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Consumption Amenities and City Population Density

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Abstract: Population density, or "crowdedness," varies widely among U.S. cities. A simple, static general equilibrium model suggests that moderate differences in cities' consumption amenities can account for much of the observed variation in crowdedness. Empirical results confirm that amenities help support high density levels and suggest that they are becoming a more important determinant of where people choose to live. However, local productivity probably remains the more important cause of local crowdedness.

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

JEL classification: R00, J00, I31

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1 Introduction

Population density, or "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 this variation (Rappaport, 2007c). Such productivity variations may, in part, arise endogenously from increasing returns to scale. However, estimates of the higher productivity *caused* by above-average population density fall considerably short of the higher productivity *required* to support such density. The estimates suggest a doubling of density increases productivity 3 to 5 percent. Numerical results suggest that doubling density requires an increase in productivity of approximately 8 percent. To what extent might consumption amenities, or "quality of life," make up this difference between the implied TFP and the required TFP? More generally, are the amenity differences required to account for the observed range of population density plausible?

To answer these questions, the present paper lays out and calibrates a simple, static general equilibrium model of city density. 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 model is a generalization of Rappaport (2007c) and is similar to models in Henderson (1974, 1987, 1988), Haurin (1980), Upton (1981), and Haughwout and Inman (2001). The model's 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 much of the observed variation in density. Under a baseline calibration, a compensating variation equivalent to 30 percent of average consumption expenditure supports the twenty-fold observed difference in density between the second-most and least crowded metropolitan areas. This variation is within the range of compensating differentials estimated by numerous researchers. 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. However, the positive empirical correlation of wages and density suggests that local productivity remains the more important cause of local crowdedness.

The paper proceeds as follows. Section 2 describes the paper's empirical motivation: the wide variations in population density 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 population density but that variations in productivity are a more important cause. A last section briefly concludes.

2 Empirical Motivation

Quantifying variations in density requires taking a stand on two issues. The first concerns the correct geographic unit to use to make comparisons. Metro areas are used herein because they best correspond to the local economies that are modeled. In particular, metro areas encompass a well-defined labor market in which people both live and work. The second issue concerns how to deal with the unequal distribution of population within any geographic unit. Raw population density—total population divided by total land area—is the most straightforward way to measure metro-area crowdedness. It describes average density as experienced by parcels of metro land. However, 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 average density experienced by parcels of metro land can be considerably biased downward for the portion of the metro area where most people actually live.

Average density as experienced by residents is instead used herein to measure metro-area crowdedness. It is constructed as a population-weighted average of raw subunit densities (Glaeser and Kahn, 2004; Rappaport, 2007c). More specifically, the Census Bureau partitions all U.S. counties into subdivisions. These subdivisions are then further partitioned into the portions of any municipalities that lie within them (many municipalities span multiple county subdivisions) along with any remaining unincorporated area. In other words, a county subdivision may have a portion of municipality 1, a portion of municipality 2, as well as some unincorporated land. A neighboring county subdivision may have a different portion of municipality 1, which is treated as a separate observation from the portion in the first county subdivision.

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 with 18.9 thousand persons per square mile (7.3 thousand per square kilometer). The next-most-crowded metro area, Los Angeles, had a weighted density less than half as large. 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.[1]

A second, harder-to-quantify, empirical motivation is the perceived wide variation in quality of life across U.S. localities. Quality of life is meant to connote the direct contribution to utility from local consumption amenities. Equivalently, quality of life can be thought of as a local area's attractiveness to individuals as a place to live abstracting from expected wage and cost-of-living considerations.

An objective way to measuring quality of life is to estimate compensating differentials (Rosen, 1979; Roback 1982). The value of a place's quality of life is inferred as the sum of the expected wage sacrifice and cost-of-living premium households accept to live there. An important problem with the compensating differential studies, however, is an omitted-variable bias. In particular, it is difficult to distinguish whether observed differences in wages are attributable to skill differences or to locational compensation. Similarly, differences in housing prices may reflect house quality rather than quality of life.

Top-twenty metro area rankings from two compensating differential studies, Blomquist et al. (1988) and Gyourko and Tracy (1991), are shown in Table 2, Panel A. Many of the

[1] An alternative measure of the variation in crowdedness, the raw population density of *municipalities* with population of at least 100,000 in 2000, shows a similar forty-five-fold multiplicative spread.

top ranked metro areas seem misplaced. For example, few would probably agree that Pueblo Colorado, a small city of approximately 100,000 that lies 40 miles south of Colorado Springs, is the nicest place to live in the United States. Similarly, Macon GA, Bighamton NY, Roanoke VA, Lackawanna PA, Tallahasse Fl, Shreveport LA, Lancaster PA, and Amarillo TX are unlikely to be among most people's choices for the nicest places to live. Conversely, many metro areas that are typically considered to have especially high quality of life are ranked poorly. For example, among 253 urban counties in 1980, Blomquist et al. 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 rank Miami number 86, Seattle number 104, and Ann Arbor number 115. Numerous other apparent large misrankings are easily identified.

An alternative approach to measuring quality of life is to grade localities using subjective criteria. Top-twenty metro area rankings for two such studies are shown in Table 2, Panel B. 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.[2]

3 Model

The model uses a static, open-city framework. The world is made up of a national economy and a city economy. The former can be interpreted as the aggregate of numerous city

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

economies. It establishes the reservation level of utility that the city economy must offer mobile individuals. In the parlance of international trade theory, the national economy is "large" and the city economy is "small". That is, outcomes in the national economy affect outcomes in the city economy but *not* vice versa. Results from modelling two interdependent economies would be qualitatively similar.

3.1 Individuals

Individuals derive utility from consumption of a traded good (x), housing (h), leisure, and consumption amenities (*quality*). The level of consumption amenities is assumed to vary exogenously between the two economies. Amenities thereby serve as the model's primary source of crowding.

Let the constant-elasticity-of-substitution (CES) operator, $\sigma_{a,b}(\cdot)$, aggregate a and b according to elasticity and weighting parameters, $\sigma_{a,b}$ and $\eta_{a,b}$:

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

Utility in each economy ($i = c, n$) takes a nested CES functional form,

$$U_i = \sigma_{xhl,q}(\, \sigma_{xh,l}(\, \sigma_{x,h}(x_i, h_i)\, ,\ leisure_i)\, ,\ quality_i) \tag{1a}$$

The innermost nesting in (1a) 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, the calibration determines an associated weighting parameter, $\eta_{x,h}$, $\eta_{xh,l}$, or $\eta_{xhl,q}$.

In the special case where the elasticity of substitution is equal across nestings, (1a) simplifies to a standard CES functional form,

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

This specialization characterizes the baseline calibration below. With a unitary elasticity of substitution, $\sigma = 1$, (1b) further reduces to Cobb Douglas utility.

Optimizing behavior by individuals equates the ratio of marginal utility to price *within* each economy. Individuals must each satisfy a budget constraint that their expenditure does not exceed their wage income. Results are qualitatively unchanged when allowing for non-wage income. Perfect mobility by individuals equates utility levels between the city and national economies:[3]

$$U_c = U_n \tag{2}$$

Since quality of life has no natural units, it is measured by individuals' willingness to pay to receive $quality_c$ rather than $quality_n$. Let p_i be the price of housing in terms of the traded good. Consider the minimum expenditure function required to obtain the national-economy level of utility at the national-economy wage-price vector, $\{w_n, p_n\}$. For present purposes, this expenditure is defined to include the opportunity cost of leisure.

$$\mathrm{e}(w_n, p_n, quality; U_n) \equiv \mathrm{Min}\,(x + p_n\, h + w_n\, leisure) \;\; \text{s.t. } \mathrm{u}(x, h, leisure, quality) = U_n.$$

The compensating variation, CV, of $quality_c$ measures an individual's willingness to pay to receive it rather than $quality_n$. It is defined as the negative transfer required for a person facing $\{w_n, p_n, quality_c\}$ to achieve U_n. That is,

$$CV \equiv \mathrm{e}(w_n, p_n, quality_n; U_n) - \mathrm{e}(w_n, p_n, quality_c; U_n)$$

Note that CV is defined to be positive when $quality_c$ exceeds $quality_n$. A normalized measure, $\widetilde{CV}$, divides CV by actual national-economy expenditure, $(x_n + p_n\, h_n)$.

The compensating variation of $quality_c$ relative to $quality_n$ can differ significantly from the compensating differential, CD, of the same. Using national-economy quantities, CD equals $(p_c - p_n)\, h_n - (w_c - w_n)\,(1 - leisure_n)$ (Rosen, 1979; Roback, 1982). For $quality_c$ close to $quality_n$, CV and CD are approximately equal. But as quality of life in the two economies increasingly differs, CV and CD increasingly differ as well. When $quality_c$ is well above $quality_n$, the valuation of the former relative to the latter will be considerably higher as measured by CD rather than by CV. The reasons include the fixed housing and leisure quantities imposed in the compensating differential calculation along with the decreasing marginal utility from traded-good consumption as it increases. For plausible differences in

[3] In the short run, mobility is unlikely to be perfect. Ciccone and Hall (1996), among others, have shown that even long lagged levels of population are good predictors of current population. Rappaport (2004) shows that even very small frictions to labor and capital mobility imply long transitions following changes in productivity or quality of life. Hence the static equilibria described herein should be interpreted as long-run steady states.

quality of life based on the numerical work herein, the two valuations may differ by more than 15 percentage points relative to average income.

3.2 Firms

Within each economy ($i = c, n$), 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 it is produced. Aggregate production within each economy is given by

$$X_i = \mathrm{A}_{X,i}\, D_{X,i}^{\alpha_{X,D}}\, K_{X,i}^{\alpha_{X,K}}\, L_{yX,i}^{\alpha_{X,L}} \tag{3}$$

$$H_i = \mathrm{A}_{H,i} \left(\eta_{D,KL} D_{H,i}^{\frac{\sigma_{D,KL}-1}{\sigma_{D,KL}}} + \left(1 - \eta_{D,KL}\right) \left(K_{H,i}^{\alpha_{H,K}} L_{H,i}^{\alpha_{H,L}} \right)^{\frac{\sigma_{D,KL}-1}{\sigma_{D,KL}}} \right)^{\frac{\sigma_{D,KL}}{\sigma_{D,KL}-1}} \tag{4}$$

Production of the traded good is Cobb Douglas. The associated assumption of constant factor income shares from traded-good production is consistent with the stylized fact of constant aggregate factor income shares, both cross sectionally and over time (Kaldor, 1961; Gollin, 2002; Willis and Wroblewski, 2007). Aggregate Cobb-Douglas production is also implied by weaker assumptions on firm-level production (Jones, 2005). 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 between land and an implicit intermediate product of capital and labor. Allowing for a non-unitary elasticity of housing production with respect to land is motivated by numerous empirical studies including McDonald (1981) and Jackson, Johnson, and Kaserman (1984). Modelling the non-land contribution to housing as Cobb Douglas reflects the evidence of constant relative shares of capital and labor in aggregate production. The elasticity of substitution between land and the capital-labor intermediate good 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 last two coefficients determine the division of factor income between capital and labor.

Total factor productivities, $\mathrm{A}_{X,i}$ and $\mathrm{A}_{H,i}$, are for the moment assumed to be fixed and equal across the two economies (i.e., $\mathrm{A}_{X,c} = \mathrm{A}_{X,n}$ and $\mathrm{A}_{H,c} = \mathrm{A}_{H,n}$). In a later section, productivity will be assumed to endogenously depend on local population density.

Capital and land factor payments are interpreted as being made to foreign owners, who reside neither in the national nor in the city economy. Numerical results are nearly identical if payments to capital and land are instead rebated to individuals on a lump sum basis.

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. 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.

3.3 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. For the national economy, traded-good consumption must equal traded-good production less any payments to absentee land and capital owners.[4] Land area is predetermined for both economies. For the national economy, population is predetermined as well.

The combined optimization conditions, individual budget constraints, and local adding-up constraints can be reduced to two nonlinear systems of seven equations each. The first system calibrates the utility and housing-production weighting parameters to achieve target national-economy outcomes. It also determines the reservation level of utility that must be met in the city economy. The second system then solves outcomes for the city economy including its population. The absence of any sort of increasing returns to scale combined with the fixed land supply and decreasing marginal utility together suggest that the solution to this combined system is unique.

[4]Traded-good consumption may differ from production in the city economy via trade with the national economy. But such trade does not relax the national economy's traded-good constraint since the city economy is too small to do so.

4 Calibration

A primary purpose herein is to gauge the approximate magnitude of the variation in consumption amenities that is required to match the wide observed variation in density across U.S. metro areas. In this spirit and to not imply a false level of precision, parameters are set to round values. The numerical results section, which follows, includes an extensive sensitivity analysis. Table 3 summarizes the calibration, including the sensitivity of results to variations in specific parameters.

4.1 Utility

The calibration of the utility function, (1a), 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 national-economy share of consumption spent on housing and the national-economy share of time devoted to leisure.

The elasticity of substitution between the traded good and housing, $\sigma_{x,h}$, is assumed to equal 0.5. This calibration derives from cross-sectional data on housing prices and the housing share of consumption expenditures. The dots in Figure 1 Panel A plot the housing consumption share against housing prices for 24 large metro areas.[5] The lines represent housing expenditure shares for each of three elasticities of substitution.[6] 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,

[5]The housing share measure is from the Consumer Expenditure Survey. 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 important characteristics such as square footage, parking, and location. Hence the index measures a hybrid of housing prices and housing expenditures. A correctly measured house price should result in a scatter more horizontal than is depicted in Figure 1, in turn implying a higher elasticity of substitution.

[6]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.

1996; Ionnides and Zabel, 2003). For the sensitivity analysis, $\sigma_{x,h}$ is assumed to equal 0.25 and 0.75.[7]

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 aggregate 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 optimal 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.[8] Calibrating $\sigma_{xh,leisure}$ to equal 0.5 exactly matches the total increase in leisure from 1965 to 2003. The implied negative elasticity of labor hours with respect to the real wage is consistent with estimates summarized in Pencavel (1986). In contrast, more recent dynamic estimates, summarized in Blundell and MaCurdy (1999), typically find a positive elasticity of labor hours with respect to the real wage. However, it is difficult to map the intertemporal context of the more recent studies into the present static setting.

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 relative level of $quality_c$ required to support a given relative population density, not its valuation. To keep things simple, $\sigma_{xhl,quality}$ is set equal to 0.5, thereby reducing (1a) to its standard CES form, (1b).

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 national-economy individuals spend 18%

[7] Davis and Ortalo-Magne (2007) argue that the distribution of housing expenditure shares based on micro data of renters from several decennial censuses is more consistent with $\sigma_{x,h}$ equal to 1. But renters represent a non-random, minority sample of residents facing a different choice set of housing units. And the inclusion of utility expenses in rental payments likely dampens variation across metro areas. The Consumer Expenditure Survey, on which the present calibration is rests, is based on both renter and owner expenditures. It calculates the latter as the sum of mortgage interest and charges, property taxes, insurance, maintenance, and repairs. It does *not* impute an equivalent rent, thereby addressing Davis and Ortalo-Magne's main objection to using owner-occupied data. In any case, Davis and Ortalo-Magne's estimated distribution of housing shares, which ranges from 0.20 for Cincinnati up to 0.29 for Miami, is largely consistent with the present calibration.

[8] Biological necessities are assumed to require 9 hours per day, which leaves 105 hours per week of potential leisure. The optimal 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.

of their consumption expenditures on housing. This approximately matches the aggregate U.S. value from 2001 to 2003 based on the Bureau of Labor Statistics' Consumer Expenditure Survey. The sensitivity analysis alternatively assumes national-economy housing expenditure shares of 14% and 22%. The parameter $\eta_{xh,leisure}$ is chosen such that national-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 national-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.

4.2 Production

The calibration of production requires determining the national-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. The rate of return determining capital intensity also needs to be specified.

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).[9] 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 hold in both economies.

Non-Cobb-Douglas production in the housing sector implies that factor income shares differ between the two economies. Under the baseline parameterization, land's national-economy factor share 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).[10] Using microeconomic data, several other researchers have

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

[10]Davis and Heathcote find that between 1975 and 2004, land accounted for an average of 47% of the

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 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 in the baseline calibration, land's factor share would be below average in such places 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, the results reported below are completely insensitive to the parameterization of r_K. This makes sense since the framework has no natural time context.

5 Numerical Results

The model's mechanics are straightforward. The national economy serves to calibrate the utility and production weighting parameters. It also determines the reservation level of utility that city-economy residents must attain. An increase in the city economy's level of consumption amenities attracts an inflow of labor, putting downward pressure on wages

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.

and attracting a complementary inflow of capital. The increase in city-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 prices. A second subsection shows how resistance to crowdedness (i.e., the magnitude of the quality of life difference required to attain a given increase in density) 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 the city-economy relative population density (horizontal axis) that is caused by various normalized valuations of city-economy quality of life (vertical axis). In other words, the vertically-plotted $\widetilde{CV}$ should be interpreted as exogenous. The horizontally-plotted relative population density should be interpreted as an endogenous response. Equivalently, for any relative density, the depicted locus gives the required quality-of-life differential.

For example, the $quality_c$ that induces city-economy population density to be one-fourth that of the national economy has a $\widetilde{CV}$ of -0.13. In other words, national-economy residents facing the required $quality_c$ rather than $quality_n$ at the national-economy wage-price vector need a transfer equivalent to 13% of their original traded-good and housing consumption in order to continue to attain U_n. Conversely, the $\widetilde{CV}$ associated with a relative population density of four is 0.18. In this case, national-economy residents facing the required $quality_c$ rather than $quality_n$ at the national-economy wage-price vector could transfer away 18% of their original consumption while still attaining U_n.

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 of the traded good, leisure, and especially housing become extremely high.

The required variations in quality of life are probably of plausible magnitude to account for most, but probably not all, of observed variations in population density. The difference in required expenditure between a city 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 national-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 city 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 national-economy consumption. Even allowing for overstatement, a compensating variation of this magnitude probably falls within the estimated range.

The remaining panels of Figure 2 plot the relationships of a number of other endogenous outcomes against population density. The desire by individuals to live in high-quality-of-life locales induces an inverse correlation between the traded-good-denominated wage and population density (Panel B). At a one-fourth density, city-economy wages are 4.3% above those in the national economy; at a four-fold density, they are 4.3% below national-economy wages. 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). At a one-fourth density, land accounts for 26% of housing factor income, which is nearly identical to the micro-based estimate for Knoxville discussed in the calibration section above. At a four-fold density, land accounts for 46% of housing factor income.

At the same time, the residential-demand-driven rise in land prices pulls land out of traded good production into housing production (not shown). As density increases from one fourth to one to four, the percent of city-economy land devoted to housing production increases from 63 to 74 to 83. In other words, the share of the city economy's geographic area devoted to production of the traded good falls as density rises.

In contrast, 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 national-economy level. At a four-fold density, land per unit housing is approximately two fifths its national-economy level. This low land content is consistent with the construction of increasingly tall apartment buildings as density increases.

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% of a conventionally-calculated compensating differential between the two economies. At a four-fold density, higher housing prices account for 81% of the compensating differential.

As the price of housing rises, the share of expenditures devoted to housing also rises. The increasing housing consumption share follows directly from the assumed less-than-unitary elasticity of substitution between traded goods and housing, $\sigma_{x,h} < 1$. Because house prices rise with density, the housing consumption share rises with density 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, 1.06 and 1.36. At a four-fold density, relative traded and housing consumption are 0.92 and 0.64.

Lastly, leisure also falls slightly with density (Panel H). As density rises from one fourth to four, relative leisure falls from 1.04 to 0.94. As is the case with traded and housing consumption, a fall in leisure helps compensate for the rise in quality of life. However, this inverse correlation of leisure with density depends closely on the model's parameterization. On the one hand, the lower wages in dense metros make people poorer and hence want to consume less of everything. On the other hand, lower wages decrease 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.

5.2 Sensitivity Analysis

The wide uncertainty characterizing the baseline parameterization makes sensitivity analysis imperative. Doing so establishes how the model's implied resistance to crowdedness—the magnitude of the quality-of-life difference required to achieve a given difference in city density—depends on its various parameters.

Land is the model's only source of congestion. Changes that increase its implicit factor share of national-economy consumption—either by explicitly increasing land's factor share in production or by increasing the expenditure share on land-intensive housing—increase resistance to crowding. In other words, the higher the implicit land share of consumption, the greater the variation in quality of life that is required to support a given variation in density. Less obviously, decreasing elasticities of substitution in the production and utility functions increases resistance to crowding at high relative densities but leaves resistance essentially unchanged at low relative densities. Different combinations of parameter values yield a huge range in the resistance to crowdedness. A high implicit land share is sufficient for resistance to be strong (large required quality of life differences). But a low implicit land share does not guarantee weak resistance (small required quality of life differences).

Figure 3 illustrates the sensitivity of required quality of life to six key model parameters. Resistance to crowding depends closely on land's share of housing factor income. Increasing land's share from 20% through its baseline value of 35% to 50% causes a large counterclockwise rotation of the $\widetilde{CV}$-to-density locus (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 land share requires a $\widetilde{CV}$ of -0.17. Whereas achieving a four-fold density under a 20% housing land share requires a $\widetilde{CV}$ of 0.11, doing so under a 50% housing land share requires a $\widetilde{CV}$ of 0.26. A higher housing land share also results in a moderately larger variation in land prices and a considerably larger variation in housing prices (not shown). Under the low housing land share calibration, relative housing prices rise from 0.78 to 1.46 as density rises from one quarter to four. Under the high housing land share calibration, relative housing prices rise from 0.46 to 2.88.

Required quality-of-life differences are 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 (Panel B). But the rotation is quite small, especially moving from the low calibration to baseline and especially at high relative densities. This insensitivity derives from two partly-offsetting forces. On the one hand, increasing land's share of traded production makes such production more subject to congestion. On the other hand, increasing land's share implies a larger equilibrium amount of land that can be switched from traded to housing production. The ability to pull land out of traded production lessens resistance because of the greater difficulty substituting away from land in housing production. With land's traded factor share equal to 0.4%, the share of city-economy land devoted to housing rises from 86% to 96% as density increases from one quarter to four. With land's traded factor share equal to 4.8%, the share of land devoted to housing rises from 59% to 86%.

Resistance to crowding also increases with housing's share of national-economy consumption expenditure (Panel C). Housing is the more land-intensive good, and so increasing its share of expenditure implicitly increases land's factor share of the national-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 density 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 (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 (not shown). 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 marginal product of land in the production of housing is extremely high in a densely-settled economy (as reflected by the high price of land in such an economy). Hence, the resistance to high levels of crowdedness is quite sensitive to the ability to substitute away from land. But in a sparsely-settled economy, the marginal product of land in the production of housing is quite low. Land is abundant and so its price is low. The capital-labor composite is likely to be relatively abundant as well. Capital is supplied with infinite elasticity; labor is perfectly mobile; and the ability to substitute between capital and labor is high. With this abundance of the housing inputs, there is little sensitivity to the elasticity of substitution with land.

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 (Panel E). The increase in resistance as $\sigma_{x,h}$ goes from 0.75 to 0.25 is considerably smaller than the increase in resistance as $\sigma_{D,KL}$ goes from 1 to 0.50. Accommodating individuals' low willingness to substitute away from housing proves easier than accommodating a low technological ability to substitute away from land.

Resistance to crowding is almost completely insensitive to the elasticity of substitution with respect to leisure, $\sigma_{xh,leisure}$ (Panel F). To be sure, resistance is slightly higher when this elasticity equals 0.25 rather than 1. Less willingness to substitute into leisure when real wages are low, as they are in a consumption-amenity driven crowded economy, requires a slightly greater compensating differential to support a given density.

Required quality-of-life differences are similarly insensitive to the model's two remaining parameters, the leisure share of national-economy time and the elasticity of substitution with respect to quality of life. Resistance to crowding is very slightly higher when $leisure_n$ is calibrated to equal 0.50 rather than 0.20 (not shown). This is a general equilibrium result whose mechanism is unclear. Resistance is completely insensitive to $\sigma_{xhl,quality}$ (not shown). Differences in $\sigma_{xhl,quality}$ do affect the difference between $quality_c$ and $quality_n$ required to support a given density. But the actual *valuation* of that difference, along with all remaining endogenous variables, remain exactly the same.[11]

Different combinations of the parameterization choices imply 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 F—as enumerated in the "Loose" column of Table 3—places a lower bound on plausible resistance to crowdedness (Panel G, 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—as enumerated in the "Tight" column of Table 3—places an upper bound on plausible resistance to crowdedness (Panel G, 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.

[11] Allowing for substantial non-wage income very slightly weakens resistance to crowding. The likely mechanism is that individuals are less negatively impacted by the lower wages in a high-amenity economy.

A different combination pairs together the high-land and high-elasticity values (Panel H, dashed-dotted line). Even with a relatively easy ability to substitute away from land, a national-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 (Panel H, dashed line). But at densities above one, resistance rapidly increases.

5.3 Endogenous Productivity and Quality of Life

The numerical results so far assume that productivity and quality of life are exogenous. 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). Allowing productivity to depend on density can greatly lessen resistance to amenity-driven crowding. Similarly, increases in density from very low levels probably 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. On the other hand, increases in density from very high levels probably decrease quality of life. For example, such higher density might increase traffic, pollution, and other non-priced sources of congestion.

Figure 4 shows some general equilibrium results from allowing TFP to depend on density. Let the elasticity with which density *causes* total factor productivity to increase be denoted by υ_X for the traded good and by υ_H for housing. Each economy ($i = c, n$) produces the traded good with TFP, $A_{X,i} = A_X \cdot density_i^{\upsilon_X}$.[12] A parallel formula holds for TFP in producing housing. To match empirical estimates, which are typically of aggregate agglomeration, the elasticity of TFP with respect to density is assumed to be the same for the traded good and for housing ($\upsilon_X = \upsilon_H = \upsilon$). Estimates of υ range from a lower bound of 0.03 (Combes, Duranton, and Gobillon, 2007) to an upper bound of 0.05 (Ciccone and Hall, 1996; Ciccone, 2002).[13]

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 equal to 0, which is the maintained assumption

[12]More generally, the "exogenous" component, A_X, might vary between economies as well.

[13]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).

above of no endogenous productivity, an increase in city-economy density from one quarter to four requires an increase in $\widetilde{CV}$ from -0.13 to 0.18. For υ equal to its lower-bound estimate, the required rise in $\widetilde{CV}$ is from -0.06 to 0.13. For υ 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 population density become easily plausible.

With the upper-bound estimate of υ, resistance at densities below one is negligible. A 2% $\widetilde{CV}$ 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 $\widetilde{CV}$ very slightly below zero. Such extreme lack of resistance captures that υ equal to 0.05 almost completely offsets endogenous, priced congestion as density varies below the national economy level.

The endogenous increase in productivity with density can reverse the amenity-driven negative correlation between wages and density. As υ 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 equal to its lower-bound estimate is sufficient to cause wages to become upward sloping as density increases. A value of υ equal to its upper-bound estimate causes wages to be even more strongly increasing with density.

Like productivity, quality of life can be modeled as endogenous. The required $\widetilde{CV}$-to-density loci shown in Figures 2 and 3 above hold regardless of the source of the quality-of-life differences. Allowing quality of life to depend on density is equivalent to adding an extra equation to the current system.

Figure 5 shows one possible dependence of quality of life on density. The required, solid locus gives the combinations of quality of life and density that are consistent with equilibrium for the city economy. The four remaining loci give the quality of life level that each of four city economies would experience at different densities. The vertical differences between the curves reflect differences in quality of life that do not depend on density. These "exogenous" variations in quality of life can be measured by the level of quality of life that would prevail at a unitary density. The circles along the vertical axis thus depict the four exogenous amenity levels. For example, one of the economies has exogenous amenities such that at a unitary density, its quality of life is equal to that of the national economy ($\widetilde{CV}$ at a unitary density equals zero). The "nicest" of the economies has exogenous amenities such that at a unitary density, it has quality of life for which national economy residents would pay 20% of their income ($\widetilde{CV}$ at a unitary density equals 0.20).

Quality of life is assumed to also have a component that endogenously depends on density. In particular, quality of life endogenously increases as density rises to an intermediate level above one and then endogenously decreases as it rises further. For instance, the economy with exogenous amenities equal to that of the national economy sees its quality of life rise to a maximum $\widetilde{CV}$ of 0.04 at a relative density of 2.8. For the economy with the highest level of exogenous amenities, quality of life rises to a maximum $\widetilde{CV}$ of 0.24 at a relative density of 2.8. If, instead, quality of life did not depend on density, the dashed lines in Figure 5 would be horizontal. In this case, the endogenous component of quality of life would be zero.

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 challenge would be distinguishing the endogenous relationship from the required one. This problem of identification is discussed in the next section.

6 Empirics: the Importance of Quality of Life

The generalized version of the static model above has only two possible sources of variation in local density: variation in quality of life and variation in productivity. Within a dynamic context, the model suggests that *changes* in quality of life and productivity are 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 that quality-of-life differences are indeed an important factor helping to underpin cross-sectional differences in population density. In particular, density is strongly positively correlated with several quality-of-life indices based on subjective criteria. In addition, population *growth* is strongly positively correlated with several exogenous consumption amenities, which suggests that quality of life is becoming a more important determinant of metro density. Nevertheless, the positive empirical correlation between wages and density suggests that variations in productivity are probably the more important factor underpinning the current cross-sectional distribution of population density.

Figure 5 illustrates two distinct, predicted cross-sectional correlations between density and quality of life. The first is that density should be positively correlated with exogenous amenities. Higher vertical intercepts of the dashed-line, endogenous curves are associated with higher density intersections with the solid, required $\widetilde{CV}$ curve.[14] The second prediction is that density should be positively correlated with overall quality of life, which is the sum of the exogenous and endogenous components. If productivity is the same across local economies, the required locus is identical across them as well. Different levels of exogenous amenities vertically shift the endogenous curve, whatever its slope, thereby identifying the required locus. In Figure 5, the three intersections of the endogenous curves with the required curve illustrate this identification. Each of these three points, along with many other intersections corresponding to other exogenous quality of life levels, lie along the required curve and are what would be observed by a researcher.

Of course, productivity also varies across local economies. It can do so exogenously due to fixed local characteristics such as access to raw materials and navigable water. Exogenous differences in productivity vertically shift the required $\widetilde{CV}$ locus. Productivity can also vary endogenously due to variations in local population density. As discussed in the previous section, the positive dependence of productivity on density causes a clockwise rotation of the required locus. If either exogenous or endogenous sources of quality of life are positively correlated with productivity, density's positive correlation with quality of life should strengthen. If quality of life is negatively correlated with productivity, density's positive correlation with quality of life should weaken.

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 empirical 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). Growth is even more strongly and robustly positively correlated with nice weather (Rappaport,

[14] A sufficiently steep endogenous curve might also seem to suggest that higher exogenous amenities could be associated with lower density. However, the associated low-density equilibrium would be unstable.

2007b).[15]

There is also some ambiguity on the correlation of density with overall quality of life. Among four leading studies that use 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 metro-area compensating differentials summed with national median household income should give the expenditure required to attain a national 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. For two of the remaining studies, an absence of correlation between density and overall quality of life cannot be rejected. The Gyourko and Tracy (1991) rankings are characterized by a statistically-significant negative correlation of density with quality of life.[16]

A drawback of the compensating-differential studies, however, is that the estimation of quality of life may include serious omitted-variable biases (Gyourko, Tracy, Kahn, 1999; Combes, Duranton, Gobillon, 2007). In particular, unobserved higher skills rather than lower quality of life may account for observed higher wages. Unobserved higher house quality rather than high quality of life may account for observed higher housing prices. The failure to sufficiently account for such unobserved individual and house attributes may thus account for the seeming misranking of metro areas' quality of life discussed in Section 2 above.

Population density is strongly positively correlated with the subjective overall quality-of-life rankings by Savageau (2000) and Sperling and Sander (2004) (Table 5, Panels B and C). The Spearman correlation coefficient of density with the former is 0.42 and with the latter is 0.49. Both coefficients 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.[17]

[15] Some portion of this move to nicer weather likely stems from the advent of air conditioning and increased mobility of the elderly. But Rappaport (2007b) argues that a large portion is due to an increased valuation of nice weather as a consumption amenity.

[16] Davis and Ortalo-Magne (2007) also find that the correlation of density with quality of life is negative.

[17] 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.

To the extent that these subjective quality-of-life rankings seem more reasonable than those of the compensating-differential literature, evidence suggests that quality-of-life differences help underpin density differences. The likelihood that many 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 suggests that quality of life may serve more as a reinforcing mechanism for productivity-driven differences in density rather than as an exogenous impetus.

The strong, positive partial correlation of population *growth* with nice weather suggests that quality of life may be becoming a more important 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 was positively correlated with several measures of consumption amenities. Similarly, Shapiro (2006) concludes that a large portion of the faster growth of high-human-capital cities is attributable to amenities.

Nevertheless, the observed positive correlation between wages and density places an upper bound on the importance of quality of life as a source of local crowdedness. If crowdedness depended solely on quality of life, the cross-sectional correlation between wages and metro density would be negative. Instead, the correlation between wages and metro density is robustly positive. Using data on U.S. metropolitan areas in 2000, Rappaport (2006) estimates that the elasticity of median labor income with respect to density lies between 0.10 and 0.20. Using data on French employment areas in 1998, Combes et al. (2007) report an elasticity of mean wages with respect to density of 0.05.[18] Both estimates should be interpreted as simple correlations with no implied causal relationship.[19] Combes et al. show that variations in individual-specific characteristics account for almost half of geographic wage disparities. Hence the elasticity of a nationally-representative agent's wage with respect to density, again without any implication of causality, is likely to be significantly below the

[18] On the other hand, Lee (2005) finds that the wages of very high-skilled medical workers are decreasing with city size.

[19] There are several possible reasons for the difference in magnitudes between the two estimates. First is the difference in countries. Second is the different unit of observation. The 341 French employment districts discretely partition the country. The 332 U.S. metro areas house more than 80% of U.S. residents but account for only slightly more than a quarter of continental U.S. land area. Third is the weighted construction of the U.S. metro densities as described in the empirical motivation section above.

reported estimates.

Conversely, the 0.05 magnitude of the simple correlation of wages with density estimated by Combes et al. suggests a positive *lower* bound on the importance of quality of life in supporting observed density differences. With solely productivity-driven crowding, the present model under the baseline parameterization predicts that the elasticity of wages with respect to density is 0.08. Bringing this wage-to-density elasticity down below the reported Combes et al. estimate requires that quality of life be an important determinant of local density as well.

Overall, the empirics suggest that quality of life helps 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 independent rankings of overall quality of life based on subjective criteria. However, 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

Population density varies hugely across U.S. metropolitan areas. A calibrated general equilibrium model suggests that plausible differences in consumption amenities across metro areas can account for much of this variation. Under a baseline calibration, a compensating variation equivalent to 30 percent of national-economy consumption expenditure supports the twenty-fold observed difference in population density between the second-most and least-crowded metro areas. Sensitivity analysis shows that resistance to crowdedness depends closely on the housing production function as well as on the implicit land share of national-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 steeply. 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 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 positive empirical correlation of population density with wages suggests that variations in productivity are the more important source of current variations in population density.

The present, simple model is an ideal platform on which to build a richer framework. One important direction 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 important direction is to introduce heterogeneity among individuals, in terms of skills, wealth, and mobility. 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, consistent with Gyourko, Mayer, and Sinai (2006). Heterogenous mobility implies that average realized utility will be higher in some metro areas than in others. Without any modification to the model, technological progress in the form of shared TFP growth across economies implies persistent migration to cities where quality of life is highest (Rappaport, 2007a). Still another important direction for future research is to model a full system of cities so as to be able to match the distribution of density across U.S. metro areas.

More generally, the paper's model and results emphasize the need to better understand the determinants of local quality of life. Along with productivity, it is one of the few fundamental determinants of local population and population density. Any story of different metro outcomes usually maps to a story of different productivity facing firms and different quality of life facing individuals. Agglomeration, in particular, can be seen as being mediated via these two mechanisms. The present model can thus serve as a 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
8	Boston-Cambridge-Quincy, MA-NH	5.0
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
52	St. Louis, MO-IL	2.7
:	:	:
:	:	:
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

6.8 times

49 times

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. Compensating Differential Methodology

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

B. Subjective Methodology

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

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[1] ("Loose")	High Resistance[1] ("Tight")	Primary Source of Calibration	Sensitivity of Required Amenity Differences to Calibration
Land Factor Income Share[2] (national economy)					
Traded Good:	**1.6%**	0.4%	4.8%	Jorgenson, Ho, and Stiroh (2005)	medium
Housing:	**35%**	20%	50%	Davis and Heathcote (2005)	high
Housing Production CES ($\sigma_{D,KL}$)	**0.75**	1	0.50	McDonald (1981); Jackson, Johnson, and Kaserman (1984)	high
Required Capital Rent (r_K)	**0.08**			3% real return plus 5% depreciation	none
Utility CES Parameters					
$\sigma_{x,h}$	**0.50**	0.75	0.25	CEX housing consumption shares vs. apartment rents	medium
$\sigma_{xh,leisure}$	**0.50**	1	0.25	Time diary studies vs. real wages	very low
$\sigma_{xhl,quality}$	**0.50**			Arbitrary	none
Consumption Expenditure Shares (national economy)					
Housing	**18%**	14%	22%	Consumer Expenditure Survey	medium
Leisure (share of time)	**35%**	20%	50%	Time Diary Studies	very low

[1]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.

[2]Non-land factor income is divided between capital and land on a one third to two thirds basis for both the traded good and for housing.

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}= 0.03	28%
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}= 0.03	16%
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%

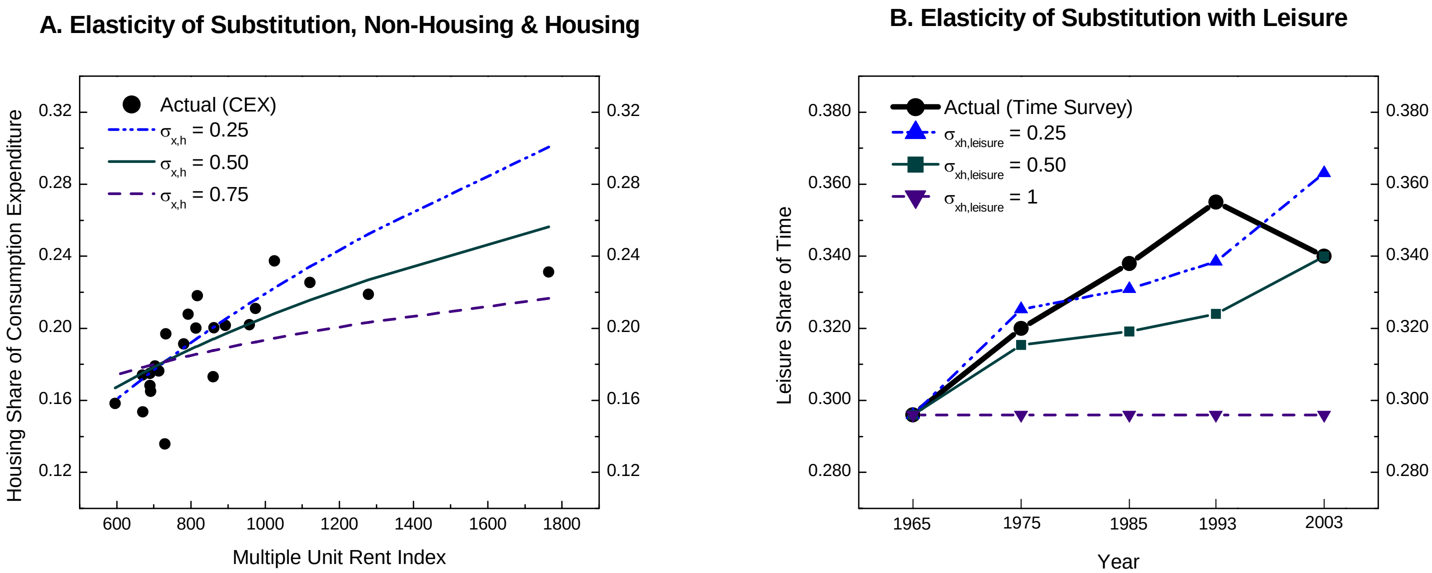
Modeled compensating variation is reported relative to national economy per capita income. Estimated compensating differential range is reported relative to median household income.

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}= 0.03	-0.064
Endogenous productivity, υ_{TFP}= 0.05	-0.035
Estimated Elasticity (std. error)	
Blomquist 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)

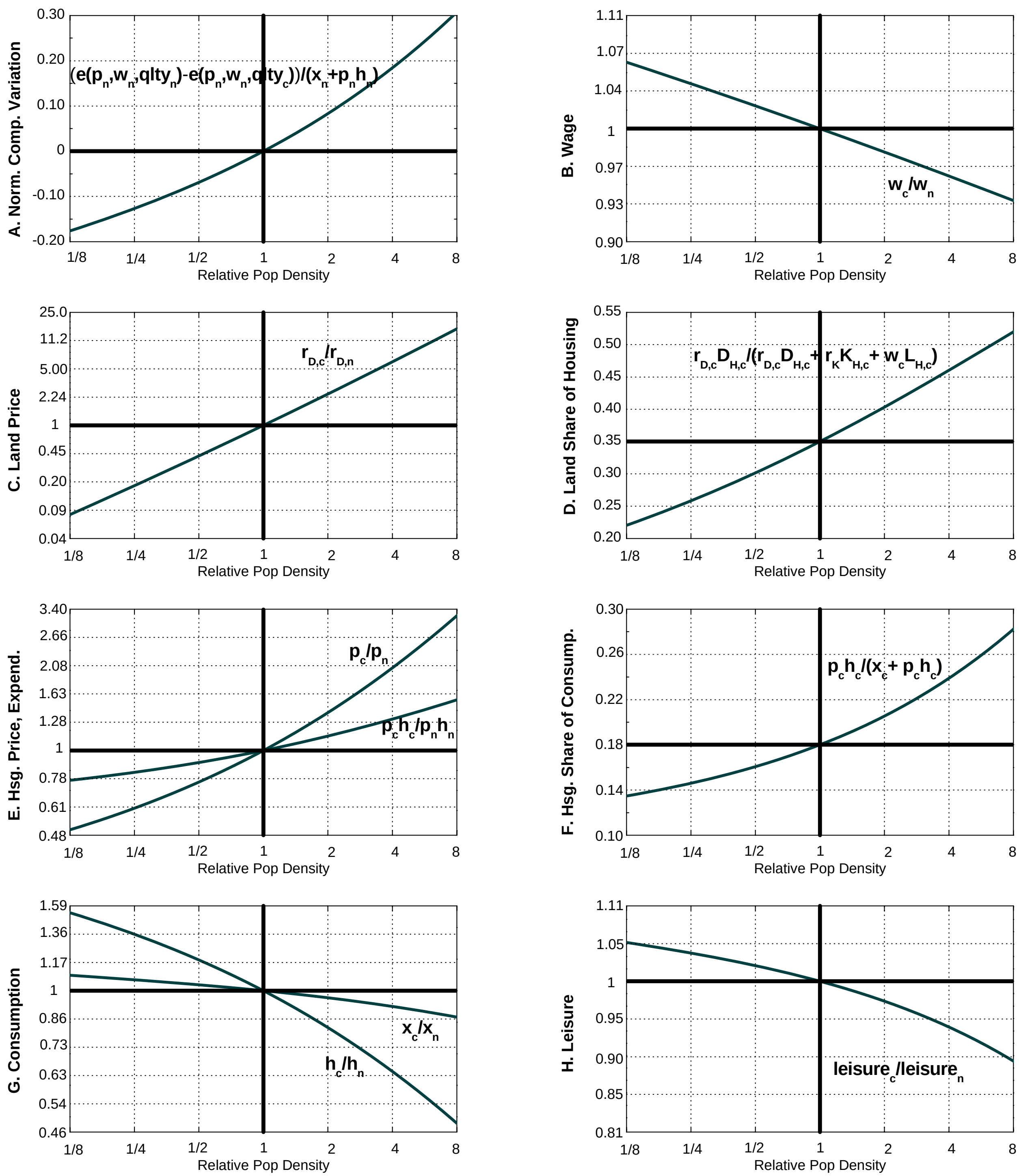
Blomquist et al. and Gyourko and Tracy correlations are with density in 1990.
Remaining correlations are with density in 2000.

Figure 1: Calibration of Consumption Elasticities



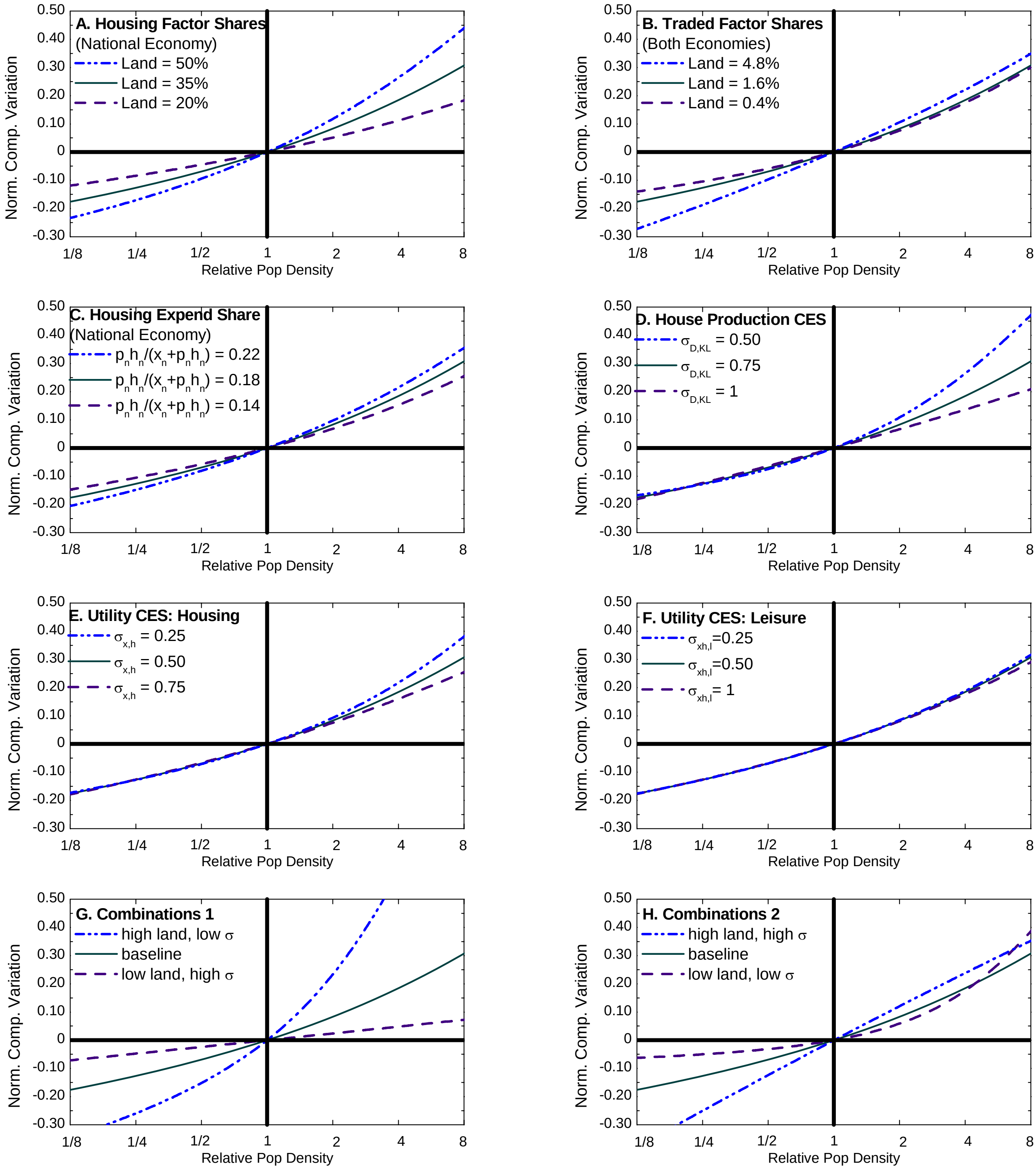
Panel A: Dots plot aggregate share of consumption devoted to shelter in each of 24 large metro areas (BLS Consumer Expenditure Survey, 1997–to–2002 average) against Torto-Wheaton multi-unit rental price index (1997–to–2002 average). Lines represent expected housing shares against the price index for 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



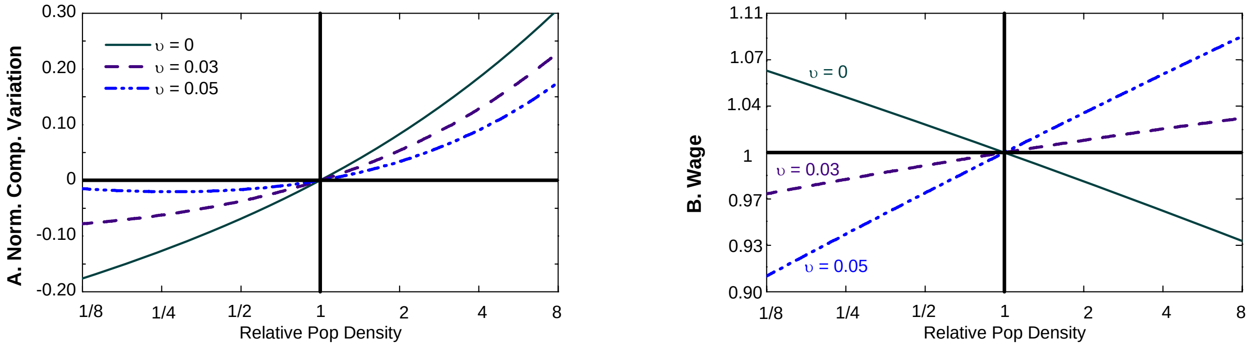
Panel A shows the difference between city-economy and national-economy quality of life, measured as a compensating transfer to national-economy residents as a share of their income, required to achieve different relative densities under the baseline calibration. Remaining panels show implied ratios of 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



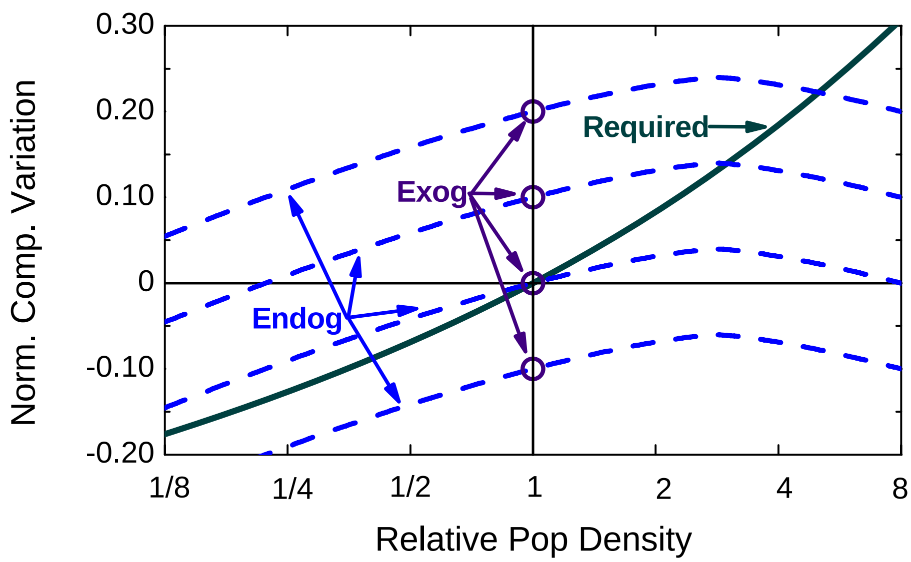
Panels show the difference between city-economy and national-economy quality of life, measured as a compensating transfer to national-economy residents as a share of their income, required to achieve different relative densities under variations from the baseline calibration. Horizontal axes are plotted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