expenditures understate variations in prices. An accurately measured house price would likely result in a scatter more horizontal than that depicted in Figure 1. An additional shortcoming of the present price index is that it fails to measure the price of owner-occupied housing. The resulting direction of bias is less clear.

[5]For each elasticity, the weighting parameter $\eta_{x,h}$ is chosen so that the expected expenditure share passes through the fitted expenditure share for Pittsburgh based on a linear regression. Pittsburgh's weighted density is close to the population median.

[6]Biological necessities are assumed to require 9 hours per day, which leaves 105 hours per week of potential leisure. The expected values assume individuals have no non-wage income. For each elasticity, the weighting parameter $\eta_{xh,leisure}$ is chosen so that the expected leisure share for 1965 matches its actual value.

form, (6b).

Finally, the weighting parameters $\eta_{x,h}$, $\eta_{xh,leisure}$, and $\eta_{xhl,quality}$ need to be calibrated. For a given set of elasticities, $\eta_{x,h}$ is chosen such that large-economy individuals spend 18% of their consumption expenditures on housing. This approximately matches the aggregate U.S. value from 2001 to 2003. The sensitivity analysis alternatively assumes large-economy housing expenditure shares of 14% and 22%. The parameter $\eta_{xh,leisure}$ is chosen such that large-economy individuals choose to spend 35% of their time on leisure. This matches the share for 2003 shown in Figure 1. The sensitivity analysis alternatively assumes large-economy leisure shares of 20% and 50%. As will become clear, all numerical results are extremely robust to these latter variations. The lack of units for quality of life makes the choice of $\eta_{xhl,quality}$ immaterial.

5 Numerical Results

The model's mechanics are straightforward. The large economy serves to calibrate the utility and production weighting parameters. It also determines the reservation level of utility that small-economy residents must attain and the amount of non-labor income they receive when factor payments are recycled. An increase in the small economy's level of consumption amenities attracts an inflow of labor, putting downward pressure on wages and attracting a complementary inflow of capital. The increase in small economy population dominates the lower wages to increase housing demand, which in turn puts upward pressure on land prices. Consumption of the traded good, housing, and leisure all fall.

The first subsection below illustrates these mechanics under the baseline calibration. Compensation for higher consumption amenities comes largely via higher housing and land prices. A second subsection shows how resistance to crowdedness changes with variations to each of the model's main parameters. Resistance to crowdedness depends most closely on the calibration of the housing production function. A third subsection relaxes the assumptions that quality of life and productivity are completely exogenous. Allowing productivity to depend positively on density can considerably lower resistance to quality-of-life-driven crowding.

5.1 Baseline Calibration

Numerical results from the baseline calibration are shown in Figure 2. Panel A plots a valuation of the $quality_s$ that is required to achieve various small-economy relative population densities. The comparison between $quality_s$ and $quality_l$ is made at the large economy wage-price vector, $\{w_l, p_l\}$. Consider the minimum expenditure function required to obtain the large-economy level of utility. For present purposes, this expenditure is defined to include the opportunity cost of leisure:

$$\mathrm{e}(w_l, p_l, quality; U_l) \equiv \mathrm{Min}\,(x + p_l\, h + w_l\, leisure) \;\text{ s.t. } \mathrm{u}(x, h, leisure, quality) = U_l.$$

The compensating variation, CV, of $quality_s$ measures the willingness to pay to receive it rather than $quality_l$. It is defined as the negative transfer such that a person facing $\{w_l, p_l, quality_s\}$ can still achieve U_l. That is,

$$CV \equiv \mathrm{e}(w_l, p_l, quality_l; U_l) - \mathrm{e}(w_l, p_l, quality_s; U_l)$$

Note that CV is defined to be positive when $quality_s$ exceeds $quality_l$. To facilitate intuition on magnitudes, a normalized measure, $\widetilde{CV}$, divides CV by actual large-economy expenditure, $x_l + p_l\, h_l$.

CV differs slightly from the compensating differential, CD, of $quality_s$ relative to $quality_l$ (Rosen, 1979; Roback, 1982). CD, using large-economy quantities, equals $(p_s - p_l)\, h_l - (w_s - w_l)\,(1 - leisure_l)$. For $quality_s$ close to $quality_l$, CD and CV are approximately equal. But as $quality_s$ increasingly exceeds $quality_l$, CD increasingly exceeds CV. For the baseline calibration at a relative density of 4, $\widetilde{CD}$ exceeds $\widetilde{CV}$ by 5 percentage points. At a relative density of 8, it does so by 15 percentage points. The differences are due to CD's abstraction from the decreasing marginal utilities of $quality_s$ and wealth. Conversely, as $quality_s$ becomes increasingly lower than $quality_l$, CD becomes increasingly less than CV in absolute value. At relative densities of 1/4 and 1/8, it respectively does so by 1.3 and 2.3 percentage points.[7]

In Panel A, the vertically-plotted $\widetilde{CV}$ should be interpreted as exogenous. The horizontally-plotted relative population density should be interpreted as an endogenous response. So

[7] Still another comparison between $quality_s$ and $quality_l$ is the equivalent variation between the two. This equals the transfer to large-economy residents that allows them to attain $\mathrm{v}(w_l, p_l, quality_s)$, where $\mathrm{v}(\cdot)$ is an indirect utility function.

for any given quality-of-life differential, the locus gives the density that would be induced. Equivalently, for any relative density, the depicted locus gives the required quality-of-life differential. For example, consider the $quality_s$ that would induce small-economy population density to be one-fourth that of the large economy. Its $\widetilde{CV}$ is -0.13. In other words, large-economy residents facing the required $quality_s$ rather than $quality_l$ require a transfer equivalent to 13% of their original traded-good and housing consumption in order to continue to attain $\overline{U}_l$. Conversely, the $\widetilde{CV}$ associated with a relative population density of four is 0.18. In this case, large-economy residents facing the required $quality_s$ could transfer away 18% of their original consumption while still attaining $\overline{U}_l$.

Notice that the required-$\widetilde{CV}$-to-density locus is asymmetric with respect to the origin. The negative $\widetilde{CV}$ required to support a fractional density is smaller in magnitude than the positive $\widetilde{CV}$ required to support the reciprocal multiple density. Equivalently, the $\widetilde{CV}$-to-density locus has a positive second derivative. This asymmetry reflects the increasing marginal cost of crowding as the marginal return to land in production and the marginal utilities from consumption become extremely high.

The required variations in quality of life are probably of plausible magnitude to account for most, but perhaps not all, of observed variations in crowdedness. The difference in required expenditure between a small economy with relative density equal to that of the most dense metro area (New York City) and one with relative density equal to that of the least dense metro area (Dothan, Al) is equivalent to 45% of large-economy consumption. This is within the upper end of estimated compensating differentials reported by four leading empirical papers (Table 4). However, as discussed above, compensating differentials can considerably overstate compensating variations. The difference in required expenditure between a small economy with relative density equal to that of the second-most dense metro area (Los Angeles) and one with density equal to that of the least dense metro area is equivalent to 30% of large-economy consumption. Even allowing for overstatement, this should fall well within the estimated range.

The remaining panels of Figure 2 plot the relationships between population density and a number of other endogenous outcomes. The desire by individuals to live in high-quality-of-life locales induces an inverse correlation between population density and the traded-good denominated wage (Panel B). At a one-fourth density, small-economy wages are 4.3% above those in the large economy; at a four-fold density, they are 4.3% below large-economy wages. Increases in population density pull land out of traded good production into housing production (not shown). As density increases from one fourth to one to four, the percent of land devoted to housing production increases from 63 to 74 to 83.

Relative land prices vary by an order of magnitude more than do wages (Panel C). They go from 0.18 to 6.1 as relative density goes from one fourth to four. As the price of land increases, so too does its share of housing factor income (Panel D). But the actual land factor content of housing—that is, land per unit of housing—falls with density (not shown). At a one-fourth density, the quantity of land per housing unit is approximately three times its large-economy level. At a four-fold density, land per unit housing is approximately two fifths its large-economy level. The sharply rising price of land causes the price of housing to increase as well (Panel E). But the rise in house prices—from 0.61 to 2.0 as density rises from one fourth to four—is considerably more moderate than the rise in land prices. Housing expenditures rise by even less (also Panel E).

On the other hand, housing prices rise by considerably more than wages fall. As a consequence, compensation for variations in quality of life are capitalized much more into housing prices than into wages. At a one-fourth density, lower housing prices account for 62 percent of a conventionally-calculated compensating differential between the two economies. At a four-fold density, higher housing prices account for 81 percent.

As the price of housing rises, so too does the share of expenditures devoted to housing. This follows directly from the assumed less-than-unitary elasticity of substitution between traded goods and housing, $\sigma_{x,h} < 1$. Hence the housing share of consumption rises with crowdedness as well (Panel F). But the actual quantity of housing consumed falls, as does traded-good consumption (Panel G). The falling levels of traded and housing consumption offset the rising quality of life, thereby maintaining the reservation level of utility. At a one-fourth density, relative traded and housing consumption are respectively 1.04 and 1.49. At a four-fold density, relative traded and housing consumption are 0.96 and 0.59.

Lastly, leisure also falls slightly with density (Panel H). As density rises from one fourth to four, relative leisure falls from 1.04 to 0.95. As is the case with traded and housing consumption, a fall in leisure helps compensate for the rise in quality of life. However, this latter result depends on the model's parameterization. On the one hand, the inverse correlation between wealth and density contributes to the fall in leisure. On the other hand, lower wages where density is high decreases the effective price of leisure. With a unitary elasticity of substitution with leisure, the two effects exactly offset each other. With a lower elasticity, as under the baseline, the wealth effect dominates.[8]

5.2 Sensitivity Analysis

The present model requires eight key parameter choices. Figure 3 illustrates the dependence of required quality of life on those parameters to which it is most sensitive.[9] Land is the model's only source of congestion. Hence it is unsurprising that changes that increase its implicit factor share of large economy consumption—either by explicitly increasing land's factor share in production or by increasing the expenditure share of land-intensive housing—increase resistance to crowding. Less obviously, decreasing the production and consumption elasticities increases resistance to crowding at high relative densities but leaves it essentially unchanged at low relative densities. Different combinations of parameter sensitivity values yield a huge range in the resistance to crowdedness. A high implicit land share is sufficient for resistance to be strong. But a low implicit land share does not guarantee weak resistance.

Resistance to crowding depends closely on land's share of housing factor income. Increasing it from 20% through its baseline value of 35% to 50% causes a large counterclockwise rotation of the $\widetilde{CV}$-to-density locus (Figure 3 Panel A). Whereas achieving a one-fourth density under the 20% housing land share requires a $\widetilde{CV}$ of -0.08, doing so with a 50% housing share requires a $\widetilde{CV}$ of -0.17. Whereas achieving a four-fold density under the former requires a $\widetilde{CV}$ of 0.11, doing so under the latter requires a $\widetilde{CV}$ of 0.26.

As is intuitive, a higher housing land share results in moderately larger variation in land prices and a considerably larger variation in housing prices. Under the low housing land share calibration, p_s rises from 0.78 to 1.46 as density rises from one quarter to four. Under the high housing land-share calibration, the range of variation is more than three times this, from 0.46 to 2.88.

Resistance to crowding is less sensitive to land's share of traded factor income. Increasing land's factor share of traded-good production from 0.4% through its baseline value of 1.6% to 4.8% does cause a counterclockwise rotation of the $\widetilde{CV}$-to-density locus (Figure 3 Panel

[8]Allowing for non-wage income strengthens the substitution effect. With factor payments recycled and $\sigma_{xh,leisure}$ equal to 1, leisure increases slightly with density.

[9]A supplemental table reports endogenous outcomes for "loose" and "tight" choices of all eight parameters at relative densities of one fourth and four.

B). But the rotation is quite small, especially moving from the low calibration to the baseline one and especially at high relative densities. Two underlying forces partly offset each other. On the one hand, increasing land's share of traded production makes such production more subject to congestion. On the other hand, doing so allows for a larger amount of land that can be pulled from traded into housing production. With land's traded factor share equal to 0.4%, the share of small-economy land devoted to housing rises only 9 percentage points as density increases from one quarter to four, from 86% to 96%. With land's traded factor equal to 4.8%, it rises 22 percentage points, from 59% to 86%. The ability to pull land out of traded production lessens resistance because of the greater difficulty substituting away from land in housing production.

Resistance to crowding also increases with housing's share of large-economy consumption expenditure (Figure 3 Panel C). Housing is the more land-intensive good, and so increasing its share of expenditure implicitly increases land's factor share of the large-economy consumption bundle. A high housing share also leaves less land in the traded-good production sector that can be pulled into the housing sector as crowdedness increases.

Just as resistance to crowding depends closely on the land share of housing production, it also depends closely on the elasticity with which housing production can be shifted away from land (Figure 3 Panel D). In this case, however, the sensitivity applies only at population densities above one. For $\sigma_{D,KL}$ equal to 1, supporting a four-fold density requires a $\widetilde{CV}$ equal to 0.14. Ratcheting $\sigma_{D,KL}$ down to 0.50 causes the required $\widetilde{CV}$ to nearly double to 0.26. Correspondingly, land and housing prices are considerably higher under the lower elasticity. In contrast, supporting a one-quarter density requires approximately the same $\widetilde{CV}$, regardless of $\sigma_{D,KL}$.

To understand this asymmetric sensitivity, realize that the housing production function becomes Leontief as $\sigma_{D,KL}$ goes to zero. The very high resistance to crowding at high population densities reflects substitution away from land along the vertical portion of a housing production isoquant (with land on the horizontal axis and the capital-labor composite on the vertical one). But at low population densities, substitution away from land involves movement along a much more horizontal portion of a housing isoquant. Indeed, at relative densities below one eighth, movement is along a sufficiently horizontal portion that resistance actually increases with substitutability.

Decreasing the consumption elasticity of substitution between the traded good and housing similarly increases resistance to crowding at high relative densities but not at low ones (Figure 3 Panel E). As is visually clear, the increase in resistance as $\sigma_{x,h}$ goes from 0.25 to 0.75 is considerably smaller than the increase in resistance as $\sigma_{D,KL}$ goes from 0.50 to 1. Accommodating individuals' low willingness to substitute away from housing proves easier than accommodating a low technological ability to substitute away from land.

The remaining elasticities, $\sigma_{xh,leisure}$ and $\sigma_{xhl,quality}$, along with the large-economy leisure share play little role in determining resistance to crowding. Resistance to crowding is ever-so-slightly higher when $leisure_l$ is calibrated to equal 0.50 rather than 0.20. This is a general equilibrium result whose mechanism is unclear. Resistance is also slightly higher when $\sigma_{xh,leisure}$ equals 0.25 rather than 1. In this case, less willingness to substitute into leisure when real wages are low—as they are in the crowded economy—requires a slightly greater compensating differential to support a given density. Finally, resistance is completely insensitive to $\sigma_{xhl,quality}$. To be sure, differences in it do affect the difference between $quality_s$ and $quality_l$ required to support a given density. But the actual *valuation* of that difference, along with all remaining endogenous variables, remain exactly the same.

Different combinations of the parameterization choices just discussed cause huge differences in resistance to crowdedness. A low-resistance combination that pairs together all of the low-land and high-elasticity sensitivity values from Panels A through E—as enumerated in the second column of Table 3—places a lower bound on plausible resistance to crowdedness (Figure 3 Panel F, dashed line). Moving from a one-quarter to a four-fold density requires $\widetilde{CV}$ to vary only from -0.05 to 0.05. In sharp contrast, a high-resistance combination that pairs together all of the high-land and low-elasticity sensitivity values places an upper bound on plausible resistance to crowdedness (Figure 3 Panel F, dashed-dotted line). In this case, moving from a one-quarter to a four-fold density requires $\widetilde{CV}$ to vary from -0.25 all the way to 0.52. This upper-bound range is nearly eight times that of the lower-bound one.

A different combination pairs together the high-land and high-elasticity values (Figure 3 Panel G, dashed-dotted line). It establishes that even with a relatively easy ability to substitute away from land, a large-economy consumption bundle with an implicit high land factor share suffices to cause stiff resistance to crowding. Conversely, a low implicit land share does *not* suffice to cause weak resistance. The combination of low-land and low-elasticity values indeed causes weak resistance at densities below one (Figure 3 Panel G, dashed line). But at densities above one, resistance rapidly increases.

All of the parameter combinations so far have assumed that individuals receive no non-wage income. Alternatively assuming that they do very slightly weakens resistance to crowding. For example, capital and land factor payments—which in the large economy together equal almost two thirds of wage income—might be rebated to individuals on a lump-sum basis (regardless of where they live) rather than paid to absentee owners. With consumption funded in part by such rebates, individuals are less negatively affected by the dampening of wages that accompanies crowding. But the decrease in resistance is negligible (Figure 3 Panel H).

5.3 Endogenous Productivity and Quality of Life

The numerical results so far have been premised on the exogeneity of productivity and quality of life. But a central tenet of urban economic theory is that firms' productivity is likely to increase with the scale and density of aggregate production (Marshall, 1890; Jacobs, 1969). Indeed, this productivity benefit to agglomeration is often taken as one of the main reasons for the existence of cities in the first place. Allowing productivity to depend on density can greatly lessen resistance to amenity-driven crowding. Similarly, it seems likely that increases in density from very low levels would increase quality of life. For example, moving from low to moderate density might facilitate social interaction, allow for greater product variety, and support the provision of public goods. It also seems likely that increases in density from very high levels would decrease quality of life. For example, such higher density might increase traffic, pollution, and other non-priced sources of congestion.

Figure 4 shows some some general equilibrium results from allowing TFP—for both traded goods and housing—to depend on density. A lower-bound estimate of the elasticity with which density *causes* total factor productivity to increase, υ_{TFP}, is 0.02 (Combes, Duranton, and Gobillon, 2004). In other words, $A_i = A \cdot density_i^{\upsilon_{TFP}}$. An upper-bound estimate of υ_{TFP} is 0.05 (Ciccone and Hall, 1996; Ciccone, 2002).[10]

Increasing the elasticity of TFP with respect to density causes a clockwise rotation of the $\widetilde{CV}$-density locus (Figure 4 Panel A). For υ_{TFP} equal to 0—that is, the maintained assumption above of no endogenous productivity—an increase in small-economy density from

[10]Estimates of the elasticity with which the *scale* of economic activity increases total factor productivity range from 0.04 to 0.08 (Rosenthal and Strange, 2004).

one quarter to four requires an increase in $\widetilde{CV}$ from -0.13 to 0.18. For υ_{TFP} equal to its lower-bound estimate, the required rise in $\widetilde{CV}$ is from -0.08 to 0.15. For υ_{TFP} equal to its upper-bound estimate, the required rise is from -0.02 to 0.09. The magnitudes of the quality-of-life differences required to match observed variations in crowdedness thus become easily plausible (Table 4).

With the high estimate of υ_{TFP}, resistance at densities below one is negligible. As stated immediately above, just a 2-percent $\widetilde{CV}$ deficit is sufficient to support a density of one quarter. The $\widetilde{CV}$-density locus actually bends back up towards zero as density decreases below one quarter. A density of one sixteenth can be supported by a $\widetilde{CV}$ just a tad below zero. Such extreme lack of resistance captures that υ_{TFP} equal to 0.05 is nearly sufficient to offset endogenous, priced congestion as density varies below the large-economy level (Rappaport, 2006b).

The endogenous increase in productivity with density can reverse the amenity-driven negative correlation between wages and density. As υ_{TFP} increases, the wage-density locus rotates in a counterclockwise direction (Figure 4 Panel B). Any increase in productivity puts upward pressure on wages. A value of υ_{TFP} equal to its lower-bound estimate is sufficient to completely eliminate the inverse correlation of wages with density. Instead, wages approximately equal their large-economy value regardless of small-economy density. A value of υ_{TFP} equal to its upper bound estimate causes wages to increase moderately with density.

The assumption, so far, that quality of life is exogenous has actually been superfluous. The required $\widetilde{CV}$-to-density locus holds regardless of the *source* of quality-of-life differences. Allowing quality of life to partly depend on density, rather than just the reverse, simply adds an extra system equation.

Figure 5 shows the effect of relaxing the exogeneity assumption. Quality of life is assumed to have both an exogenous and an endogenous component. The circles along the vertical axis represent four different possible levels of exogenous consumption amenities. Exogeneity, in this case, denotes a contribution to quality of life independent of density. It can be formalized as the level of quality of life at a unitary density. For illustrative purposes, the endogenous component of quality of life is assumed to increase as density rises to an intermediate level above one and then to decrease as it rises further. The resulting concave loci are shifted up and down by the exogenous component. Actual combinations of density and quality of life come at the intersections of the endogenous and required loci.

Very little empirical evidence exists on the endogenous response of quality of life to density. A first, obvious problem is that quality of life is not observable. Even if it were, a second problem would be identification. To the extent that population mobility is indeed high, as assumed herein, and controlling for differences in productivity across localities, the observed correlation between density and quality of life would identify the required relationship, rather than the endogenous one.

6 Empirics: the Importance of Quality of Life

The generalized version of the static model above has just two possible sources of variations in local crowdedness: variations in quality of life and variations in productivity. Within a dynamic context, the model suggests that *changes* in quality of life and productivity will be the main source of variations in local growth. An obvious question, then, is how important are the quality-of-life variations relative to the productivity ones?

Empirical evidence suggests, first, that quality-of-life differences are indeed an important factor underpinning differences in current population density. In particular, density is strongly positively correlated with several quality-of-life indices based on subjective criteria. Moreover, population growth is strongly positively correlated with several exogenous consumption amenities, suggesting that the importance of quality of life as a source of local crowdedness is increasing. Nevertheless, the positive empirical correlation between wages and density suggests that variations in productivity are likely to be the more important factor underpinning the current cross-sectional distribution of population density.

Figure 5 illustrates two distinct predicted correlations between density and quality of life. The first is that density should be positively correlated with exogenous amenities. In other words, higher intercepts of the endogenous curves are associated with higher density intersections with the required $\widetilde{CV}$ curve.[11] The second is that density should be positively correlated with overall quality of life, which is the vector product of all locality attributes and the quality-of-life contribution from each. As long as a locality's productivity remains

[11]A sufficiently steep endogenous curve might also seem to suggest that higher exogenous amenities could be associated with lower density. However, any intersection of the endogenous and required curves at a density below one would be unstable.

constant, its required locus remains constant as well. Thus, shifts in the endogenous locus, whatever its slope, identify the required locus.

Of course, productivity also varies across localities. It can do so exogenously, due to local characteristics such as access to raw materials and navigable water, thereby vertically shifting the required $\widetilde{CV}$ locus. And as discussed in the previous section, it can also do so endogenously, thereby causing a rotation of the required locus. To the extent that either exogenous or endogenous sources of quality of life and productivity are positively correlated, the positive correlation of density with quality of life will increase. To the extent that quality of life and productivity are negatively correlated, density's positive correlation with quality of life will decrease.

Empirically, the correlation of density with exogenous consumption amenities is ambiguous. Coastal proximity seems one obvious exogenous amenity. Density is, indeed, strongly positively correlated with it, even after including measures of proximity to harbors in order to control for productivity differences (Rappaport and Sachs, 2003). But density's correlation with another obvious amenity, nice weather in the form of warm winters and cool summers, can be positive, negative, or zero, depending on the exact specification.

Evidence of a positive correlation of population *growth* with exogenous consumption amenities is much stronger. Growth, like density, is strongly positively correlated with coastal proximity, again controlling for proximity to harbors (Rappaport and Sachs, 2003). And growth is strongly and robustly positively correlated with nice weather.(Rappaport, 2006a).[12]

There is also some ambiguity on the correlation of density with overall quality of life. Among four leading studies that take the compensating-differential approach, only one estimates a quality-of-life index with which density is positively correlated (Table 5, Panel A). More specifically, estimated compensating differentials summed with median household income give the expenditure required to attain a nationwide reservation level of utility: $e(quality_i)$, with $e'(\cdot)$ negative. Only for Gabriel and Rosenthal (2004) is the elasticity of density with respect to this estimated expenditure negative, which implies that density is positively correlated with quality of life. Two of the remaining studies cannot reject an

[12] Some portion of this move to nicer weather likely stems from the advent of air conditioning and increased mobility of the elderly. But Rappaport (2006a) argues that a large portion is indeed due to an increased valuation of nice weather as a consumption amenity.

absence of correlation between density and overall quality of life. The Gyourko and Tracy (1991) study finds a statistically-significant negative correlation of density with quality of life.

A drawback of the compensating-differential studies, however, is that quality of life is estimated with large measurement error. Important sources of error include unobserved individual- and house-specific attributes and omitted variables that are correlated with the measured ones (Gyourko, Tracy, Kahn, 1999; Combes, Duranton, Gobillon, 2004). Such measurement error strongly biases the quality-of-life rankings if, for example, observed positive differences in wages reflect unobserved higher skills rather than lower quality of life. Certainly, the estimated indices seem to grossly misrank quality of life for many specific localities. Among 253 urban counties in 1980, Blomquist et al. (1988) rank San Francisco County number 105, neighboring Marin County number 142, and New York County (Manhattan) number 216. Among 130 large cities in 1980, Gyourko and Tracy (1991) rank Miami number 86, Seattle number 104, and Ann Arbor number 115. Numerous other apparent gross misrankings are easily identified.

An alternative approach to measuring quality of life is to grade localities based using subjective criteria. For example, Savageau (2000) ranks 327 continental U.S. metro areas in each of seven quality-of-life categories: transportation, education, climate, crime, the arts, health care, and recreation. Each of these categories, in turn, is divided into two or more subcategories that can be objectively measured. For example, the transportation category is constructed as a weighted average of daily commute time, public transit revenue-miles, passenger rail departures, interstate highway proximity, nonstop airline destinations, and proximity to other metro areas. The arts category is constructed as a weighted average of number of art museums, museum attendance, per-capita museum attendance, ballet performances, touring artist bookings, opera performances, professional theater performances, and symphony performances. An overall quality-of-life index is then constructed as a weighted average of scores in each of the seven categories. Sperling and Sander (2004) similarly rank 329 continental U.S. metro areas in eight quality-of-life categories.[13]

Population density is strongly positively correlated with both the Savageau and Sperling and Sander overall quality-of-life indices (Table 5, Panels B and C). The Spearman

[13]Savageau (2000) and Sperling and Sander (2004) also include job-opportunity and cost-of-living categories. The overall quality-of-life rankings used herein exclude these.

correlation coefficient of density with the former is 0.42 and with the latter is 0.49. Both statistically differ from zero at the 0.01 level. Density is similarly positively correlated with indices for nearly all of the subsidiary quality-of-life categories. The only exceptions are a small, negative correlation with the Savageau crime index and a moderately strong, negative correlation with the Sperling and Sander health and healthcare index.[14]

To the extent that these subjective quality-of-life rankings seem more reasonable than those of the compensating-differential literature, there is thus strong evidence that quality-of-life differences help underpin density differences. The likelihood that many of the ranked quality-of-life attributes may themselves be the endogenous result of density differences is largely beside the point. However, the relatively low, positive correlations of density with the climate rankings along with the ambiguous partial correlation of density with nice weather attributes does suggest that quality of life may serve mainly as a reinforcing mechanism for productivity-driven differences in density rather than as an exogenous impetus. Conversely, the strong, positive partial correlation of population *growth* with nice weather suggests that quality of life may be becoming a more primary source of people's location decisions. A similar conclusion is reached by Glaeser, Kolko, and Saiz (2001), who find that recent population growth in cities has been positively correlated with several consumption-amenity measures.

The observed positive correlation between wages and density places an upper bound on quality of life as a source of local crowdedness. It stands in sharp contrast to the predicted negative correlation of wages with density that follows from solely quality-of-life driven crowding (Table 6). The positive empirical correlation between wages and density is especially strong using aggregate data: Rappaport (2006b) estimates the elasticity of average labor income with respect to metro-area density to be 0.20. But much of this positive aggregate correlation likely arises from unobserved individual characteristics. Allowing for individual fixed effects, Combes et al. (2003) estimate the elasticity of wages with density to be a more modest 0.05.[15]

The modest magnitude of the positive correlation of wages with density estimated by Combes et al. also suggests a positive *lower* bound on the importance of quality of life

[14]The Spearman correlation coefficient between the two overall indices is 0.65. Correlation coefficients between comparable categories range from 0.77 for climate down to 0.18 for health and healthcare.

[15]For low- and average-skilled workers in the medical profession, Lee (2005) similarly finds wages to be increasing with city size. But for very high-skilled medical workers, he finds wages to be decreasing with city size.

in supporting observed density differences. With solely productivity-driven crowding, the present model predicts the elasticity of wages with density to be 0.08 under the baseline calibration. Bringing this wage-to-density elasticity down to the Combes et al. estimate requires that quality of life and productivity move in parallel.

Overall, the empirics suggest that quality of life does indeed help underpin differences in population density. Either the level of population or its growth rate is strongly positively correlated with several exogenous amenities. And population density is strongly positively correlated with two separate rankings of overall quality of life based on subjective criteria. But to match the observed positive correlation of wages and density requires that productivity be a more important source of crowdedness than is quality of life.

7 Conclusions

Crowdedness varies hugely across U.S. cities. A calibrated general equilibrium model suggests that plausible differences in cities' consumption amenities can account for most of such variation. Under a baseline calibration, a compensating variation equivalent to 30 percent of large-economy consumption expenditure supports the twenty-fold observed difference in crowdedness between the second-most and least dense metropolitan areas. Sensitivity analysis shows that resistance to crowdedness depends closely on the housing production function as well as on the implicit land share of large-economy consumption. A high implicit land share is a sufficient, but not necessary, condition for high resistance to crowding.

The model illustrates how several endogenous outcomes co-vary with density. Under the baseline calibration, wages fall slightly with density, house prices rise moderately, and land prices rise hugely. Compensation for high quality of life is thus primarily capitalized into land and house prices rather than into wages. In return for enjoying high quality of life, individuals sacrifice small amounts of traded-good and leisure consumption and a large amount of housing consumption.

Empirical analysis finds a strong positive correlation between population density and two subjective measures of metro-area overall quality of life. This suggests that variations in quality of life indeed help underpin variations in population density. Strong positive correlations between population growth and several exogenous consumption amenities suggest that quality of life is becoming a more important determinant of where people choose to live. But the empirical positive correlation of population density with wages establishes that variations in productivity are the more important source of current variations in crowdedness.

The present, simple model is an ideal platform on which to build a richer framework. One important direction in which to do so is to allow for the endogenous determination of land size. The elasticity of population density with respect to total population suggests that two thirds of the population attracted to higher productivity and quality of life "spills" over into larger land size rather than higher density (Table 1, bottom line). Another obvious direction is to introduce heterogeneity among individuals, either in terms of skills or wealth. Heterogenous skills together with variations in productivity suggests that cities will tend to specialize in some production technologies rather than others as in Duranton and Puga (2001) and Caselli and Coleman (2006). Heterogenous wealth together with variations in quality of life suggests that the rich will outbid the poor to live in high-amenity cities as in Gyourko, Mayer, and Sinai (2006). Without any modification to the model, technological progress in the form of shared TFP growth across economies implies migration—under the baseline calibration—to cities where quality of life is highest (Rappaport, 2004).

More generally, the paper's model and results emphasize the need to better understand the sources of local productivity and quality of life. Along with the availability of land, productivity and quality of life typically suffice as the sole "fundamental" sources of variations in local size and density. That is, any story of different outcomes usually maps to a story of different productivity facing firms and different quality of life facing individuals. Even path dependence can be seen as being mediated via these two mechanisms. The present model thus serves as an ideal simple framework to evaluate local public policy and predict future local growth.

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Table 1: Variations in Population Density

Rankings by population density in 2000 of continental U.S. metro areas with population of at least 100,000. Metro area delineations are based on 2003 OMB standard. Density, measured as thousand persons per square mile, is calculated as a population-weighted mean of county-subdivision-place/remainder densities.

Rank	Metropolitan Area	Density	
1	New York-Nrthrn New Jersey-Long Island, NY-NJ-PA	18.9	
2	Los Angeles-Long Beach-Santa Ana, CA	7.8	
3	San Francisco-Oakland-Fremont, CA	7.2	
4	Chicago-Naperville-Joliet, IL-IN-WI	6.7	
5	Miami-Fort Lauderdale-Miami Beach, FL	5.8	
6	Philadelphia-Camden-Wilmington, PA-NJ-DE-MD	5.2	
7	San Jose-Sunnyvale-Santa Clara, CA	5.1	**6.8**
8	Boston-Cambridge-Quincy, MA-NH	5.0	**times**
9	Salinas, CA	4.7	
10	Washington-Arlington-Alexandria, DC-VA-MD-WV	4.5	
11	Trenton-Ewing, NJ	4.4	
12	Modesto, CA	4.2	
13	Baltimore-Towson, MD	4.0	
14	Oxnard-Thousand Oaks-Ventura, CA	3.9	
15	Milwaukee-Waukesha-West Allis, WI	3.8	
16	Detroit-Warren-Livonia, MI	3.8	
17	Las Vegas-Paradise, NV	3.7	
18	Laredo, TX	3.7	
19	San Diego-Carlsbad-San Marcos, CA	3.7	
20	Santa Cruz-Watsonville, CA	3.7	
:	:	:	
:	:	:	
48	Tampa-St. Petersburg-Clearwater, FL	2.8	
49	Pittsburgh, PA	2.8	
50	**population median** (Omaha-Council Bluffs, NE-IA)	2.8	
51	Lincoln, NE	2.7	**49**
52	St. Louis, MO-IL	2.7	**times**
:	:	:	
:	:	:	
328	Anniston-Oxford, AL	0.5	
329	Morristown, TN	0.5	
330	Ocala, FL	0.5	
331	Bangor, ME	0.4	
332	Dothan, AL	0.4	

share of continental U.S. population: 82.0%
share of continental U.S. land area: 27.7%

elasticity with respect to population: ε = 0.34 (0.02); R^2 = 0.39

Table 2: Ranking Quality of Life

A. Subjective Methodology

Rank	Savageu (2000)	Sperling and Sander (2004)
1	San Francisco, CA	New York, NY
2	Washington, DC-MD-VA-WV	Nassau-Suffolk, NY
3	Boston, MA-NH	Seattle-Belevue-Everett, WA
4	Seattle-Bellevue-Everett, WA	San Francisco, CA
5	Orange County, CA	Boston, MA-NH
6	Nassau-Suffolk, NY	Ann Arbor, MI
7	San Jose, CA	Portland-Vancouver, OR-WA
8	Raleigh-Durham-Chapel Hill, NC	Boulder-Longmont, CO
9	Pittsburgh, PA	Washington, DC-MD-VA-WV
10	Salt Lake City-Ogden, UT	Pittsburgh, PA
11	Denver, CO	Atlanta, GA
12	New York, NY	Middlesex-Somerset-Hunterdon, NH
13	San Diego, CA	Stamford-Norwalk, CT
14	Minneapolis-St. Paul, MN-WI	Santa Fe, NM
15	Philadelphia, PA-NJ	Corvallis, OR
16	Rochester, NY	San Diego, CA
17	Cincinnati, OH-KY-IN	Denver, CO
18	Cleveland-Lorain-Elyria, OH	Madison, WI
19	Syracuse, NY	Santa Barbara-Santa Maria-Lompoc, CA
20	Milwaukee-Waukesha, WI	Bergen-Passaic, NJ

B. Compensating Differential Methodology

Rank	Blomquist, Berger, and Hoehn (1988)	Gyourko and Tracy (1991)
1	Pueblo, CO	Norwalk, CT
2	Norfolk-Virginia Beach-Portsmouth, VA	Pensacola, FL
3	Denver-Boulder, CO	Gainesville, FL
4	Macon, GA	San Diego, CA
5	Reno, NV	Stamford, CT
6	Binghamton, NY	Columbia, SC
7	Newport News-Hampton, VA	Santa Rosa, CA
8	Sarasota, FL	Bridgeport, CT
9	West Palm Beach-Boca Raton, FL	Tucson, AZ
10	Tuscon, AZ	Shreveport, LA
11	Fort Lauderdale-Hollywood, FL	Lancaster, PA
12	Fort Collins, CO	Modesto, CA
13	Charleston-North Charleston, SC	Asheville, NC
14	Salinas-Seaside-Monterey, CA	New Orleans, LA
15	Roanoke, VA	Fall River, MA
16	Lackawanna, PA	Danbury, CT
17	Tallahasee, FL	Amarillo, TX
18	Richmond, VA	Jacksonville, FL
19	Lexington-Fayette, KY	San Francisco, CA
20	Santa Barbara-Santa Maria-Lompoc, CA	San Jose, CA

Subjective rankings are based on approximately contemporary data. Compensating differential rankings are based on 1980 census data. For Blomquist et al., listed metro areas are location of ranked counties. Subjective rankings are weighted averages of a number of quality-of-life categories; they differ from published summary rankings in that they exclude jobs and cost-of-living categories.

Table 3: Baseline and Alternative Calibrations

Parameter	Base	Low Resistance* ("Loose")	High Resistance* ("Tight")
Factor Income Shares (large economy)			
Traded Good: Land, Capital, Labor	**1.6%, 32.8%, 65.6%**	0.4%, 33.2%, 66.4%	4.8%, 31.7%, 63.5%
Housing: Land, Capital, Labor	**35%, 21.7%, 43.3%**	20%, 26.7%, 53.3%	50%, 16.7%, 33.3%
Housing Production CES ($\sigma_{D,KL}$)	**0.75**	1	0.50
Required Capital Rent (r_K)	**0.08**		
Utility CES Parameters			
$\sigma_{x,h}$	**0.50**	0.75	0.25
$\sigma_{xh,leisure}$	**0.50**	1	0.25
$\sigma_{xhl,quality}$	**0.50**		
Consumption Expenditure Shares (large economy)			
Housing	**18%**	14%	22%
Leisure (share of time)	**35%**	20%	50%

*Note: The CES substitution parameters ($\sigma_{D,KL}$, and $\sigma_{x,h}$) have an asymmetric effect on resistance. The "loose" values above are those for which resistance is lower at a relative density of one and above.

Table 4: Variations in Quality of Life

Model, Required Compensating Variation	
Most Dense (NYC) to Least Dense (Dothan AL)	
No endogenous productivity	45%
Endogenous productivity, υ_{TFP}= 0.02	34%
Endogenous productivity, υ_{TFP}= 0.05	17%
Second-most Dense (Los Angeles) to Least Dense (Dothan AL)	
No endogenous productivity	30%
Endogenous productivity, υ_{TFP}= 0.02	21%
Endogenous productivity, υ_{TFP}= 0.05	7%
Estimated Compensating Differential Range	
Bloomquist et. al (1988)	31%
Gyourko and Tracy (1991)	49%
Gabriel and Rosenthal (2004)	38%
Chen and Rosenthal (2006)	26%

Modeled compensating variation is reported relative to large economy income. Estimated compensating differential range is reported relative to median household income.

Table 5: Density and Quality of Life

A. Correlation of Density with Required Expenditure	
Modeled Elasticity	
No endogenous productivity	-0.108
Endogenous productivity, υ_{TFP}= 0.02	-0.079
Endogenous productivity, υ_{TFP}= 0.05	-0.035
Estimated Elasticity (std. error)	
Bloomquist et al. (1988) 130 urban counties, 1980	-0.000 (0.004)
Gyourko and Tracy (1991), 127 metro central cities, 1980	0.026 (0.012)
Gabriel and Rosenthal (2004) 37 metro areas, 1977–to–1995 avg.	-0.051 (0.018)
Chen and Rosenthal (2006) 293 metro areas, 2000	0.006 (0.004)
B. Correlation with Savageau (2000) ranking, 327 metro areas	
Spearman's Rank Correlation (p-value)	
Overall Ranking	0.42 (p=0.00)
Climate	0.10 (p=0.08)
Transportation	0.39 (p=0.00)
Education	0.31 (p=0.00)
Healthcare	0.20 (p=0.00)
Crime	-0.05 (p=0.38)
The Arts	0.49 (p=0.00)
Recreation	0.34 (p=0.00)
C. Correlation with Sperling and Sander (2004) ranking, 329 metro areas	
Spearman's Rank Correlation (p-value)	
Overall Ranking	0.49 (p=0.00)
Climate	0.14 (p=0.01)
Transportation	0.38 (p=0.00)
Education	0.29 (p=0.00)
Health & Healthcare	-0.40 (p=0.00)
Crime	0.18 (p=0.00)
Arts & Culture	0.43 (p=0.00)
Leisure	0.59 (p=0.00)
Attractiveness/Heritage/Ease of Living	0.31 (p=0.00)

Blomquist et al. and Gyourko and Tracy correlations are with density in 1990.
Remaining correlations are with density in 2000.

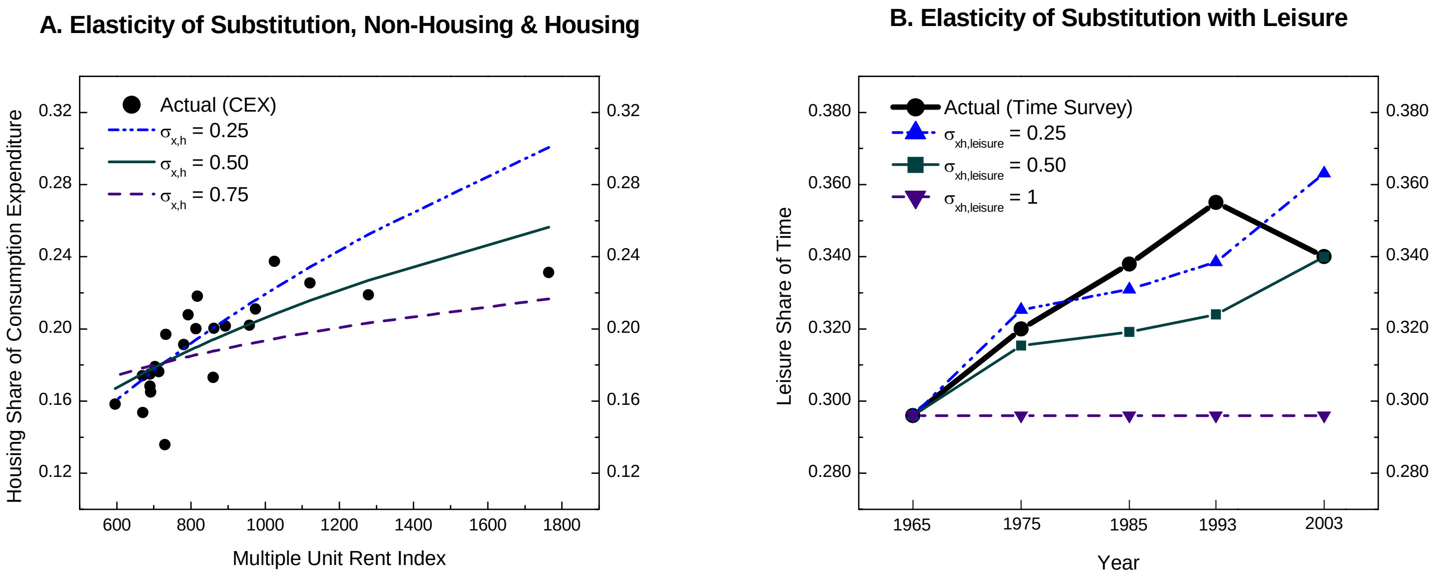
Table 6: Elasticity of Wages with Density

Model, Quality-of-Life-Driven Crowding	
No endogenous productivity	-0.031
Endogenous productivity, υ_{TFP}= 0.02	-0.001
Endogenous productivity, υ_{TFP}= 0.05	0.044
Model, Productivity-Driven Crowding	0.079
Estimated Correlation (std. error)	
Rappaport (2006b), aggregate data	0.200 (0.025)
Combes et al. (2003), micro data	0.049 (0.004)

Supplemental Table: Sensitivity of Crowding Outcomes

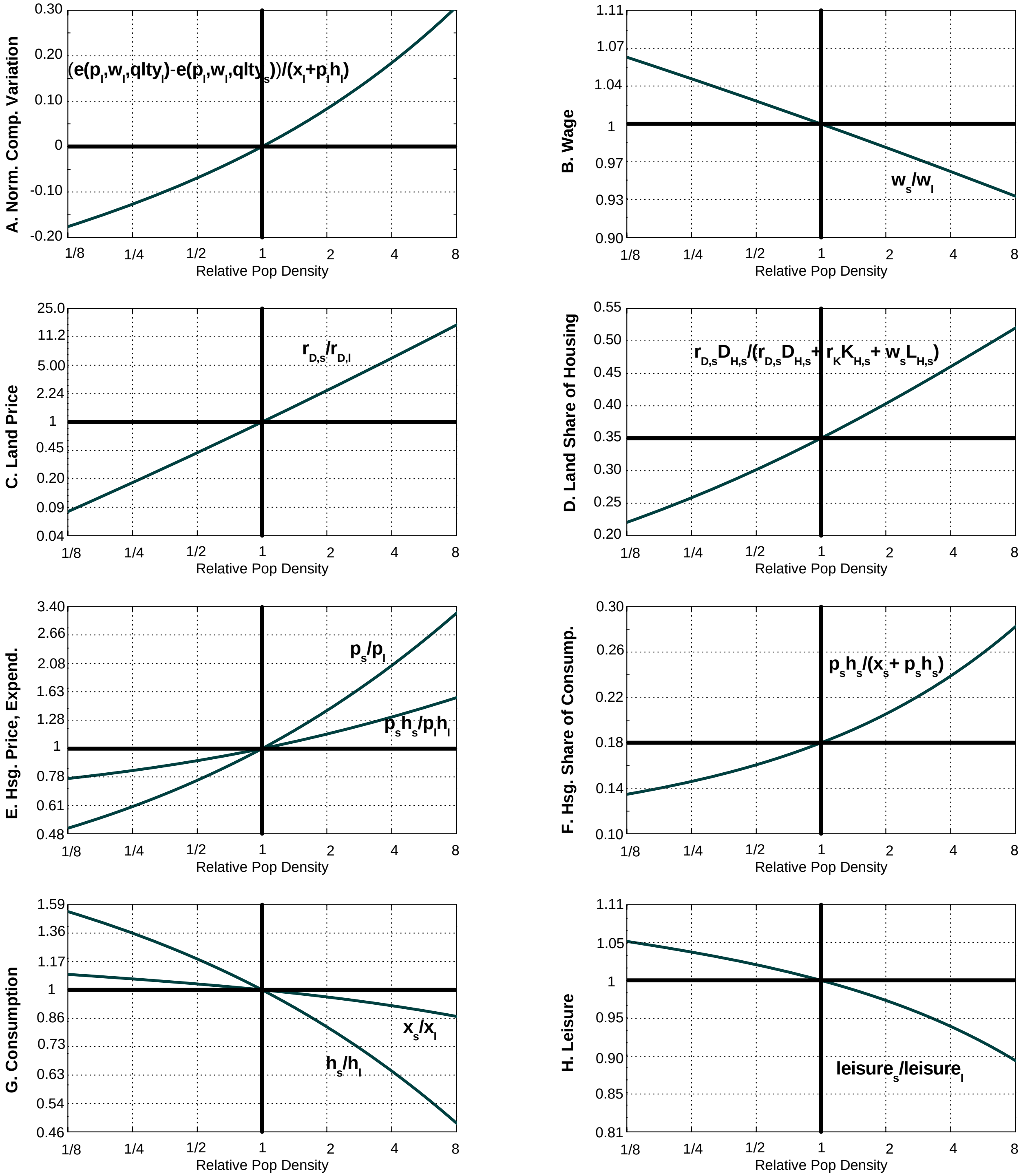
Small-Economy Outcome →	Norm CV		w		h share of D		r_D		D share of r_D		p		p h		(ph)/(x+ph)		x		h		leisure	
at rel. density → ↓ Parameterization ↓	1/4	4	1/4	4	1/4	4	1/4	4	1/4	4	1/4	4	1/4	4	1/4	4	1/4	4	1/4	4	1/4	4
Baseline	-0.13	0.18	1.04	0.96	0.63	0.83	0.18	6.12	0.26	0.46	0.61	2.04	0.83	1.31	0.15	0.24	1.06	0.92	1.36	0.64	1.04	0.94
Traded-Good Factor Shares																						
D=0.4%, K=33.2%, L=66.4%	-0.10	0.17	1.01	0.99	0.86	0.95	0.15	7.22	0.25	0.47	0.57	2.23	0.78	1.40	0.14	0.25	1.04	0.94	1.38	0.63	1.03	0.94
D=4.8%, K=31.7%, L=63.5%	-0.19	0.22	1.12	0.89	0.37	0.59	0.23	4.75	0.27	0.45	0.67	1.77	0.91	1.16	0.15	0.23	1.12	0.87	1.37	0.65	1.06	0.93
Housing Factor Shares																						
D=20%, K=26.7%, L=53.3%	-0.08	0.11	1.04	0.96	0.51	0.73	0.20	5.40	0.14	0.28	0.78	1.46	0.92	1.14	0.16	0.21	1.05	0.94	1.19	0.78	1.03	0.96
D=50%, K=16.7%, L=33.3%	-0.17	0.26	1.05	0.95	0.68	0.88	0.16	6.76	0.39	0.62	0.46	2.88	0.73	1.51	0.13	0.27	1.08	0.89	1.59	0.52	1.05	0.91
Housing Production CES																						
$\sigma_{D,KL}$ = 1	-0.12	0.14	1.04	0.96	0.69	0.78	0.22	4.60	0.35	0.35	0.60	1.68	0.82	1.21	0.14	0.22	1.06	0.94	1.37	0.72	1.04	0.95
$\sigma_{D,KL}$ = 0.50	-0.13	0.26	1.05	0.95	0.52	0.88	0.14	8.81	0.17	0.62	0.63	2.81	0.84	1.49	0.15	0.27	1.07	0.89	1.35	0.53	1.04	0.91
Utility CES, Traded and Housing																						
$\sigma_{x,h}$ = 0.75	-0.13	0.16	1.04	0.96	0.66	0.80	0.19	5.33	0.26	0.45	0.62	1.92	0.92	1.13	0.16	0.21	1.04	0.96	1.49	0.59	1.04	0.95
$\sigma_{x,h}$ = 0.25	-0.13	0.22	1.04	0.95	0.59	0.86	0.17	7.22	0.25	0.47	0.60	2.20	0.74	1.56	0.13	0.28	1.08	0.86	1.23	0.71	1.04	0.93
Utility CES, with Leisure																						
$\sigma_{xh,leisure}$ = 1	-0.13	0.18	1.04	0.96	0.63	0.83	0.18	5.86	0.26	0.46	0.61	2.01	0.85	1.26	0.15	0.24	1.08	0.89	1.39	0.63	1.00	1.00
$\sigma_{xh,leisure}$ = 0.25	-0.13	0.19	1.04	0.96	0.62	0.83	0.18	6.25	0.26	0.46	0.60	2.06	0.82	1.34	0.15	0.24	1.05	0.93	1.35	0.65	1.06	0.91
Utility CES, with Quality-of-Life																						
$\sigma_{xhl,quality}$ = 1	-0.13	0.18	1.04	0.96	0.63	0.83	0.18	6.12	0.26	0.46	0.61	2.04	0.83	1.31	0.15	0.24	1.06	0.92	1.36	0.64	1.04	0.94
$\sigma_{xhl,quality}$ = 0.25	-0.13	0.18	1.04	0.96	0.63	0.83	0.18	6.12	0.26	0.46	0.61	2.04	0.83	1.31	0.15	0.24	1.06	0.92	1.36	0.64	1.04	0.94
Housing Expenditure Share																						
$p_i h_i/(x_i+p_i h_i)$ = 0.14	-0.11	0.15	1.04	0.96	0.56	0.79	0.19	5.96	0.26	0.46	0.61	2.02	0.83	1.32	0.11	0.19	1.06	0.93	1.35	0.65	1.03	0.95
$p_i h_i/(x_i+p_i h_i)$ = 0.22	-0.15	0.21	1.04	0.96	0.68	0.86	0.18	6.21	0.26	0.46	0.60	2.06	0.83	1.30	0.18	0.29	1.07	0.91	1.38	0.63	1.05	0.93
Leisure Share of Time																						
$leisure_i$ = 0.20	-0.13	0.18	1.04	0.96	0.63	0.83	0.18	6.00	0.26	0.46	0.61	2.03	0.84	1.29	0.15	0.24	1.07	0.91	1.37	0.64	1.05	0.93
$leisure_i$ = 0.50	-0.13	0.19	1.04	0.96	0.62	0.83	0.18	6.24	0.26	0.46	0.60	2.06	0.82	1.34	0.15	0.24	1.05	0.93	1.35	0.65	1.03	0.95
Combination Parameterizations:																						
low land, high σ	-0.05	0.05	1.01	0.99	0.82	0.84	0.24	4.17	0.20	0.20	0.76	1.32	0.95	1.05	0.13	0.15	1.02	0.98	1.26	0.80	1.00	1.00
high land, low σ	-0.26	0.59	1.15	0.84	0.37	0.83	0.16	9.50	0.28	0.77	0.52	4.05	0.70	2.11	0.15	0.45	1.13	0.74	1.33	0.52	1.10	0.77
low land, low σ	-0.05	0.18	1.01	0.98	0.61	0.96	0.11	15.14	0.08	0.49	0.76	2.48	0.84	1.76	0.12	0.24	1.03	0.89	1.11	0.71	1.03	0.89
high land, high σ	-0.25	0.24	1.11	0.90	0.58	0.64	0.26	3.88	0.50	0.50	0.53	1.90	0.98	1.02	0.19	0.25	1.15	0.87	1.86	0.54	1.00	1.00
Alternative Assumptions:																						
With Capital Income	-0.11	0.17	1.04	0.96	0.73	0.90	0.17	6.51	0.25	0.46	0.60	2.10	0.82	1.33	0.14	0.24	1.06	0.92	1.37	0.63	1.04	0.94
Endogenous TFP																						
υ = 0.02	-0.08	0.15	1.00	1.00	0.62	0.83	0.17	6.35	0.15	0.24	0.61	2.05	0.80	1.36	0.15	0.24	1.03	0.95	1.32	0.66	1.03	0.95
υ = 0.05	-0.02	0.09	0.94	1.06	0.62	0.83	0.16	6.71	0.15	0.24	0.60	2.07	0.76	1.44	0.15	0.24	0.98	1.00	1.26	0.70	1.01	0.97

Figure 1: Calibration of Consumption Elasticities



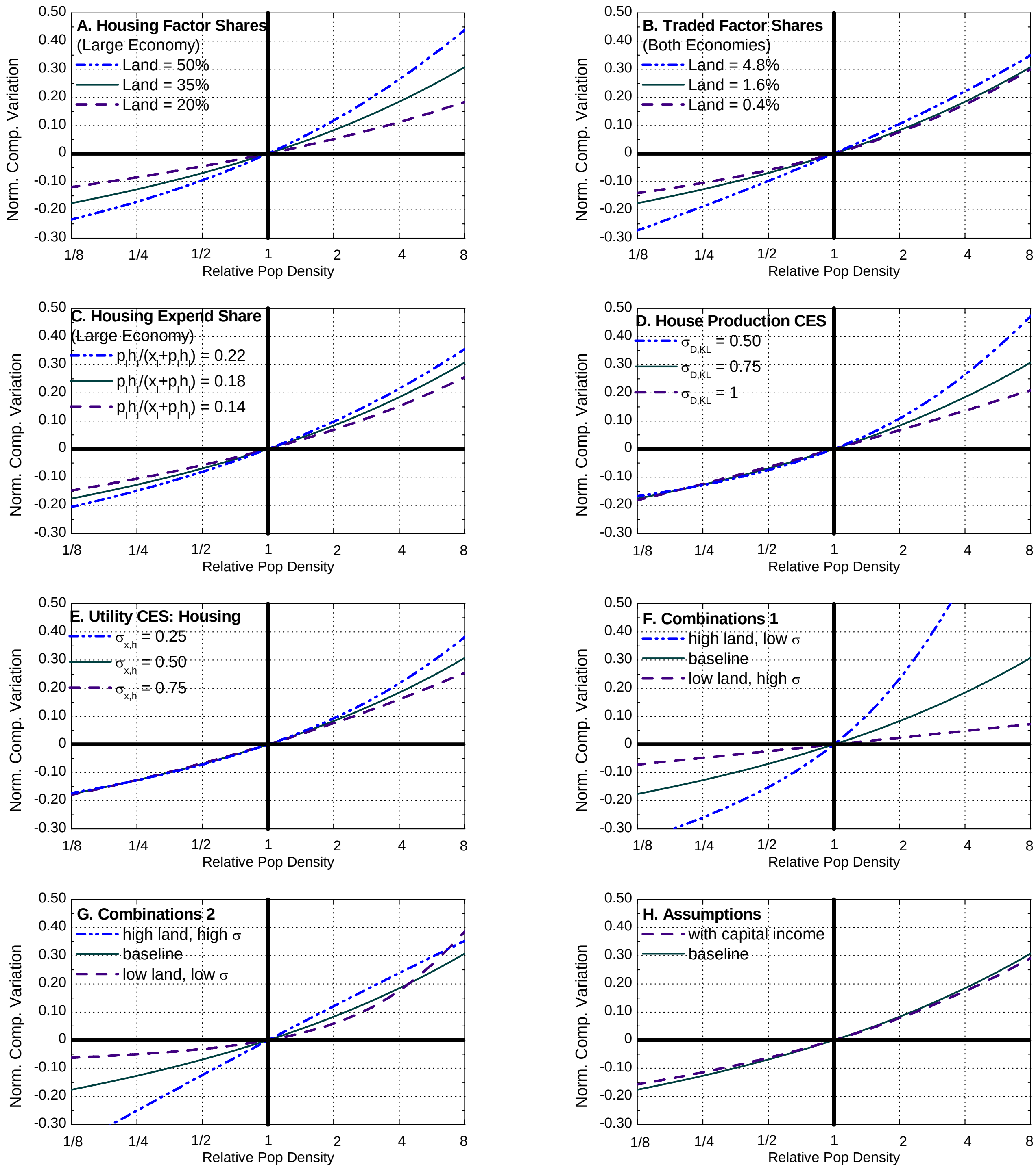
Panel A: Dots plot aggregate share of consumption devoted to shelter in each of 24 large metro areas (BLS Consumer Expenditure Survey, 1997–to–2002 average) against Torto-Wheaton multi-unit rental price index (1997–to–2002 average). Lines represent expected housing shares against the price index for each of three elasticity parameters. **Panel B**: Bold line plots actual leisure share of time for each of four years. Remaining lines plot expected leisure share given the real wage in each year (BLS hourly compensation divided by CPI) for each of three elasticity parameters.

Figure 2: Amenity-Driven Crowding



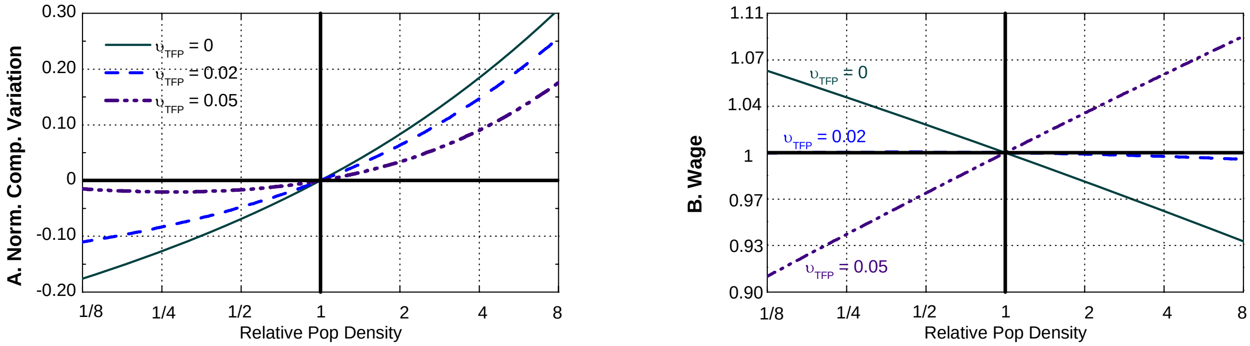
Panel A shows the difference between small-economy and large-economy quality of life, measured as a compensating transfer to large-economy residents as a share of their income, required to achieve different relative densities under the baseline calibration. Remaining panels show implied ratios of various endogenous variables. Horizontal axes are plotted using a log scale. Vertical axes are also plotted using a log scale, except in panels A, D and F.

Figure 3: Amenity-Driven Crowding, Sensitivity



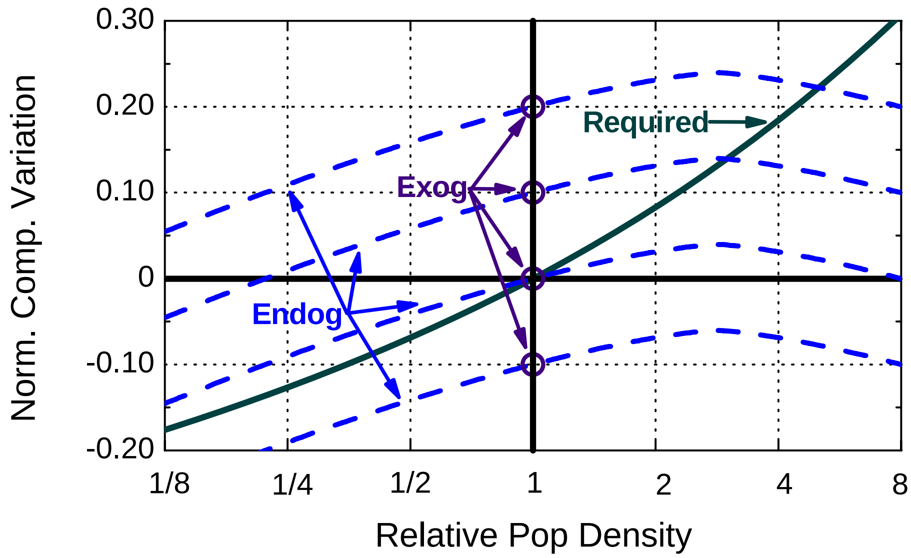
Panels show the difference between small-economy and large-economy quality of life, measured as a compensating transfer to large-economy residents as a share of their income, required to achieve different relative densities under variations from the baseline calibration. Horizontal axes are plotted using a log scale.

Figure 4: Amenity-Driven Crowding with Endogenous Productivity



Loci assume alternative endogenous TFP elasticities---both for traded good and housing---with respect to density, υ_{TFP}. All parameters are set at their baseline value.

Figure 5: Endogenous Quality of Life



Exogenous quality of life is the normalized CV at a unitary density. Actual density occurs at the intersection of the endogenous and required loci.