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Spatial Sorting

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SPATIAL SORTING^{*}

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January, 2013

Abstract

We investigate the role of complementarities in production and skill mobility across cities. We propose a general equilibrium model of location choice by heterogeneously skilled workers, and consider different degrees of complementarities between the skills of workers. The nature of the complementarities determines the equilibrium skill distribution across cities. We prove that with extreme-skill complementarity, the skill distribution has fatter tails in large cities; with top-skill complementarity, there is first-order stochastic dominance. Using the model to back out skills from wage and housing price data, we find robust evidence of fat tails in large cities. Big cities have big inequality. This pattern of spatial sorting is consistent with extreme-skill complementarity: the productivity of high skilled workers and of the providers of low skilled services is mutually enhanced.

Keywords. Complementarity. Cities. Sorting. Price-Theoretic Measure of Skills. Population Mobility. City Size. Matching Theory. General equilibrium. Skill Distribution.

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“If I can make it there I’ll make it anywhere...” (Frank Sinatra – New York, New York)

“Rock Bottom, yeah I see you, all my Detroit people” (Eminem – Welcome 2 Detroit)

1 Introduction

Complementarities are important for the productivity and composition of workers in firms, for student achievement in classrooms (peer effects) and for the accomplishments of teams. The presence of more productive co-workers affects the performance of some if not all other co-workers, and this in turn determines who chooses to work where and with whom. In this paper we investigate the role of complementarities at an aggregate level – the level of a city. Complementarities are akin to knowledge spillovers (Marshall, 1890), but rather than flowing between innovating firms, complementarities affect the productivity of *differentially* skilled workers within the local labor market. We propose a model that elucidates both the nature of cities and the role of complementarities in production. Our main theoretical finding is that the specifics of the complementarities determine the distribution of skills within a city and how it varies with city size. Our approach sheds new light on the sources of the urban wage premium, a major puzzle in the literature. It is well known that wages in large cities are higher, but it is unclear why. Little is known about the skill composition across cities. Are wages higher because workers in large cities are more skilled? Most people can provide casual evidence that the skill level in the top percentiles of New York and large cities in general is higher than anywhere else. Making it there – in New York, NY – rather than in Akron, OH is the ultimate aim of many professionals in many trades: artists, musicians, advertising and media professional, consultants, lawyers, financiers, ... Yet, cities are not just populated by superstars and high earning professionals, even if these are highly visible. In this paper, we address the sorting decision of workers over the entire range of skills, including medium and low skills. Our main empirical finding is that the distribution of skills in the US has fat tails in large cities: large cities disproportionally attract both high and low skilled workers, while average skills are constant across size. From the theory, this allows us to conclude that there are complementarities between high and low skilled workers, which mutually boosts their productivity.

We consider two competing hypotheses concerning the complementarities between skills. A first hypothesis is whether the superstars boost their productivity most in the presence of other high skilled workers. For example, under this assumption the best lawyers are more productive when surrounded by top legal assistants. Or the cancer surgeons at Sloan Kettering in NY work best with top residents and top nurses, whereas the General Practitioners with fewer years of training and fellowships collaborate with less trained nurses and assistants. We refer to this hypothesis as *Top-Skill Complementarity*. A second hypothesis posits that high skilled workers boost their productivity most with low skilled services. What dominates in the aggregate is that the high skilled worker has a disproportionately high productivity increase from the presence of low skilled services. Given the value of her time, at her job she hires more low skilled administrative help, other services (sales, legal, catering...) and she demands low skilled services through child care, schooling and help in the household. We label this hypothesis as *Extreme-Skill Complementarity*.

The premise of our analysis is that the presence of those complementarities determines the location decision of differentially skilled workers, i.e. spatial sorting. We propose a theory that identifies a one to one relationship between those features of the technology, on the one hand, and the equilibrium outcome of the skill distributions across cities, on the other. Our model is a tractable version of the multi-worker matching model à la Kelso and Crawford (1982) applied to a concrete labor market setting. Complementarities determine competitive wages and therefore the location decision of workers. Our objective is to uncover the nature of the complementarities from the observed sorting pattern of workers, i.e. the skill distribution across cities. This is very much in the spirit of Krusell, Ohanian, Rios-Rull and Violante (2000) in the macro literature, who derive properties of complementarities in technology from the observed wage distributions. The two broad hypotheses outlined above give rise to five possible technological configurations: for each, one with complements and one with substitutes, and in addition one with no skill-specific complementarity, i.e., Constant Elasticity of Substitution (CES). And there are five possible outcomes for the distribution of skills with different first-order stochastic dominance (FOSD) or tail properties.

Our labor market model is tailored to investigate the nature of cities, and the *contribution* of the paper is threefold: First, we identify a mechanism of skill complementarities and the resulting skill distribution that we can explicitly solve.

This, despite the fact that models with varying elasticity of substitution are notoriously hard to solve analytically, as Krusell, Ohanian, Rios-Rull and Violante’s (2000) dynamic model illustrates. Second, qualitatively we discover an extremely robust empirical pattern of fat tails in the distribution of skills: average skills are independent of city size, while the standard deviation increases with city size. Together with the results from the theory, this allows us to conclude that the observed pattern of skills is due to the complementarities between extreme skills. We believe that the theoretical link between the complementarities and the distribution in local labor markets is both theoretically and empirically novel. Third, our analysis makes further headway in our understanding of one of the major outstanding puzzles in urban economics, namely the mechanism behind the urban wage premium. Wages are not higher because skills are uniformly higher. Instead, complementarities between extreme skills act as a multiplier of existing differences in total factor productivity across cities. Our theory of differential complementarities provides an explanation for this phenomenon.

The normative implications in the baseline model are particularly relevant when evaluating inequality. Our results show that from a social welfare viewpoint, wage inequality and urbanization are intimately related. This can have far-reaching policy implications. Consider for example the current income taxation system that progressively taxes individuals and households on their nominal income. Effectively, given the urban wage premium, this means that the current fiscal system subsidizes the countryside at the expense of the cities. The implication is that the population in large cities is too small compared to the laissez-faire outcome, and as a result, output produced is suboptimal.

Prices play a key role in our equilibrium model of city choice. Heterogeneously skilled citizens earn a living based on a competitive wage and choose housing in a competitive housing market. Under perfect mobility, their location choice will make them indifferent between consumption-housing bundles, and therefore between different wage-housing price pairs across cities. Wages are generated by firms that compete for labor and that have access to a city-specific technology summarized by that city’s total factor productivity (TFP). This naturally gives rise to a *price-theoretic measure of skills*. Larger cities pay higher wages, and are more expensive to live in. Under worker mobility, revealed preference location choices imply that wages adjusted for housing prices are a measure of skills.

Using this price based measure of skills, we can establish two robust empirical facts: average skills are constant across cities, and the standard deviation increases with city size. Big cities are characterized by big real inequality. The city size-wage premium is thus not driven by a high average skill level. Instead, larger cities have fatter tails in the skill distribution and disproportionately attract both higher and lower skilled agents. In New York City for example there is not only a huge contingent of high skilled workers in Manhattan, but there are also disproportionately many low skilled workers living in the South Bronx and Newark. Similarly, while Detroit has disproportionately many low skilled individuals and a reputation for inner city poverty, it also disproportionately attracts high skilled individuals, many of whom live in the wealthy neighborhood of Bloomfield Hills. In that respect, large cities like New York and Detroit are more similar to each other than they are to small cities because of the systematic pattern of fat tails in the skill distribution of large cities.

We document that this systematic pattern of spatial sorting is extremely robust to different measures: we use educational attainment and occupation as direct measures of skills and control for industry selection, we investigate the role of migration, we consider different definitions of large versus small cities, we use three different data sources for local housing values, and we include local price differences in consumption goods. To our knowledge, this pattern of spatial sorting – that mobility across cities driven by differential skill complementarity determines the skill distribution – has not been documented in the literature.

The fat tails in the skill distribution are nonetheless consistent with the well-documented city-size wage premium. The gap between average wages in the smallest cities in our sample (with a population of around 160,000, more than 100 times smaller than New York) and the largest cities is 25%. In Figure 1.A, we plot a kernel of the wage distribution of those living in all cities larger than 2.5 million inhabitants and that of those in cities smaller than one million inhabitants. Not only are average wages higher, there is a clear first-order stochastic dominance relation. At all wage levels, more people earn less in small cities than in large cities. This clearly indicates that there is a city-size wage premium across the board.

However, larger cities tend to be more expensive to live in, so in order to be able to compare skill distributions, we need to adjust for housing prices. Identical agents will make a location choice based on the utility obtained, which depends both on wages and the cost of housing. Indifference for identical agents will therefore require equalizing differences. We use homothetic preferences to adjust for housing consumption and construct a housing price index based on a hedonic

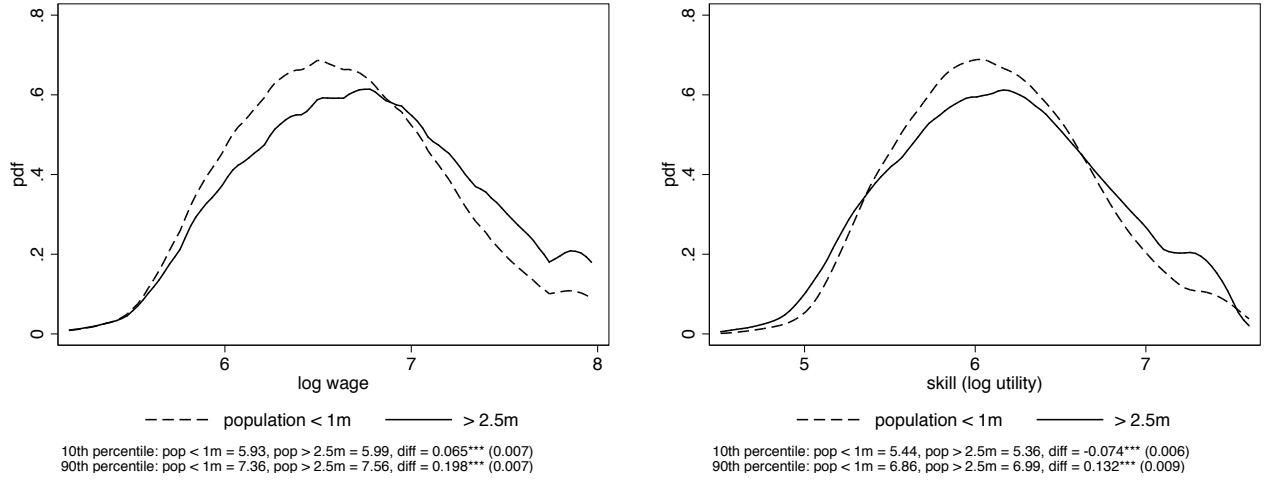


Figure 1: Wage and skill distribution for small and large cities, Kernel density estimates (Epanechnikov kernel, bandwidth = 0.1); A. Wages; B. Skills.

regression to calculate the difference in housing values across cities. Figure 1.B displays the kernel of the induced skill distribution. Our main finding is that the skill distribution in larger cities has fatter tails both at the top and at the bottom of the distribution. Large cities disproportionately attract more skilled and more unskilled workers. This finding sheds light on the nature of the underlying technology: the fat tails result is consistent with Extreme-Skill Complementarity.

A key feature of our approach is the price-theoretic measure of skills which allows us to characterize a smooth distribution of skills. This is in contrast to the common approach of using observable skills such as attained education levels or years of education. To investigate the role of observables in the spatial sorting pattern, we decompose the difference in the skill distribution between large and small cities. We find an asymmetry: in the lower tail, virtually none of the city size difference is explained by observables, while in the upper tail about half is explained, mainly by education. The high skilled are more educated in large cities than in small cities, while the low skilled are equally educated across city sizes.

There are of course other possible alternative explanations. And while we cannot exhaustively analyze all alternatives empirically, we can rule out a few prominent candidate alternatives and establish the robustness of our findings with respect to industry composition, migration and age or life cycle patterns. We discuss competing theoretical explanations such as the role of home versus market production in a world where agents have preferences for low skilled services. We also investigate the role of non-homothetic preferences and within-city sorting.

2 Related Literature

The model we propose builds on the urban location model in Eeckhout (2004) and Davis and Ortalo-Magné (2009) (see also Guerrieri, Hartley, and Hurst (2011), who augment the model with local externalities) where identical citizens who have preferences over consumption and housing choose a city in order to maximize utility. This model has been used to explain population dynamics (see also Gabaix, 1999) and expenditure shares. Because of differences in productivity across cities, wages differ and housing prices adjust in function of the population size of the city. Productivity differences are due to TFP and agglomeration effects. Given perfect mobility and identical agents, utility equalizes across cities. Our main innovation over the existing model is the introduction of heterogeneity in the inputs of production (skills) which gives rise to a distribution of skills within the city. This is necessary to meaningfully address sorting of heterogeneous agents within and across cities. Technology allows for varying degrees of complementarities between different skill types. Equilibrium is determined by the sorting decision of agents. The work by Behrens, Duranton and Robert-Nicoud (2010) also analyzes sorting of heterogeneous agents into cities. They find that more productive workers locate in large cities and less productive workers in small cities. As a result, they predict, as we do, the effect in the upper tail, but not that in the lower tail. Finally, Van Nieuwerbrugh and Weill (2010) set up a spatial equilibrium model to explain the increase

in housing price dispersion resulting from an increase in productivity dispersion of heterogeneous workers. As in our model, worker mobility in response to productivity shocks and endogenous housing prices are the main ingredients of their explanation. The key difference is the production function for consumption goods which is linear in labor and does not feature skill complementarities.

There is a long tradition in the Urban Economics literature investigating differences across city sizes, in particular with respect to varying standards of living between cities. Behrens, Duranton and Robert-Nicoud (2010) regress log nominal wages on log city size across 276 MSA areas using 2000 Census data. They find an average urban premium of 8% without controlling for talent, measured by education, and 5% when controlling for it. In addition, they regress housing costs on city size using both rental prices and an index formed of rental price and housing values of owner-occupied units. They find coefficients for housing costs similar to those for nominal wages, suggesting that there is no substantial difference in real wages. This is consistent with our finding that the mean of house-price adjusted wages is the same. They do not analyze the higher variance in larger cities. Albouy (2008) calculates real urban wages for 290 MSAs using the 2000 Census (5% IPUMS). Nominal wages are deflated using rental prices from the Census and local prices for consumption goods. The ACCRA Cost-of-Living index is the basis of the latter but not directly used because of its limited quality. Albouy regresses the ACCRA index on local rental prices and uses the predicted values as an index for local cost-of-living differences. Differences in real wages across MSAs are interpreted as quality-of-life differences. He finds that when local differences in federal taxes, non-labor income and observable amenities such as seasons, sunshine, and coastal location are controlled for, quality of life does not depend on size.

This body of work is consistent with our finding that the average of the skill distribution is remarkably constant across different sized cities. Of course, that does not allow us to conclude that there is no sorting of high-skilled workers into large cities and of low skilled workers into small cities. As we will show below, the data reveals quite the contrary. The mean is constant across cities of different size, but the variance increases substantially. The latter indicates an important role for sorting of high and low skill types into large cities and of medium types into small cities.

Our findings are also related to the previous literature on variations in the measured skill distributions across city sizes. Bacolod, Blum and Strange (2009) study the difference in skill distributions across city sizes using jointly Census and NLSY data and the Dictionary of Occupational Titles (DOT), defining skills as a combination of qualities instead of just education. They find a small variation in cognitive, people, and motor skills across city sizes which they attribute to skills being defined nationally. However they are not able to address local differences in occupational requirements of skills. Once they look at differences in the Armed Forces Qualification Test (AFQT) and the Rotter Index – measures of intelligence and social skills, respectively – they find that, even though the average scores are quite similar across city sizes, the scores in large cities for the lowest scores (10th percentile) are much lower than the ones in small cities. Similarly, the highest scores (90th percentile) are much higher in large cities than in small ones, which is consistent with our robustness exercise reported in section 6.1 on direct measures of education. Also Gautier and Teulings (2009, Table 1) report a higher measured standard deviation in educational attainment across larger cities, which is consistent with our findings. However, they find first order stochastic dominance rather than fat tails as we do, because the mean is also higher. The reason is that their measure of skill is really a measure of wages. It is independent of housing prices and it is constructed as predicted wages net of unobserved heterogeneity using a Mincerian wage regression. Consistent with the urban wage premium, average wages increase with firm size. Instead, our measure of skills adjusts wages for the equilibrium mobility decision by means of housing prices and we find that average skills are independent of city size. Together with the fact that the standard deviation increases with city size, this gives us fat tails, and not first order stochastic dominance. Note also that the first order stochastic dominance in Gautier and Teulings (2009) is not consistent with the direct measures of skills as reported in section 6.1 or as documented by Bacolod, Blum and Strange (2009). The distributions of those direct measures have fat tails in large cities – equal means, higher standard deviation – just as our wage-based measure that is adjusted for housing prices. In sum, while the *wage* distribution has been shown to satisfy first order stochastic dominance in city size (increasing mean, increasing standard deviation), we establish that the distribution of our wage-based measure of *skills* has fat tails in large cities (equal mean, increasing standard deviation).

Finally, there is little direct evidence on the role of complementarities between heterogeneously skilled agents. One notable exception is the work by Hamilton, Nickerson and Owan (2003), who analyze the effect of team composition

on productivity in a textiles production plant. They find that heterogeneous teams are more productive with average productivity held constant. While their setup is very specific and other theories can certainly rationalize this outcome, their finding is consistent with a technology that has extreme-skill complementarity.

3 The Model

Population. Consider an economy with heterogeneously skilled workers. Workers are indexed by a skill type i . For now, let the types be discrete: $i \in \mathcal{I} = \{1, \dots, I\}$. Associated with this skill order is a level of productivity y_i . Denote the country-wide measure of skills of type i by M_i . Let there be J locations (cities) $j \in \mathcal{J} = \{1, \dots, J\}$. The amount of land in a city is fixed and denoted by H_j . Land is a scarce resource.

Preferences. Citizens of skill type i who live in city j have preferences over consumption c_{ij} , and the amount of land (or housing) h_{ij} . The consumption good is a tradable numeraire good with price equal to one. The price per unit of land is denoted by p_j . We think of the expenditure on housing as the flow value that compensates for the depreciation, interest on capital, etc. In a competitive rental market, the flow payment will equal the rental price.¹ A worker has consumer preferences over the quantities of goods and housing c and h that are represented by: $u(c, h) = c^{1-\alpha}h^\alpha$, where $\alpha \in [0, 1]$. Workers are perfectly mobile, so they can relocate instantaneously and at no cost to another city. Because workers with the same skill are identical, in equilibrium each of them should obtain the same utility level wherever they choose to locate. Therefore for any two cities j, j' it must be the case that the respective consumption bundles satisfy $u(c_{ij}, h_{ij}) = u(c_{ij'}, h_{ij'})$, for all skill types $\forall i \in \{1, \dots, I\}$.

Technology. Cities differ in their total factor productivity (TFP) which is denoted by A_j . For now, we assume that TFP is exogenous. We think of it as representing a city's productive amenities, infrastructure, historical industries, persistence of investments, etc.²

In each city, there is a technology operated by a representative firm that has access to a city-specific TFP A_j . Output is produced by choosing the right mix of differently skilled workers i . For each skill i , a firm in city j chooses a level of employment m_{ij} and produces output: $A_j F(m_{1j}, \dots, m_{Ij})$. Firms pay wages w_{ij} for workers of type i . It is important to note that wages depend on the city j because citizens freely locate between cities not based on the highest wage, but, given housing price differences, based on the highest utility. Like land, firms are owned by absentee capitalists (or equivalently, all citizens own an equal share in the country-wide real estate bond).

Market Clearing. In the country-wide market for skilled labor, markets for skills clear market by market, and for housing, there is market clearing within each city:

$$\sum_{j=1}^J C_j m_{ij} = M_i, \quad \forall i \quad \sum_{i=1}^I h_{ij} m_{ij} = H_j, \quad \forall j. \quad (1)$$

where C_j denotes the number of cities with TFP A_j .

4 The Equilibrium Allocation

The Citizen's Problem. Within a given city j and given a wage schedule w_{ij} , a citizen chooses consumption bundles $\{c_{ij}, h_{ij}\}$ to maximize utility subject to the budget constraint (where the tradable consumption good is the numeraire, i.e.

¹We will abstract from the housing production technology; for example, we can assume that the entire housing stock is held by a zero measure of absentee landlords.

²In an earlier version of the paper, we endogenize A_j and let it be the result of agglomeration externalities. This is also documented in the Additional Material Section.

with price unity)

$$\begin{aligned} \max_{\{c_{ij}, h_{ij}\}} u(c_{ij}, h_{ij}) &= c_{ij}^{1-\alpha} h_{ij}^\alpha \\ \text{s.t. } c_{ij} + p_j h_{ij} &\leq w_{ij} \end{aligned} \quad (2)$$

for all i, j . Solving for the competitive equilibrium allocation for this problem we obtain $c_{ij}^* = (1 - \alpha)w_{ij}$ and $h_{ij}^* = \alpha \frac{w_{ij}}{p_j}$. Substituting the equilibrium values in the utility function, we can write the indirect utility for a type i as:

$$U_i = \alpha^\alpha (1 - \alpha)^{1-\alpha} \frac{w_{ij}}{p_j^\alpha} \implies w_{ij} = U_i p_j^\alpha \frac{1}{\alpha^\alpha (1 - \alpha)^{1-\alpha}}, \quad (3)$$

where U_i is constant across cities from labor mobility. This allows us to link the wage distribution across different cities j, j' . Wages across cities relate as:

$$\frac{w_{ij}}{w_{ij'}} = \left(\frac{p_j}{p_{j'}} \right)^\alpha. \quad (4)$$

The Firm's Problem. All firms are price-takers and do not affect wages. Wages are determined simultaneously in each submarket i, j . Given the city production technology, a firm's problem is given by:

$$\max_{m_{ij}, \forall i} A_j F(m_{1j}, \dots, m_{Ij}) - \sum_{i=1}^I w_{ij} m_{ij}, \quad (5)$$

subject to the constraint that $m_{ij} \geq 0$. The first-order condition is: $A_j F_{m_{ij}}(m_{ij}) = w_{ij}, \forall i$.³

Because there is no general solution for the equilibrium allocation in the presence of an unrestricted technology, we focus on variations of the Constant Elasticity of Substitution (CES) technology, where the elasticity is allowed to vary across skill types. As a benchmark therefore, we consider the CES technology:

$$A_j F(m_{1j}, \dots, m_{Ij}) = A_j \left(\sum_{i=1}^I m_{ij}^\gamma y_i \right) \quad (6)$$

with $\gamma < 1$. In this case the first-order conditions are $A_j \gamma m_{ij}^{\gamma-1} y_i = w_{ij}, \forall i$.

Below we will solve the allocation under CES as a special case of the more general technology. Even without fully solving the system of equations for the equilibrium wages, observation of the first-order condition reveals that productivity between different skills i in a given city is governed by two components: (1) the productivity y_i of the skilled labor and how fast it increases in i ; and (2) the measure of skills m_{ij} employed (wages decrease in the measure employed from the concavity of the technology). Without loss of generality, we assume that wages are monotonic in the order i .⁴ This is consistent with our price-theoretic measure of skill.

We now proceed by introducing varying degrees of complementarities between different skills, starting from the CES technology. This implies the technology now has an elasticity of substitution that is no longer constant. For tractability, let there be two cities, $j \in \{1, 2\}$ and three skill levels $i \in \{1, 2, 3\}$. Consider any subset of the skills, say i, k , between which there is a degree of complementarity λ , and none with the remaining skill level l . Then the technology can be written as $(m_{ij}^\gamma y_i + m_{kj}^\gamma y_k)^\lambda + m_{lj}^\gamma y_l$. Depending on the subset of skills, we distinguish between the following configurations.

³In what follows, the non-negativity constraint on m_{ij} is dropped. This is justified whenever the technology satisfies the Inada condition that marginal product at zero tends to infinity whenever A_j is positive. This will be the case since we focus on variations of the CES technology.

⁴For a given order i , wages may not be monotonic as they depend on the relative supply of skills as well as on y_i . If they are not, we can relabel skills such that the order i corresponds to the order of wages. Alternatively, we can allow for the possibility that higher skilled workers can perform lower skilled jobs. Workers will drop job type until wages are non-decreasing. Then the distribution of workers is endogenous, and given this endogenous distribution, all our results go through. For clarity of the exposition, we will assume that the distribution of skills ensures that wages are monotonic.

Definition 1 Consider the following technologies:

*I. **Extreme-Skill Complementarity.** High skill workers are complementary with low skill workers.*

$$A_j F(m_1, m_2, m_3) = A_j \left[(m_{1j}^\gamma y_1 + m_{3j}^\gamma y_3)^\lambda + m_{2j}^\gamma y_2 \right], \quad (7)$$

when $\lambda > 1$ relative to CES. Instead, skills 1 and 3 are substitutes when $\lambda < 1$.

*II. **Top-Skill Complementarity.** High skill workers are complementary with medium skill workers.*

$$A_j F(m_1, m_2, m_3) = A_j \left[(m_{2j}^\gamma y_2 + m_{3j}^\gamma y_3)^\lambda + m_{1j}^\gamma y_1 \right], \quad (8)$$

when $\lambda > 1$ relative to CES. Instead, skills 2 and 3 are substitutes when $\lambda < 1$.

Observe that we could also introduce bottom-skill complementarities. In terms of the distributional implications, this is equivalent to top-skill substitutabilities, i.e., technology II with $\lambda < 1$. There are therefore 5 distinct configurations of the technology: two for technology I, with complements ($\lambda > 1$) or substitutes ($\lambda < 1$), two for technology II. ($\lambda > 1$ and $\lambda < 1$), and CES ($\lambda = 1$).

It is worth pointing out that for our purpose, three skills is the minimal requirement to fully capture first order stochastic dominance and fat tails. Distinguishing between the two cannot be achieved with two skills only. At the same time, with a larger number of skills, we do not obtain qualitatively different results. With one hundred skill types, one can of course analyze the properties of each percentile, but that does not provide essential additional information about the existence of fat tails or stochastic dominance. We nonetheless investigate the generality of this setup. In the Online appendix we report the same properties that we derive below for general technologies with any N skills, and for more general patterns of gross complementarities. While we can handle a large number of cities, for analytical purposes, we cannot generalize the setup beyond two cities types. That is, we can compute the equilibrium allocation⁵, but we cannot find an analytical solution for it. We can however analyze the setting for *any* number of cities with types A_1 or A_2 , i.e., for any C_1, C_2 .

We first derive the equilibrium conditions for case *I*, Extreme-Skill Complementarity. The first-order conditions are for each j and all skill types i , respectively:

$$\lambda A_j [m_{1j}^\gamma y_1 + m_{3j}^\gamma y_3]^{\lambda-1} \gamma m_{1j}^{\gamma-1} y_1 - w_{1j} = 0 \quad (9)$$

$$\gamma A_j m_{2j}^{\gamma-1} y_2 - w_{2j} = 0 \quad (10)$$

$$\lambda A_j [m_{1j}^\gamma y_1 + m_{3j}^\gamma y_3]^{\lambda-1} \gamma m_{3j}^{\gamma-1} y_3 - w_{3j} = 0 \quad (11)$$

Using labor mobility, we can write the wage ratio in terms of the house price ratio for all i , $\frac{w_{i2}}{w_{i1}} = \left(\frac{p_2}{p_1}\right)^\alpha$ and equate the first-order condition in both cities for a given skill, for example for $i = 1$:

$$A_1 [m_{31}^\gamma y_3 + m_{11}^\gamma y_1]^{\lambda-1} m_{11}^{\gamma-1} = \left(\frac{p_1}{p_2}\right)^\alpha A_2 [m_{32}^\gamma y_3 + m_{12}^\gamma y_1]^{\lambda-1} m_{12}^{\gamma-1} \quad (12)$$

Using market clearing, $m_{12} = \frac{M_1}{C_2} - \frac{C_1}{C_2} m_{11}$ in the local labor market, we can solve for the first-order conditions for each skill to obtain the equilibrium quantities:

$$m_{11} = \frac{\left[\left(\frac{p_1}{p_2}\right)^\alpha \frac{A_2}{A_1}\right]^{\frac{1}{\lambda\gamma-1}} \frac{M_1}{C_2}}{1 + \frac{C_1}{C_2} \left[\left(\frac{p_1}{p_2}\right)^\alpha \frac{A_2}{A_1}\right]^{\frac{1}{\lambda\gamma-1}}}, \quad m_{21} = \frac{\left[\left(\frac{p_1}{p_2}\right)^\alpha \frac{A_2}{A_1}\right]^{\frac{1}{\gamma-1}} \frac{M_2}{C_2}}{1 + \frac{C_1}{C_2} \left[\left(\frac{p_1}{p_2}\right)^\alpha \frac{A_2}{A_1}\right]^{\frac{1}{\gamma-1}}}, \quad m_{31} = \frac{\left[\left(\frac{p_1}{p_2}\right)^\alpha \frac{A_2}{A_1}\right]^{\frac{1}{\lambda\gamma-1}} \frac{M_3}{C_2}}{1 + \frac{C_1}{C_2} \left[\left(\frac{p_1}{p_2}\right)^\alpha \frac{A_2}{A_1}\right]^{\frac{1}{\lambda\gamma-1}}}, \quad (13)$$

and likewise in city 2.

⁵Here it is worth drawing a parallel to the work by Krusel, Ohanian, Rios-Rull and Violante (2000). They compute an infinite (or long finite horizon) economy with intertemporal prices. The parallel to their dynamic economy is our cross section of cities with spatial prices.

So far we have consumer optimization for consumption and housing, the location choice by the worker, and firm optimization given wages. The next step is to allow for market clearing in the housing market given land prices. The system is static and solved simultaneously, which is reported in the Appendix. In what follows, we assume $H_j = H$ for all cities j . Below, we will discuss the implications where this simplifying assumption has bite.

The Main Theoretical Results. First we establish the relation between TFP and city size. Denote by S_j the size of city j where $S_j = \sum_{i=1}^I C_j m_{ij}$. When cities have the same amount of land, we can establish the following result.

Theorem 1 *City Size and TFP.* Let $A_1 > A_2$ and $\lambda\gamma < 1, \gamma < 1$. Then the more productive city is larger, $S_1 > S_2$.

Proof. In Appendix. ■

We establish this result for cities with an identical supply of land. Clearly, the supply of land is important in our model since in a city with an extremely small geographical area, labor demand would drive up housing prices all else equal. This may therefore make it more expensive to live in even if the productivity is lower. Because in our empirical application we consider large metropolitan areas (NY city for example includes large parts of New Jersey and Connecticut), we believe that this assumption does not lead to much loss of generality.⁶

We now establish the main theorem characterizing the skill distribution across firms. We already know that more productive cities are larger, but this does not necessarily mean that the distribution of skills in larger cities differs from that in smaller cities. In fact, it depends on the technology.

Theorem 2 *Extreme-Skill Complementarity and Fat Tails.* Given $A_1 > A_2$, $\lambda > 1$ and $\lambda\gamma < 1$, the skill distribution in the larger city has fatter tails.

Proof. In Appendix. ■

Two corollaries immediately follow from the main theorem.

Corollary 1 *CES technology.* If $\lambda = 1$ and $\gamma < 1$, then the skill distribution across cities is identical.

Under CES technology, cities have identical skill compositions. This is due to the homotheticity of CES technology: the marginal rate of technical substitution is proportional to total employment, and, as a result, firms in different cities and with different technologies will employ different skills in the same proportions. The proof of the result follows immediately from setting $\lambda = 1$ in the proof of Theorem 2. Even though the city size distribution under CES technology is the same across cities, the more productive city will be larger. This follows from Theorem 1.

The second Corollary establishes the mirror-image result under extreme-skill substitutability.

Corollary 2 *Extreme-Skill Substitutability and Thin Tails.* Given $A_1 > A_2$, $\lambda < 1$ and $\lambda\gamma < 1$, the skill distribution in the larger city has thinner tails.

These two corollaries can help build intuition for the result in Theorem 2. Consider first CES as a benchmark. Homotheticity implies that even though the level of employment differs across skills, firms will always choose to hire different skills in exactly the same proportions for a given wage ratio. Since housing prices affect all skills within a city in the same way, the wage ratio is unaffected.

Instead with extreme-skill complementarity, the marginal product of both the low and the high skilled workers is higher than for medium skills, thus breaking the homotheticity. Given the complementarity between TFP A_j and the skill aggregator, the marginal impact on productivity of the extreme skills will now be disproportionately higher in larger than in smaller cities. This induces the relative increase in demand for extreme skills. Observe that this cannot be offset by higher housing prices because these are determined by real wage equalization at *all* skill levels, including the medium

⁶In fact, the equal supply of housing condition is only sufficient for the proof, but not necessary. However, our model does not address the important issue of within-city geographical heterogeneity, as analyzed for example in Lucas and Rossi-Hansberg (2002). In our application, all heterogeneity is absorbed in the pricing index by means of the hedonic regression. In Section 7.1, we empirically analyze the implications of within city sorting and find no qualitative impact on the results. This is consistent with recent work by Fu and Ross (2010), who find little evidence of sorting within metropolitan areas based on agglomeration.

skilled. The higher real wages for low and high skilled workers in large cities will attract those skill types into the large cities driving down nominal wages until real wages are equalized. This in-migration of low and high skilled workers leads to the fat tails in the large cities.

Top-Skill Complementarity. Now consider the technology $A_j F(m_1, m_2, m_3) = A_j \left[(m_{2j}^\gamma y_2 + m_{3j}^\gamma y_3)^\lambda + m_{1j}^\gamma y_1 \right]$. Without going through the detailed analysis in the text, we obtain the equivalent to Theorem 2 above (Theorem 1 readily extends as well) :

Theorem 3 *Top-Skill Complementarity and First Order Stochastic Dominance.* Given $A_1 > A_2$, $\lambda > 1$ and $\lambda\gamma < 1$, the skill distribution in the larger city first-order stochastically dominates.

Proof. In Appendix. ■

And the corollary establishing the mirror-image result under extreme-skill substitutability.

Corollary 3 *Top-Skill Substitutability and First Order Stochastic Dominance.* Given $A_1 > A_2$, $\lambda < 1$ and $\lambda\gamma < 1$, the skill distribution in the larger city is first-order stochastically dominated.

Under top-skill complementarity, the highest skilled are complements with the next highest skill types, thus generating disproportionately higher output in larger cities. This complementarity breaks the homotheticity property, and leads to disproportionate demand in larger cities. Free mobility and real wage equalization across cities implies that the distribution in the larger city has disproportionately more of the top skill types. This induces first order stochastic dominance.

In Theorems 2 and 3 we identify a mechanism of skill complementarities in the production technology that generates a systematic pattern in the skill distribution. There is exactly one distribution pattern that corresponds to each of the 5 technology patterns (extreme-skill and top-skill, each with complements or substitutes, and CES). From the systematic pattern of fat tails in the distribution in large cities that we observe below, we can qualitatively deduce that this is due to the complementarities between extreme skills. As in the macro literature on differential complementarities (most notably Krusell, Ohanian, Violante and Rios-Rull, 2000), we obtain information about the technology from the observed equilibrium distribution. We believe that the theoretical link between the complementarities and the distribution is novel. Moreover, from a theoretical viewpoint, we are able to explicitly analyze a tractable matching problem à la Kelso and Crawford (1982) with complementarities (peer effects) that are applied in a concrete labor market setting. Thus far, only general properties such as existence rather than explicit characterizations have been analyzed in these models.

We have chosen to model city difference by means of exogenously given TFP differences. In reality, there are reasons why the productivity of cities is endogenous. We report a model with endogenous agglomeration externalities in the Additional Material Section, available online. The main finding is that agglomeration externalities can lead to asymmetric equilibria with cities of different sizes, even if they are ex ante identical. This occurs provided the external effect is strong enough. We further show that once cities are heterogeneous, the fat tail results extend to this setting with endogenous externalities. And in addition to these production externalities, there could be consumption externalities from the presence of amenities. Unfortunately in our analysis, because we identify unobservable skills from wages, we cannot jointly determine skills and amenities from the same wages. While there is no doubt that amenities matter for citizens' location decisions, based on evidence from Albouy (2008) there seems to be no systematic relation to city size, unlike the relation of skill composition to city size as we derive in our results.

Finally, we also report some further results on housing and consumption expenditure. It is immediate from our model that in large cities, citizens will spend more on housing, yet they will consume less of it.

Proposition 1 *Consider a general technology F . For a given skill i , expenditure on housing $p_j h_{ij}^*$ is higher in larger cities. The size of houses h_{ij}^* in larger cities is smaller.*

Proof. From the consumer's problem, we have: $p_j h_{ij} = \alpha w_{ij}$. Since $w_{i1} > w_{i2}$, we must have $p_1 h_{i1} > p_2 h_{i2}$, $\forall i$. Similarly, from the same equality in the consumer's problem, we have $h_{ij} = \alpha w_{ij} / p_j$. Since:

$$\frac{w_{i1}}{p_1} < \frac{w_{i2}}{p_2} \quad (14)$$

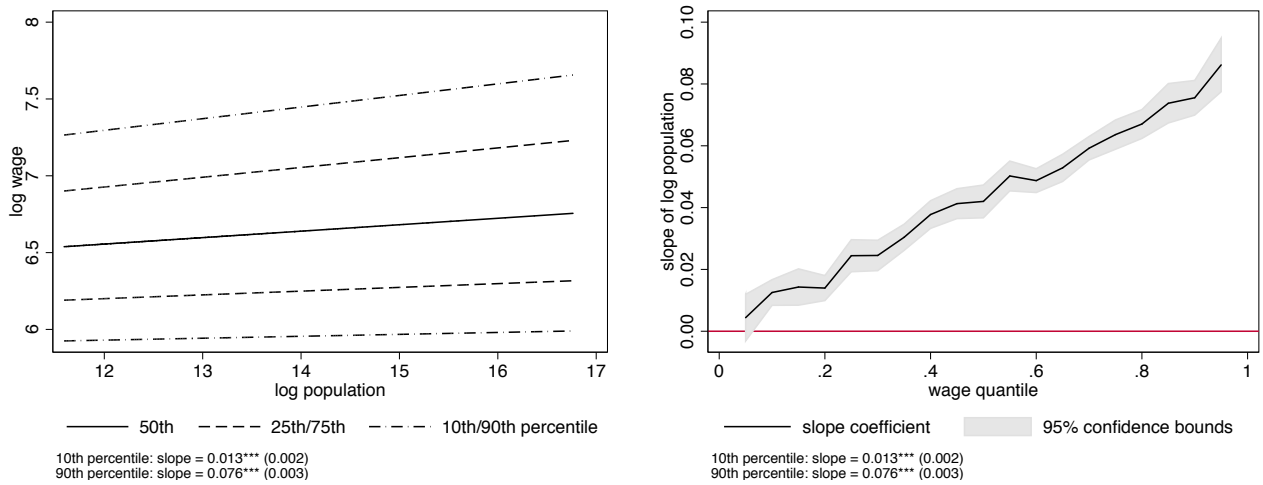


Figure 2: Quantile regression of wage on population. A. 5 selected quantiles; B. Estimated slope for all quantiles.

it follows that $h_{i1} < h_{i2}$. ■

Then given homothetic preferences for consumption, it immediately follows that:

Corollary 4 *Expenditure on the consumption good is higher in larger cities.*

Our model predicts that expenditure on both housing and consumption is higher in larger cities, though the equilibrium quantity of housing h_{ij}^* is lower. As cities become larger (or as the difference in TFP increases), at all skill levels total income increases and therefore total expenditure increases. Because housing prices increase as well, there will be substitution away from housing to the consumption good. As a result, inequality in consumption expenditure will increase.

5 The Empirical Evidence of Fat Tails: Big Cities, Big Inequality

We use the one-to-one relation between skills and equilibrium utility to back out the skill distribution from observable variables. The worker's indirect utility in equilibrium is independent of the city, given perfect mobility, and assuming Cobb-Douglas preferences, it satisfies

$$U_i = \alpha^\alpha (1 - \alpha)^{1-\alpha} \frac{w_{ij}}{p_j^\alpha} \quad (15)$$

where we need to observe the distribution of wages w_{ij} by city j , the housing price level p_j by city and the budget share of housing α .

5.1 Data

The analysis is performed at the city level. We define a city as a Core Based Statistical Area (CBSA), the most comprehensive functional definition of metropolitan areas published by the Office of Management and Budget (OMB) in 2000. See Table 4 in the appendix for the list of the largest and smallest cities and their 2009 population.

We use wage data from the Current Population Survey (CPS) for the year 2009. We observe weekly earnings for 102,577 full-time workers in 257 U.S. metropolitan areas. CPS wages are top-coded at around \$150,000 which we will take into account in the statistical analysis. In the data appendix, we provide detailed information on data source, sample restrictions and variables.

Local housing price levels are estimated using the American Community Survey (ACS) for 2009. We observe monthly rents for 274,000 housing units in 533 CBSAs. The ACS reports the number of rooms, the age of the structure, and the number of units in the structure. With these data we estimate city specific housing price indices using hedonic regressions. See the appendix for details and a theoretical motivation of this approach.⁷

⁷In an earlier version of this paper we show that our findings are robust to using other housing price data such as from the National

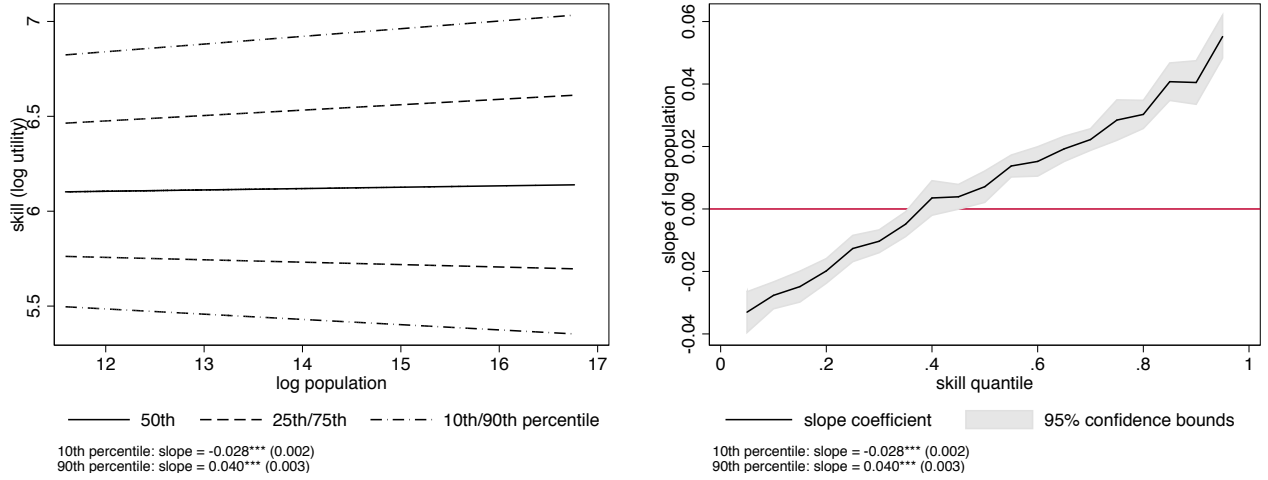


Figure 3: Quantile regression of skills (utility) on population. A. 5 selected quantiles; B. Estimated slope for all quantiles.

5.2 Wage distribution

Figure 1.A in the introduction shows the distribution of weekly wages for full-time earners both in cities with a population of more than 2.5 million and in cities with a population between 100,000 and 1 million. We clearly see that wages in larger cities are higher and that the top tail of the distribution is substantially fatter in large cities.⁸ A simple t-test shows that wages in large cities are 13.2% higher than in small ones ($t = 28.3, p < 0.01$). Controlling for right censoring from top-coding and weights in a censored (tobit) regression leads to almost exactly the same comparison: $\Delta \log \text{wage} = 13.1\%$ (robust $t = 24.7, p < 0.01$). A look at the tails of the two distributions shows that the large cities have a fatter tail at the top and the small cities at the bottom. The 90th percentile for large cities is 7.56 compared to 7.36 for small cities ($\Delta = 0.198, se = 0.007, p < 0.01$). The 10th percentile for large cities is 5.99 compared to 5.93 for small cities ($\Delta = 0.065, se = 0.007, p < 0.01$).⁹

The above partitioning of wages into a group of small cities and a group of large cities is arbitrary. We therefore perform quantile regressions of wages on city population size. Panel A in Figure 2 shows the estimated regression lines for the 10th, the 25th, the 50th, the 75th and the 90th percentile. Panel B in Figure 2 shows the slope coefficients for all quantiles. The slopes are all significantly above 0, which implies that the upper tail of the wage distribution increases with city size while the lower tail decreases. For the median (50th percentile), for example, the slope is 0.042: a doubling of city size leads to a 4.2% increase in wages.

5.3 Skill distribution

Davis and Ortalo-Magné (2007) document that expenditure shares on housing are remarkably constant across U.S. metropolitan areas with a median expenditure share of 0.24. We use this as our estimate of α . Together with our estimate for local housing prices p_j we can back out the indirect utility u_{ij} for the observed wages using equation (15).

The variation in housing prices is substantial. While wages increase by 4.2% as city size doubles, housing prices increase by 16.9% for the same change in city size, i.e. a fourfold increase. With the 0.24 expenditure share, this implies that the average cost of living is of a factor $1.169^{0.24} = 1.038$. In other words, the 4.2% wage gain from living in a larger city is virtually completely absorbed by a 3.8% disutility increase due to the cost of living.

Figure 1.B in the introduction shows the *entire* distribution of skills for full-time earners both in cities with a population of more than 2.5 million and cities with a population between 100,000 and 1 million. In contrast to the wage distribution,

Association of Realtors or from the Council for Community and Economic Research (C2ER).

⁸Note that the “bumps” in the top tail for both large and small cities are an artifact of the top-coded *nominal* wage data.

⁹Percentiles and their difference are estimated in a quantile regression of wages on a dummy variable for large cities. We use CPS earnings weights and bootstrapped robust standard errors.

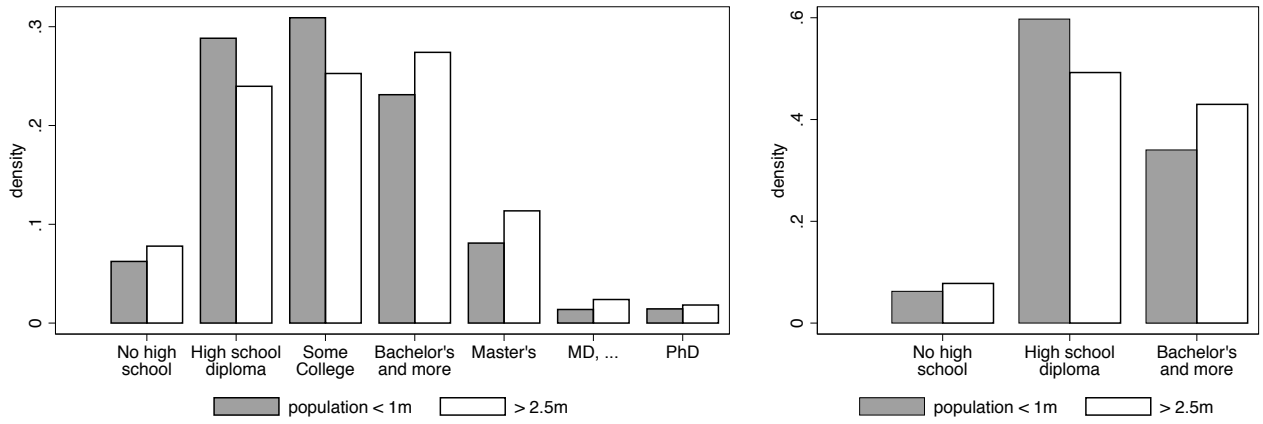


Figure 4: Observed educational attainment for small and large cities. Highest completed grade of full-time wage earner in 2009 CPS. A. Grouped in 7 categories; B. Grouped in 3 categories.

the skill distribution in large cities is only marginally shifted to the right. However, both the upper and the lower tail of the distribution is thicker in the large cities, thus confirming the consistency with the theoretical prediction of fat tails from extreme-skill complementarity.¹⁰ An explicit look at the tails of the two distributions confirms the fat tail prediction in a statistical sense. The 90th percentile for large cities is 5.36 compared to 5.23 for small cities ($\Delta = 0.125$, $se = 0.010$, $p < 0.01$). The 10th percentile for large cities is 3.72 compared to 3.80 for small cities ($\Delta = -0.080$, $se = 0.007$, $p < 0.01$). So the large cities have both a significantly lower 10th percentile and a significantly larger 90th percentile, which implies the fat tails.

As with the wage distribution, one could argue that our partitions of cities into small and large ones is arbitrary. We therefore also run quantile regressions of our implicit skill measure on city population. Figure 3 visualizes the results of these regressions. It shows that the median (50th percentile) barely changes with city sizes while the lower percentiles significantly decrease and the upper percentiles significantly increase. This reiterates our finding that the average of skills does not change systematically with city size while the variance of skills increases significantly. The quantile regressions also perfectly account for the top coding in the wage data up to about the 95th percentile.

6 Robustness

Our measure of skills is a price based measure, calculated as the residual of wages after adjusting for housing prices, yet it does not use any observable characteristics. In this section we verify the robustness of the spatial sorting result. The price-theoretic measure encompasses both observed and unobserved heterogeneity. Therefore we attempt to verify the claim based on an observed, direct measure of skills.

More specifically, we check the robustness of our findings on spatial sorting and the resulting fat tails in the distribution of skills as follows. In the first instance, we use years of schooling (section 6.1) and occupation (6.2) as direct measures of skills instead of our wage based measure. Then, we investigate whether there is any systematic variation in the industry composition across cities of different sizes (6.3). We then investigate the role of mobility and migration that is systematic by nationality (6.4) and whether there are any location decisions determined by age over the life cycle (6.5). We then quantify the impact of those observables simultaneously (6.6) and decompose the tails into an explained and an unexplained component. Finally, we verify the robustness of our results to alternative measures of prices (6.7).

6.1 Education: A Direct Measure of Skills

As a robustness check and as external validation, we compare our implicit skill distribution with observed measures of skill. Figure 4.A. shows the distribution of educational attainment for the same CPS population as our wage data, where

¹⁰Note again that the “bumps” in the top tail are due to top coding, see footnote 8. Top codes appear more to the left for large cities because *real* wages are deflated with higher housing prices.

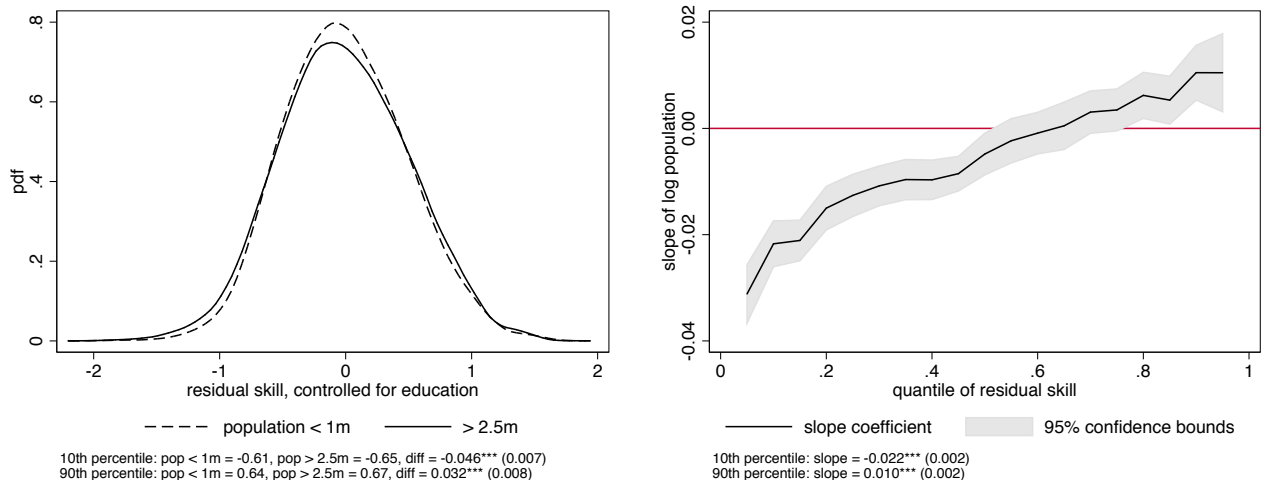


Figure 5: Unobserved (residual) skill conditional on 16 observed education levels. A. Skill distribution for small and large cities. B. Slopes in quantile regressions of log utility on log population.

workers are grouped in 7 education categories. The same pattern as with our implicit measure arises: both the highest and the lowest skilled workers are disproportionately more frequent in larger cities than in smaller ones.

This can be observed even more transparently when we group the education levels into three groups (Figure 4.B). What is most striking about this observation is that the fat tails in the distribution of educational attainment are obtained *independently* of how we constructed our measure of skills before. Here, no theory is needed and the measure of skills is determined exogenously. Using observable, self-reported measures of skills we find a distribution with fatter tails in larger cities, both in the aggregate and at the individual city level.

In principle, individual skills can be decomposed into an observed component, e.g. education, and an unobserved component, e.g. ability. We already know that the *observed* component indeed exhibits fat tails. To get to the unobserved component, we regress our skill measure (log utility) on dummy variables for all 16 observed education categories.¹¹ The residual of this regression is the “residual skill” after controlling for observed education. A high value means that the worker is more skilled relative to other workers with the same education. This can be a very successful lawyer or a high-school-dropout-become-successful-entrepreneur.

Figure 5 shows the resulting distribution of residual skills for large and small cities. We see that the fat tails persist for the unobserved component, and are more pronounced at the bottom than at the top. Large cities seem to host more of the relatively *low* skilled even after controlling for education category. Taken together, these two pieces of evidence mean that large cities attract relatively more of the best educated and more of the least educated workers. In addition, they attract the more talented, given their education level. We also see that there is an asymmetry between the upper and the lower tail in Figure 5. This indicates that the sorting of the most talented workers is based more on the observed component of skills (education) while the sorting of the least talented is based more on the unobserved component. A finding that we will reiterate in the next section, where we condition on occupations.

6.2 Occupation: An Alternative Direct Measure of Skills

Like education, occupation can be interpreted as a direct measure of skills. More highly skilled individuals are likely to be employed in higher ranked occupations. If we can find a way to rank occupations, it can give us some insights into the sorting of workers based on this observed characteristic.

¹¹We estimate censored (tobit) regression, accounting for the top-coding of the wage data. We regress $\log(u_{ij})$ on a constant and a set of dummy variables for education with basic education as reference group. This dummy variable regression is fully consistent with our theoretical model. Recall that the wage ratio of skill type i relative to skill type 1 is constant across cities, $\log(w_{ij}/(w_{1j})) = \log(w_{ij}) - \log(w_{1j}) = \beta_i$ and therefore the ratio of log utility, too, $\log(u_{ij}/p_j^\alpha/(u_{1j}/p_j^\alpha)) = \log(u_{ij}/(u_{1j})) = \log(w_{ij}/(w_{1j})) = \beta_i$. The log utility of skill type i can therefore be expressed as $\log(u_{ij}) = \beta_1 + \beta_2 * d_2 + \dots + \beta_i * d_i + \dots$ where β_1 is $\log(\text{utility}_{ij}) = \log(\text{utility}_i)$ of the reference skill type 1, which is constant across cities j . Notice, that regressing $\log(\text{wage})$ on a constant and dummy variables for education would not be consistent with our theoretical model as the constant, $\log(w_{1j})$, would be city specific. The usual wage regression therefore needs city fixed effects, which we do not need.

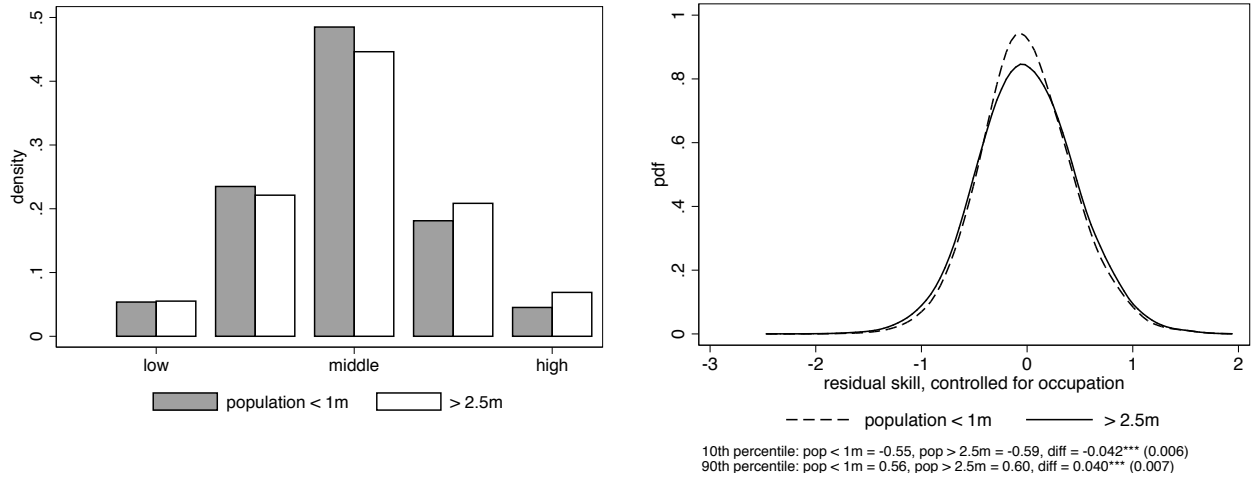


Figure 6: A. Distribution of observed skill level based on reported occupations for small and large cities. Full-time wage earner in 2009 CPS. 498 occupations ranked by median country-wide wage and grouped into 5 categories. B. Unobserved (residual) skill conditional on 498 occupations for small and large cities.

The current population survey contains the occupation of workers, in addition to wages and education. This occupational classification has been used as an alternative direct measure of skills before (see e.g., Autor, Levy, Murnane, 2003). The CPS reports occupations in 498 categories from the 2000 Standard Occupational Classification by the U.S. Bureau of Labor Statistics. We use country-wide median wages by occupation category as a proxy of their skill requirement (this approach is used in e.g. Goos, Manning, Salomons, 2009). We then group the 498 occupation categories into 5 groups: group 1 includes the lowest paid occupations covering 5% of all workers, group 2 the next 20%, the middle group 3 covers 50% of workers, group 4 the next 20%, and the high skill group 5 includes the highest paid occupations covering 5% of all workers. The low skill group 1 includes occupations such as dishwashers, waiters, and child care workers; the middle group 3 occupations like secretaries and truck drivers; the high skill group includes chief executives, surgeons and lawyers.

Figure 6.A shows the distribution of these 5 occupation groups separately for small cities (CBSA population between 100,000 and 1M) and for large cities (CBSA population above 2.5M). It shows that workers in the highest paid occupations locate relatively more often to large cities while the middle occupations locate more to small cities. The lowest paid occupations locate slightly more often to large cities, too. This direct evidence of fat tails is very similar to the result we found for education groups. The effect on the lower tail is less pronounced than for the upper tail.

As in the analysis of education, we next decompose skills into a component observed through occupations and the residual unobserved component. We regress our skill measure (log utility) on dummy variables for all 498 occupation categories.¹² The residual of this regression is the “residual skill” after controlling for observed occupation. Figure 6.B shows the resulting distribution of residual skills for large and small cities. We see that the fat tails persist for the unobserved component. In particular, large cities seems to host more of the relatively low skilled in each occupation than small cities. As a result, large cities attract relatively more workers in the highest paid occupations and more in the lowest paid occupations. In addition, they attract the more talented, given their occupation. We also see that the sorting of the most talented workers is based more on the observed component of skills (occupation) while the sorting of the least talented is based more on the unobserved component. A finding that we already made using education as a direct measure.

6.3 Industrial composition

A potential threat to our identification of skills is the different industrial composition of cities. Wages systematically differ across industries and the mobility of workers varies across sectors (see for example Davis, Faberman and Haltiwanger, 2006). At the same time, industrial composition changes across cities: some cities specialize in particular industries and other cities have a diverse industrial mix. If industry composition varies systematically with city size, this could be an alternative explanation for our finding of fat tails.

¹²We estimate censored (tobit) regression accounting for the top-coding of the wage data.

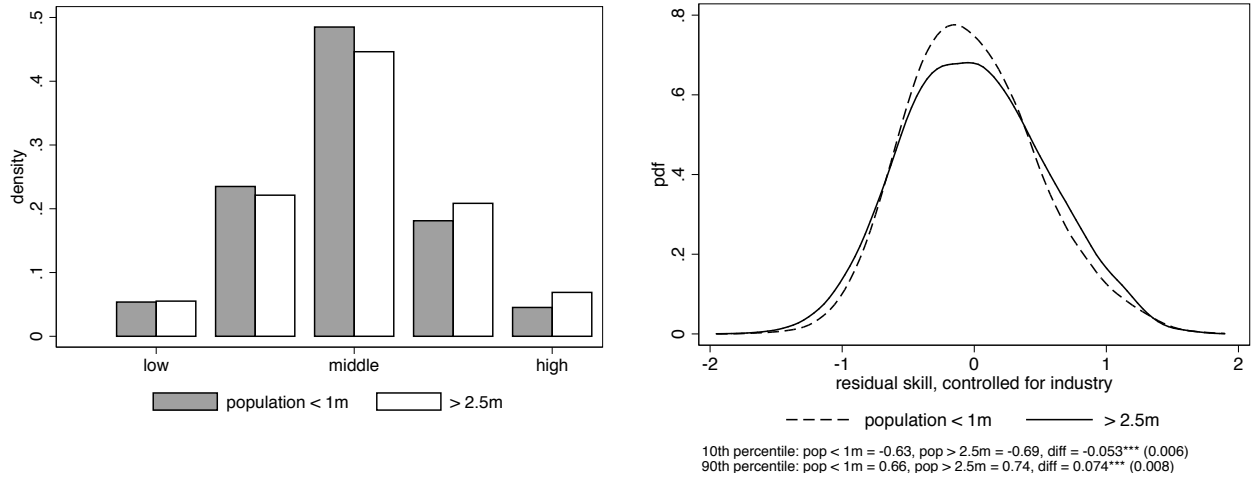


Figure 7: A. Distribution of observed skill level based on reported industry affiliation for small and large cities. Full-time wage earner in 2009 CPS. 262 4-digit industries ranked by median country-wide wage and grouped into 5 categories. B. Unobserved (residual) skill conditional on 262 industry sectors for small and large cities.

We therefore seek to control for the wage component related to the industry. As in the analysis of education, we next decompose skills into a component observed through occupations and the residual unobserved component. We regress our skill measure (log utility) on dummy variables for all 262 4-digit industries.¹³ The residual of this regression is the “residual skill” after controlling for the industry the worker operates in. Figure 7 shows the resulting distribution of conditional and residual skills for large and small cities. We see that the fat tails are virtually unchanged when controlling for industries. This shows that while the industrial composition may vary substantially across cities, it does not do so systematically across small and large cities.

6.4 Migration

Casual observation suggests that large cities tend to have a disproportionate representation of low skilled immigrant workers. Often kitchen staff in restaurants or construction workers are immigrants with low skills and incomes. And indeed, while the foreign born are overall a relatively small fraction of the working population (less than 10%), the data confirms that they are much more likely to locate in large cities (12% of the work force) than in small cities (5%). Maybe the effect of disproportionate representation of the low skilled in large cities is driven by immigration.

In the context of our model it does not matter whether it is low skilled Americans or low skilled immigrants who disproportionately locate to large cities. In equilibrium they should be indifferent. Of course, there is likely to be within-skill heterogeneity (in preferences for example), and some low skilled workers will strictly prefer to locate to either large or small cities. While we do not model this, in equilibrium there should still be arbitrage by the marginal worker within a skill type. Thus it may well be the case that migrants have certain benefits from locating to large cities. For example networks (see Munshi, 2003) play an important role in the location decision of migrants, and if only migrants have that benefit, at a competitively set wage, migrants will strictly prefer to locate to the city that offers the same utility plus the network benefit. Alternatively, migrants may locate to large cities due to limited information about smaller cities.

In any event, because even with those additional benefits for migrants, or any within-skill heterogeneity, the model still predicts that in equilibrium, low skilled workers disproportionately move into large cities. It is sufficient that the marginal type within a skill class arbitrages the difference.

To evaluate the role of migrants in the location decision, we split the sample up into natives and foreign born workers. Figure 8 reports the plot of both distributions. Not surprisingly, the implied skill distribution for the foreign born is more skewed to the left than that of the natives. We find that even the distribution of foreign born workers has fat tails, *both* for the low- *and* the high-skilled. The latter is maybe most surprising: not only do the low-skilled foreign born

¹³We estimate a censored (tobit) regression, accounting for the top-coding of the wage data.

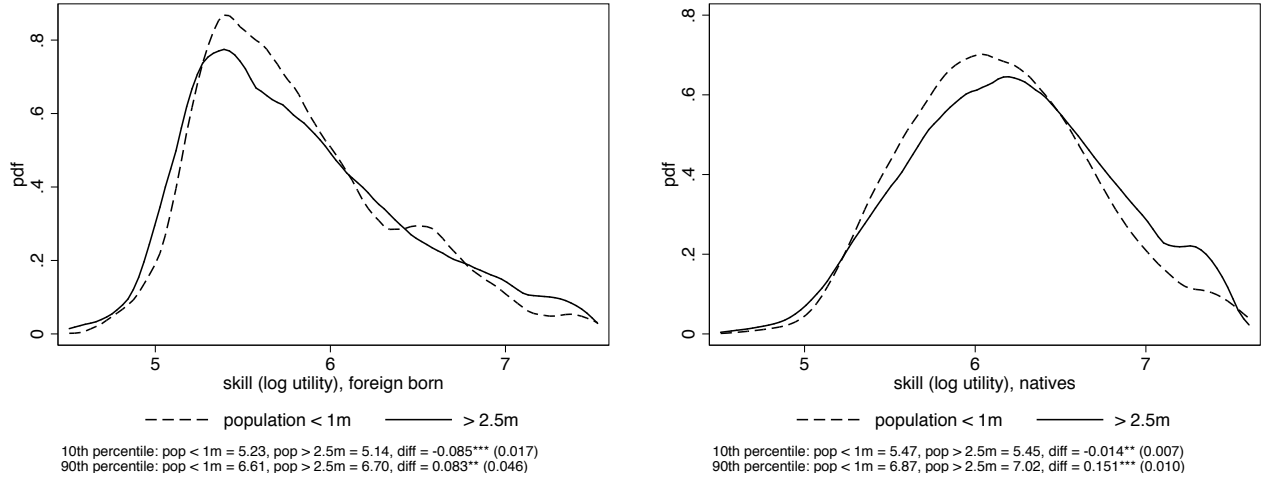


Figure 8: Skill distribution for small and large cities. A. Foreign born workers; B. Natives.

disproportionately migrate to large cities, so do the high-skilled migrants. Most importantly, even after subtracting all migrants, the distribution of natives has fatter tails in large cities. The fat tails are therefore not driven by selective migration decisions by non-natives.

6.5 Age: Location Decisions over the Life Cycle

One plausible mechanism, and different from the technological one we propose, is that the spatial sorting pattern is driven by location decisions that vary over the life cycle. We distinguish between three candidate mechanisms in the presence of human capital accumulation. First, age dependent preferences could lead to variation in the location decision over the life cycle. Young people prefer the excitement of the city, while older people settle for a quiet life. Second, family and marriage considerations determine whether to live in an urban or rural environment, for example as in Gautier, Svarer and Teulings (2009). Singles find a better marriage market in the big city, while those married with children look for green spaces and schools for the children. Third, labor market learning and human capital accumulation may affect the location decision (as in Puga and De la Roca, 2012). Young workers try their luck in the big city, starting off at low salaries. At an later age, those who have learned (or are lucky) to be very productive stay and earn high salaries, while the unlucky who have learned little and have added limited human capital return to their small town at moderate salaries.

Each of these three mechanism induces a systematic spatial sorting pattern and as a result a systematic skill distribution for the entire cross section. This can lead to fat tails or first order stochastic dominance. Most importantly, if it is life cycle driven, it will differ for different age groups. For example, there may be stochastic dominance of the small cities for the young and stochastic dominance of the large cities for the old, thus leading to fat tails overall. For that purpose, we split the sample into four different age cohorts and investigate the tail properties of the skill distribution for each cohort as reported in Figure 9. For each of the cohorts, there are fat tails, and the statistics show they are highly significant. While we can obviously not rule out that any of the mechanisms mentioned above is at work, this evidence lends support to the fact that these mechanisms are sufficiently strong to undo the impact of the extreme-skill complementarities.

6.6 Decomposition by Education, Occupation, Industry and Individual Attributes

This section seeks to explain the differences in the tails of the skill distribution *simultaneously* by all three variables in sections 6.1 to 6.3 (education, occupation, industry) plus individual attributes (sex, age, race, foreign birth). In regression models explaining the mean, this can easily be done by the Oaxaca-Blinder decomposition (Oaxaca, 1973; Blinder, 1973). However, we are interested in explaining differences in the *tails* of the skill distribution, which is a much harder task. Fortunately, there is a fast evolving econometrics literature on the decomposition of entire (wage) distributions (Juhn, Murphy, Pierce, 1993; DiNardo, Fortin, Lemieux, 1996; see Fortin, Lemieux, Firpo, 2011 for a review).

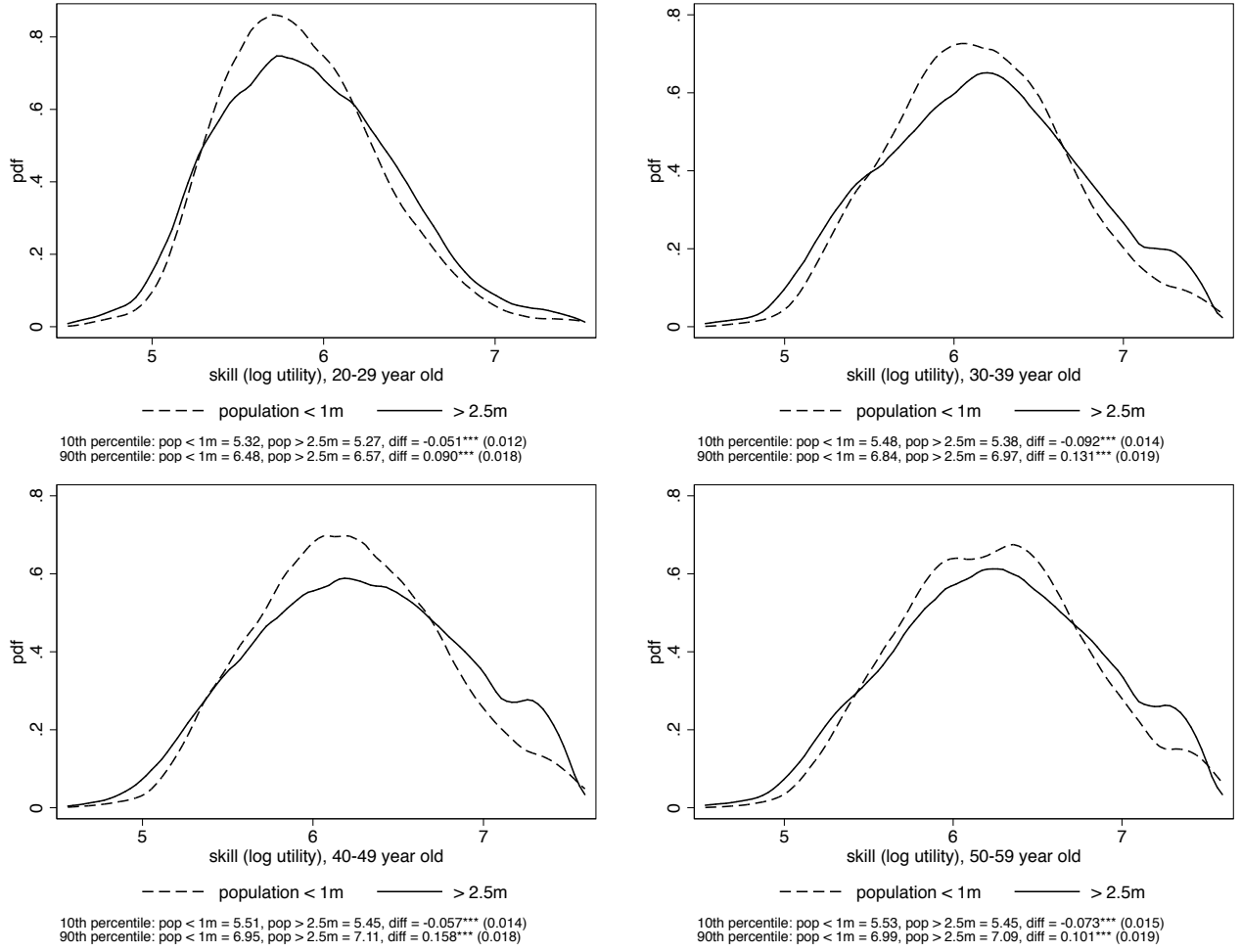


Figure 9: Skill distribution for small and large cities by age group.

We are using two very recent approaches. The first approach is based on Chernozhukov, Fernández-Val, Melly (2012). This approach estimates the entire distribution of skills *conditional* on the observed covariates for both groups (small and large cities) separately using quantile regressions. They then integrate the conditional distributions over the covariates to get the predicted *marginal* distribution of each group. With this they can predict counterfactual marginal distributions such as the distribution of skills in the large city, given that it had the same distribution of covariates as the small city. We refer to the difference between the marginal distribution and the counterfactual distribution as the “unexplained” difference.¹⁴

We summarize the results by reporting the impact on the 10th and 90th percentile. Chernozhukov, Fernández-Val, Melly (2012) cannot easily decompose the explained difference into different sets of covariates. We therefore also apply an alternative decomposition proposed by Firpo, Fortin, Lemieux (2009). Their approach, based on so-called rescaled influence functions (RIF), allows to conveniently decompose the explained differences in the quantiles into the contribution of each covariate. A downside of Firpo, Fortin, Lemieux (2009) is that the basic approach is less intuitive.¹⁵

The original classification into 16 education categories, 498 occupations and 262 4-digit industries would lead to over 900 parameters in each city group, which are hard to identify with our data. We therefore use 2-digit industry classification

¹⁴In labor economics, the unexplained difference is often called a “wage structure effect”. This is because the difference in the conditional distributions between the two groups may stem from different wage schemes, i.e. returns to e.g. education. However, it may also stem from different conditional (i.e. residual) skill distributions in the two groups. The decomposition by Chernozhukov et al. and Firpo et al. do not and cannot disentangle wage structure from residual skills. We do not take a stance at either interpretation and simply call it the unexplained difference.

¹⁵Firpo, Fortin, Lemieux (2009) is an approximation for a *marginal* location shift of the distribution of the covariate. It is not known how good this approximation is if the change in the distribution of the covariate of interest is large or if the covariate of interest is discrete (like dummy variables). See Rothe (2012, Appendix B) for a discussion.

Table 1: Decomposing the skill distributions of large and small cities.

	10% Quantile			90% Quantile		
Observed Quantiles:						
- Large cities	5.365	(0.004)	***	6.994	(0.006)	***
- Small cities	5.439	(0.005)	***	6.862	(0.007)	***
- Difference	-0.074	(0.006)	***	0.132	(0.009)	***
Firpo, Fortin, Lemieux (2009)						
Predicted Quantiles:						
- Large cities	5.387	(0.005)	***	7.022	(0.005)	***
- Small cities	5.454	(0.004)	***	6.878	(0.008)	***
- Difference	-0.068	(0.007)	***	0.144	(0.009)	***
Explained by observables:						
- Education (16 categories)	0.003	(0.002)	**	0.052	(0.002)	***
- Occupation (22 categories)	0.004	(0.002)	*	0.025	(0.003)	***
- Industry (51 categories)	-0.001	(0.002)		0.013	(0.002)	***
- Race (4 groups)	-0.004	(0.001)	***	-0.015	(0.001)	***
- Sex	-0.001	(0.001)	*	-0.002	(0.001)	*
- Foreign born	-0.020	(0.002)	***	-0.004	(0.001)	***
- Age (2nd order polynomial)	0.000	(0.001)		-0.002	(0.001)	*
Total explained by observables	-0.018	(0.004)	***	0.067	(0.005)	***
Not explained by observables	-0.049	(0.006)	***	0.077	(0.008)	***
Chernozhukov, Fernández-Val, Melly (2012)						
Predicted Quantile difference	-0.068	(0.006)		0.113	(0.009)	
Explained by observables	-0.019	(0.004)		0.064	(0.005)	
Not explained by observables	-0.050	(0.007)		0.049	(0.007)	

Notes: Large cities: population > 2.5m; small cities: population <1m. Bootstrapped standard errors in parentheses; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. 2009 CPS data on 25,584 workers in 204 small CBSAs and 34,999 workers in 21 large CBSAs.

(52 classes), and 2-digit occupation codes (22 categories), which are both assigned by the NBER. Age enters as a second order polynomial and race in 4 groups (White, Black, Asian, Other).

Table 1 shows the results of the two approaches. The first 3 rows report the raw sample quantiles of the skill, log(utility), distributions as in Figures 5.A, 6.B and 7.B. Both methods predict these quantiles well. With the method of Firpo, Fortin, Lemieux (2009), only about 26% of the predicted difference in the 10th percentile can be explained by the composition of observed characteristics. However, 46% of the predicted difference in the 90th percentile can be explained by observed characteristics. Most of this is explained by education (36%) and occupation (17%). The strong explanatory power of observables for the top tail and the relatively low explanatory power for the bottom tail reiterates the findings in the 3 previous sections. The method of Chernozhukov, Fernández-Val, Melly leads to very similar results. 57% of the 90th percentile is explained by the composition of observables and 28% of the 10th percentile.

The novel finding here is that there is an asymmetry between the low and the high skilled. For the low-skilled, very little of the difference between big and small cities can be explained by observables, whereas for the high-skilled about half can be explained by observables.

6.7 Variation in Consumption Prices

Local prices are crucial for our strategy to back out skills from observed nominal wages. In this section we look not only at local housing prices but also at local prices of consumption goods. It may well be that consumption prices in large cities are systematically higher than in smaller cities, thus adding further to the real cost of living in large cities. We use the ACCRA Cost of Living Index from C2ER (The Council for Community and Economic Research). See the data appendix for details. The variation in consumption prices is substantially lower than in housing prices (standard deviation across metropolitan areas is 30.1 for the housing prices index compared to 9.6 for grocery items, 14.7 for utilities, 6.7 for transport, 8.9 for health and 6.9 for services; all price indices are normalized to mean 100).

Figure 10 plots the distribution of skills for large and small cities. The measure is wages adjusted for local price

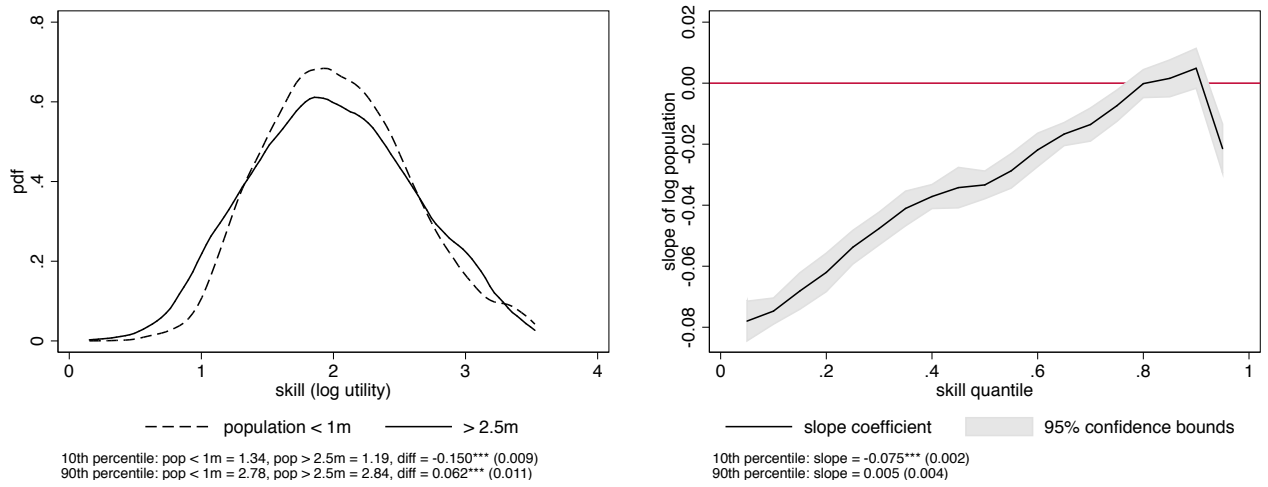


Figure 10: Skill distribution using ACCRA cost-of-living index, adjusting for variation in prices for all goods. A. Skill distribution for small and large cities. B. Slopes in quantile regressions of log utility on log population.

differences in all goods categories reported in the ACCRA data, including housing, consumption goods and services.¹⁶ When including the price index for all consumption and housing, we find that the left tail difference becomes more pronounced while the right tail difference is less so. This indicates that consumption prices are systematically higher in larger cities, but to a limited extent, since this effect does not annihilate the existence of fat tails. Note again, that the the third crossing at the very top is an artefact of the top-coding (see footnote 10).

These findings should be interpreted with some caution and a few caveats. First, the quality of the ACCRA data is dubious.¹⁷ Second, even within a given location, there could be variation in consumption prices paid by skill level. For example, due to different search intensity, the existence of locally segregated markets, etc., the low-skilled may end up paying different prices for similar goods within the same city. Using scanner data on household purchases, Broda, Leibtag and Weinstein (2009) find that the poor pay less. Third, data consisting of price indexes and price surveys are likely to not fully account for quality and diversity differences. Due to their size, large cities have more variety on offer and the quality of goods may differ substantially across different cities. Even if a consumer pays higher prices, a price index incorporating the diversity and quality on offer will be lower.¹⁸ We therefore see the results in Figure 10 as a very conservative upper bound of how the inclusion of consumption price differentials affects our initial findings.

7 Discussion and Extensions

In this Section, we pursue further extensions and variations of the analysis, both with respect to the theory and to the empirical implementation. First, we extend the analysis to allow for sorting within cities (section 7.1). If household systematically sort themselves across the urban space within cities, using a unique citywide price may bias our measure of skill. Second, we relax the assumption that the expenditure share of consumption is constant in income and allow for preferences that exhibit non-linear Engel curves (7.2). Third, we quantify the differential complementarities in our original production technology (7.3). Finally, we explore an alternative explanation driven by preferences: we consider a model economy with home production and preferences for low skilled services (7.4).

¹⁶ACCRA reports a composite price index which is the weighted average of the six sub-indices, i.e. $P_{composite} = \alpha_{grocery}P_{grocery} + \dots + \alpha_{services}P_{services}$, where the α s are the expenditure shares of the six categories summing up to 1. We do not use this aggregation as it is inconsistent with Cobb-Douglas utility. Instead, we use $P_{composite} = (P_{grocery})^{\alpha_{grocery}} \cdot \dots \cdot (P_{services})^{\alpha_{services}}$. The implied skills are calculated as $U_i = w_{ij}/(P_{grocery,j}^{0.1249} \cdot P_{housing,j}^{0.2918} \cdot P_{utilities,j}^{0.0998} \cdot P_{transport,j}^{0.111} \cdot P_{health,j}^{0.0406} \cdot P_{services,j}^{0.3319})$.

¹⁷Koo et al. (2000) discuss several problems of the ACCRA data.

¹⁸This also appears to be an issue when studying price differences across different countries. Comparing the results of price differences across borders, Broda and Weinstein (2008) find that significant price differences that are found using price indexes are not replicated once they use US and Canadian barcode data. Their work is supportive of simple pricing models where the degree of market segmentation across the border is similar to that within borders.

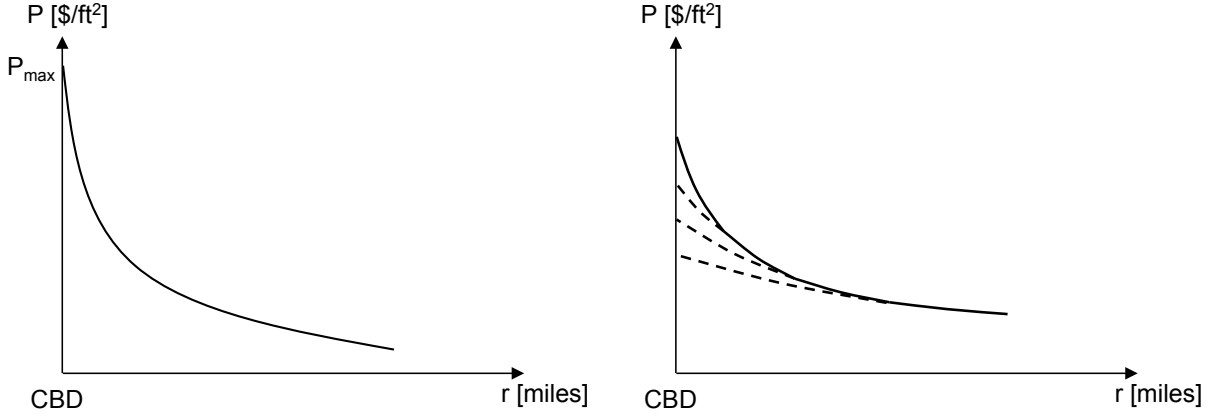


Figure 11: Equilibrium rental prices (bid-rent) in the monocentric city: A. without within-city sorting; B. with sorting.

7.1 Sorting within Cities

In our analysis, the endogenous choice of housing is a central component. High-skill workers in the same city consume more housing h than low-skill workers, and at the same time there is substitution between housing and other consumption goods: same skilled workers consume less housing in large, expensive cities than in small ones. In order to obtain our wage-based measure of skills, and guided by the theory, we adjust wages by a city-wide housing price index, which measures the unit cost (say, per square foot) of housing. To adjust for different choices of quantities, we have obtained that unit cost by means of a hedonic regression that conditions on observables, such as the number of rooms, bathrooms, etc. Implicit in this specification is the assumption that all neighborhoods are equally attractive, and citizens with different incomes will therefore share the same neighborhoods, albeit in houses of different sizes.

In reality there may be sorting within cities, for example due to the commuting cost or because of the presence of local externalities from schooling and other public goods. To address this issue, in this section we allow for the possibility of within-city sorting in the mono-centric city model, where a citizen's utility decreases in distance from the center (the center can be the geographical center such as Manhattan, New York, or the most attractive neighborhood with the best schools, such as Bloomfield Hills, Detroit). If the opportunity cost of distance is complementary with income, then the richest citizens will sort into the neighborhoods closest to the center. The size of the city is determined by the marginal citizen who is indifferent between living in this city and the best outside option.¹⁹

The within-city sorting pattern now has implications for the way our housing price index within cities is calculated. Because there is a tradeoff, the housing price now also reflects the opportunity cost. The further away from the center, the lower the housing price, even for identical agents. As a result, there is a so-called bid-rent function that decreases with increased distance from the center. This is illustrated in Figure 11.A. As a result of the tradeoff, the only housing price that is devoid of the opportunity cost is the one in the center, since there is no commuting cost to get there. Anywhere else, the housing price is too low since it consists of both the cost of living and the commuting cost. To abstract from commuting cost, we therefore repeat our analysis using the hedonic housing price index for the richest neighborhoods. This is calculated based on the Public Use Microdata Area (PUMA), a relatively small area of around 100,000 inhabitants. We estimate hedonic price indices for all PUMA areas across the U.S. We then take the average price index of the top 10% PUMA areas per city, i.e. CBSA. The imputed skill distribution based on this maximal housing price index is reported in Figure 12. Consistent with our earlier results, the fat tails continue to exist. We tend to see a somewhat bigger tail at the bottom than at the top.

In addition to the opportunity cost of commuting, there may be sorting because citizens with different skills have different preferences for distance and therefore there is a bid-rent function that is income specific. This is illustrated in Figure 11.B. There is a bid-rent function for each type that is only observed where a citizen type actually lives: at the center for the high income types, in the middle for the middle income types and at the outskirts for the low income types.

¹⁹For an overview of the different variants of the mono-centric city model and a full characterization, see Fujita (1989).

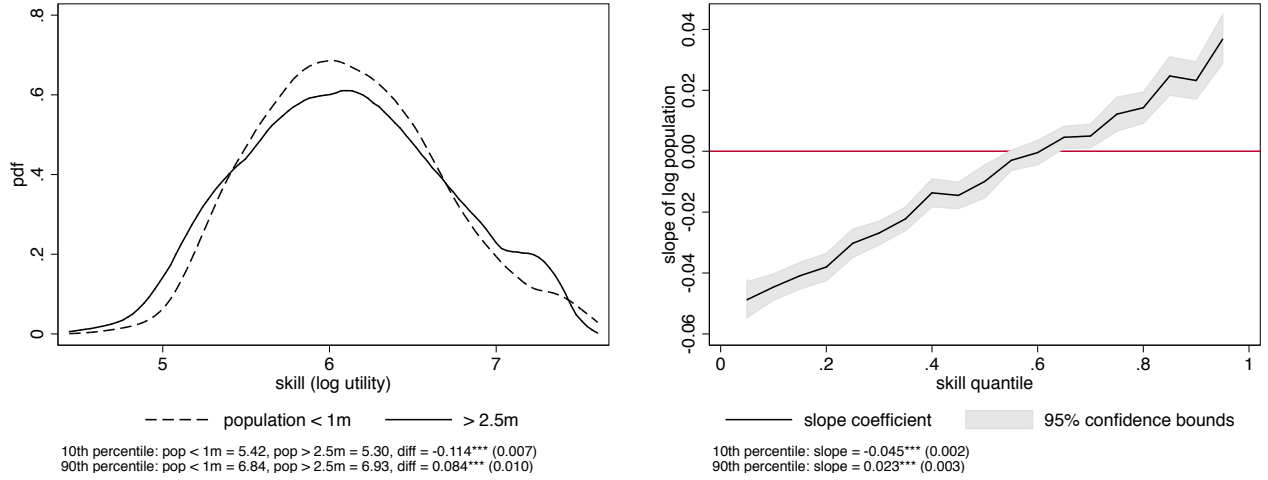


Figure 12: Skills based on the average housing price index in the top 10% neighborhoods (PUMA) of a city. A. Skill distribution for small and large cities. B. Slopes in quantile regressions of log utility on log population.

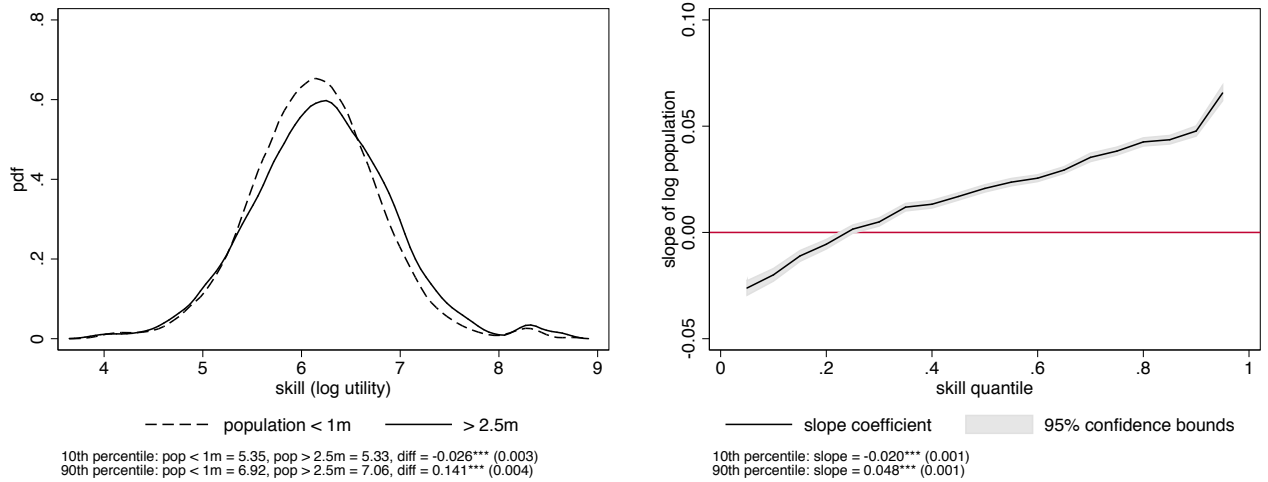


Figure 13: Skills based on the housing price in the neighborhood of residence. Wage data from the 2009 American Community Survey. A. Skill distribution for small and large cities. B. Slopes in quantile regressions of log utility on log population.

In the case of perfect sorting, each type would live in a dedicated neighborhood between intersections of the bid-rent functions. The relevant price for utility comparisons which reflects the costs of distance would be the intersection of the respective bid-rent function with the vertical axis. This price, however, is only observed for the highest type, i.e. the central neighborhood. The observed prices for neighborhoods outside the center is a lower bound of the relevant price, with the actual price index for each neighborhood being strictly higher. We estimate this lower bound as the hedonic price index of the PUMA area. Unfortunately, the wage data from the CPS do not identify the PUMA area of the worker. We therefore use wages from the 2009 American Community Survey (ACS) for this analysis, i.e. wage data from the same source as the price data.²⁰ In Figure 13 we report the density after adjusting for this new price index.

Quite remarkably, even in the presence of this biased price index, the fat tails continue to exist. It is not surprising that the lower tail difference is thinner, but it is still significant. More importantly, because this housing price index is a lower bound, the actual tail difference must be thicker. We interpret the exercise in this section as one in which we put bounds on the tails. The neighbourhood (PUMA) price index is the lower bound and shifts the distribution too little to

²⁰The 2009 ACS contains about 10 times as many observations as the 2009 CPS. However, the CPS is generally considered the more reliable data source for wage data as the survey is performed personally by phone while the ACS questionnaires are mailed. We therefore use CPS data where possible.

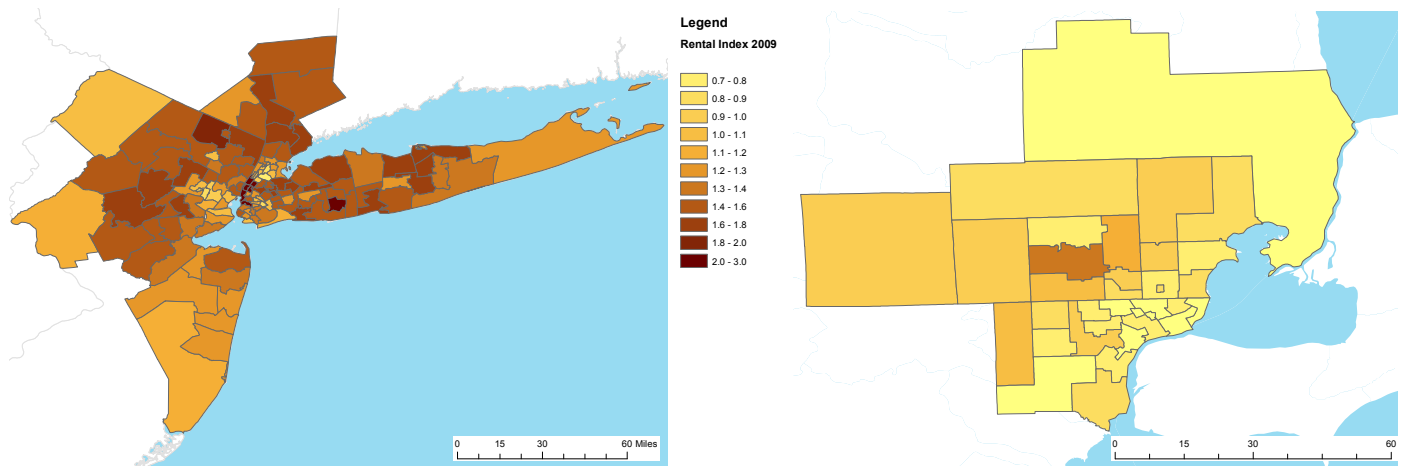


Figure 14: Average rental housing prices across PUMA areas in A. New York and B. Detroit. The housing price index is normalized to 1 for the US sample average.

the left, resulting in a small lower tail effect. The maximum price index is the upper bound and shifts the distribution too much to the left, generating a big lower tail effect but hardly any upper tail effect. The relevant price index, and hence the distributions, is somewhere in between.

The fact that within-city sorting does not have much impact on the price index may at first seem surprising. A closer look at the data however, reveals that in fact there is a remarkably small price difference across different neighborhoods and at the same time large price variation across cities. This is illustrated in Figure 14 with the price variation across PUMA areas in two cities, New York and Detroit. Among the most expensive residential areas in New York, for example, are the Upper East Side in Manhattan and East Meadow on Long Island. The least expensive areas are East Harlem in Manhattan and the Bronx. Yet, few of the cheapest areas in New York are less expensive (less dark on the map) than the most expensive areas in Detroit. The important point to take away from this is that the differences in prices within cities are relatively small. This relatively small price variation between neighborhoods is evidence that sorting between neighborhoods is limited and that the lion's share of price differences comes from sorting between cities.

7.2 Non-Linear Engel Curves

Throughout we have assumed homothetic (Cobb-Douglas) preferences over housing and consumption. Motivated by the empirical finding of Davis and Ortalo-Magné (2009) that housing expenditure is on average remarkably constant across different cities, we have used their estimated expenditure share on housing of $\hat{\alpha} = 0.24$. Yet, even if the average expenditure share of housing is constant across cities of different size, there may well be variation across individuals of different incomes. As a result, the Engel curve that relates expenditure to income is no longer linear as it is under Cobb-Douglas. Below we show that there is indeed evidence in our data of a concave Engel curve: the rich spend proportionally less on housing.

Non-homothetic preferences have important consequences for both our theoretical model and our empirical strategy. First, decreasing housing expenditure shares w.r.t. income introduce an alternative mechanism for sorting across cities as high-skill workers care less about local housing prices than low-skill workers.²¹ Second, our price-based skill measure derived from the homothetic Cobb-Douglas preferences needs to be adjusted.

It is straightforward to introduce non-homothetic preferences into our theoretical framework. We follow the most common way in the literature and model it by means of Stone-Geary preferences. They can be written as $u(c, h) = c^{1-\alpha}(h - \underline{h})^\alpha$ where $\underline{h}$ is the subsistence level of housing, and housing consumption is restricted to $h \geq \underline{h}$. Given housing prices p and the budget constraint $c + ph \leq w$, from the first order conditions optimal expenditures on housing and

²¹See e.g. Schmidheiny (2006) who studies within-city sorting from assuming non-homothetic (Stone-Geary) preferences.

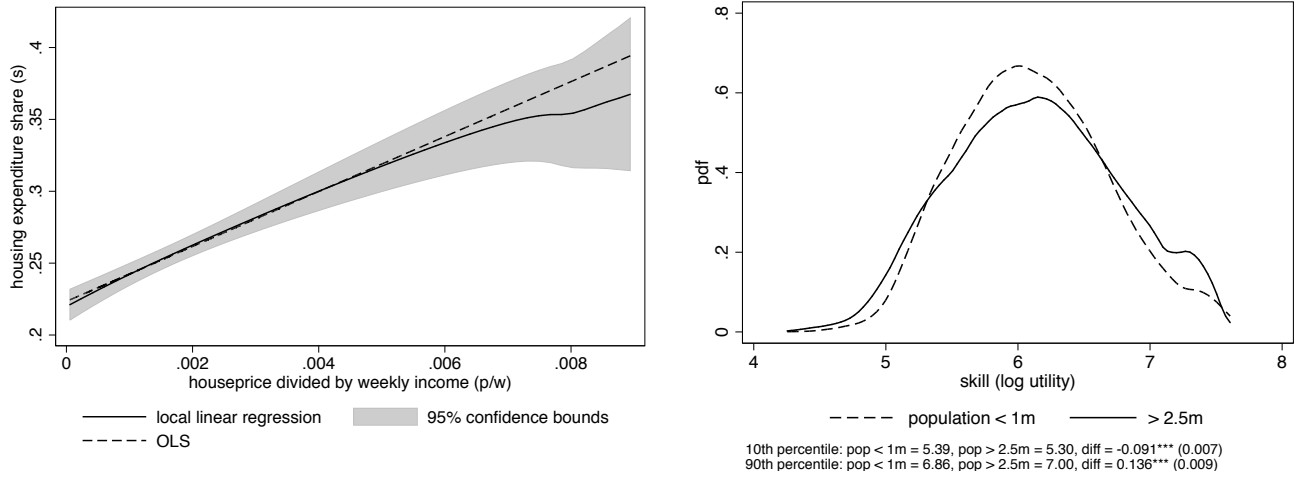


Figure 15: Expenditure Share (A) and Skill distribution (B) using Stone-Geary preferences, $\hat{\alpha} = 0.224$, $\hat{h} = 27.7$.

consumption can be written as $ph^* = \alpha w + (1 - \alpha)p\bar{h}$ and $c^* = (1 - \alpha)(w - p\bar{h})$, with the indirect utility given by

$$u(c^*, h^*) = (1 - \alpha)^{1-\alpha} \alpha^\alpha p^{1-\alpha} \left(\frac{w}{p} - \bar{h} \right). \quad (16)$$

Assuming the CES production technology and Stone-Geary preferences with $\bar{h} > 0$, our model predicts FOSD of the skill distribution in large cities in simulations.²² Hence, non-homothetic preferences do not generate fat tails per se. But allowing for extreme-skill complementarities in addition, our model still predicts fat tails, for $\bar{h}$ positive but small. In the next paragraph we therefore explore which mechanism prevails empirically.

When housing expenditure varies by income, the utility and therefore our measure of skill must be adjusted. Assuming Stone-Geary preferences, the expenditure share on housing is a linear function in the *inverse* of wages: $\frac{ph^*}{w} = \alpha + (1 - \alpha)h^* \frac{p}{w}$. This give us a regression of the housing expenditure share s_i on p_j/w_i :

$$s_i = \alpha + \beta \frac{p_j}{w_i} + \varepsilon_i \quad (17)$$

where $s_i = \frac{p_j h_i^*}{w_i}$. The parameter α is estimated directly while the parameter $\bar{h}$ is estimated as $\hat{\bar{h}} = \hat{\beta}/(1 - \hat{\alpha})$.

We use individual data on expenditure shares (see the data appendix for details) from the Consumer Expenditure Survey (CEX) to estimate the two parameters α and $\bar{h}$. We obtain $\hat{\alpha} = 0.224$ (s.e. = 0.005), and $\hat{\bar{h}} = 27.7$ (3.8). The implied expenditures shares vary considerably, from 35% for low-income households to 22% for high-income households as graphed in Figure 15.A. Figure 15.A. also shows that the functional form assumed by Stone-Geary fits the data astonishingly well. Yet, the varying expenditure share and the resulting non-linearity of the Engel curve do not substantially alter the emergence of fat tails. Figure 15.B. shows the resulting skill distribution, which has very similar properties to those under Cobb-Douglas preferences. If anything, the fat tail differences in both the lower and the upper tail are slightly more pronounced. This shows that our evidence for extreme-skill complementarities still holds even after accounting for non-homothetic preferences.

7.3 Quantifying the Production Technology

Using the observed skill distributions, we now perform a very simple quantitative exercise to get an idea of the magnitude of the underlying parameter values of the production technology. To that end, we can actually solve the system of equations explicitly (see the appendix for the derivation) to obtain a system of 5 equations in 5 unknowns $\lambda, A_1, A_2, y_1, y_3$ and

²²Matlab code for the simulations can be obtained on request.

Table 2: Quantifying the Production Technology.

Observed model outcomes:							
city j	w_{1j}	w_{2j}	w_{3j}	m_{1j}	m_{2j}	m_{3j}	C_j
1	416	844	1923	730,509	1,953,303	730,509	21
2	354	717	1634	30,900	105,516	30,900	204
Implied production technology for different values of γ :							
γ	λ	A_1	A_2	y_1	y_2	y_3	
0.655	1.0407	190,228	59,107	0.2329	1	1.0762	
0.8	1.0193	19,118	9,065	0.3189	1	1.4733	
0.9	1.0086	3,992	2,534	0.3964	1	1.8317	

where y_2 is normalized to 1.²³

$$\lambda = \frac{1}{\gamma} \left[1 + \frac{(\gamma - 1) \log \left(\frac{C_2 m_{21}}{M_2 - C_1 m_{21}} \right)}{\log \left(\frac{C_2 m_{11}}{M_1 - C_1 m_{11}} \right)} \right], \quad A_1 = \frac{w_{21}}{\gamma y_2 m_{21}^{\gamma-1}}, \quad A_2 = A_1 \left(\frac{p_2}{p_1} \right)^\alpha \left(\frac{C_2 m_{21}}{M_2 - C_1 m_{21}} \right)^{\gamma-1}, \quad (18)$$

$$y_1 = \left(\frac{w_{11}}{\lambda \gamma A_1 \left[m_{11} + m_{31} \frac{w_{31}}{w_{11}} \right]^{\lambda-1} m_{11}^{\lambda(\gamma-1)}} \right)^{\frac{1}{\lambda}}, \quad y_3 = \left(\frac{w_{31}}{\lambda \gamma A_1 \left[m_{31} + m_{11} \frac{w_{11}}{w_{31}} \right]^{\lambda-1} m_{31}^{\lambda(\gamma-1)}} \right)^{\frac{1}{\lambda}}$$

We partition the distribution into three types $i = 1, 2, 3$ corresponding to the 20-60-20 percentiles, and construct two city types $j = 1, 2$; type 1 with population less than 1 million and city type 2 with population larger than 2.5 million. We then use observable values for wages w_{ij} within each city type and skill group²⁴, the actual number of agents of each type in each city m_{ij} ,²⁵ and the number of cities in the sample C_j . Housing prices p_j satisfy equation (4).²⁶ We use the parameter values $\alpha = 0.24$ (the share of expenditure on housing) and estimate the production technology parameters for different values of γ in Table 3.

For $\gamma = 0.655$ which corresponds to an elasticity of substitution between low- and high-skill workers of 2.9 (Acemoglu and Autor, 2012), TFP is 3 times higher in the large city than in the small city, while the top skill group is 4.6 times as productive as the bottom skill group, but merely 8% more productive than the middle skill types. The parameter λ that measures the extent of the complementarities/substitutabilities is larger than 1, confirming that there are complementarities between the extreme skill types. The magnitude of λ is 1.041. Instead, for higher γ there is less curvature on the amount of labor in output produced, and as a result TFP differences are much closer. For $\gamma = 0.8$, TFP is double, and the high-skilled are still 4.6 times more productive than the low-skilled (this is also the case for $\gamma = 0.9$) but now they are 47% more productive than the middle-skilled. For $\gamma = 0.9$, TFP is 57% higher in the large cities, and the high-skilled are 80% more productive relative to the middle-skilled types. The technology seems to more reasonably capture the TFP differences and productivity y_3 for high γ , corresponding to high elasticities of substitution. This is consistent with the fact that we do not condition on age (or other observables for that matter), where the age elasticity within skill group is typically large (of the order of 5).

7.4 Preferences for Services and Home Production

In this section we explore the micro foundations for the complementarities between extreme skills. We consider an explanation based on preferences for low skilled services in combination with home production. Households have preferences for low skilled services. Those services can be produced with home production and they can be traded on the market.

²³In a CES technology, there is an indeterminacy between the A_j 's and the y_i 's. Here, since the skill $i = 2$ is CES with the composite of skills 1 and 3, it is proportional to A_j (see the second equation), we can normalize it to 1.

²⁴We use median wages because the tails are truncated lognormals, and thus heavily skewed. We adjust the observed wages such that the relative wages of different skill types are constant across cities as the theory predicts.

²⁵We impose symmetry on the observed numbers for skill types 1 and 3.

²⁶The observed prices for the two city groups are very similar to that implied by relative wages.

Citizens have preferences over the quantity of a consumption good c , services s and the amount of housing h represented by $u(h, s, c) = h^\alpha s^\beta c^{1-\alpha-\beta}$ where α, β , and $(\alpha + \beta) \in [0, 1]$. All workers have a unit endowment of time to be divided between home production denoted by t and market production $1 - t$. Home productivity is independent of the worker's skills. The amount of services generated in home production is equal to Γt^δ , where Γ is a positive parameter, but the agent incurs a quasi fixed cost K , a cost that is incurred only if there is positive production. Services can be traded at a city-specific price $r_j \geq 0$. As before, output in the formal sector generates a wage that is contingent on the worker's skill and produced with the technology $A_j F(\cdot)$ that is either CES or satisfies top- or extreme-skill complementarity.

A citizen i in city j chooses the bundle $\{h, s, c\}$ to maximize utility subject to the budget constraint:

$$\begin{aligned} \max_{\{h, s, c, t\}} u(c, h, s) &= h^\alpha s^\beta c^{1-\alpha-\beta} \\ \text{s.t. } ph + rs + c &\leq w(1 - t) + I \end{aligned} \quad (19)$$

where the quantities h, s, c, t, w are all city- and skill-specific and the prices p, r are city-specific, but we have dropped the subscripts for notational convenience. We denote by I the income generated through services provided. The decision problem to produce services t is given by $\max_{0 < t \leq 1} \{r\Gamma t^\delta - K + wt\}$, if $t > 0$, and 0 otherwise. Observe that K acts as a cost of entry in the services sector. Solving this problem, and given the cost K , the optimal solution satisfies:

$$I = \max_t \left\{ r\Gamma \left(\frac{r\delta\Gamma}{w} \right)^{\frac{\delta}{1-\delta}} - K, 0 \right\}. \quad (20)$$

Because of the fixed cost, there will be an occupational choice decision whether or not to produce services, and if so, how much (t). With this optimal allocation of time between production of services and of market output, we can pin down the demands for consumption, services, and housing as:

$$h = \frac{\alpha}{p} [w(1 - t^*) + I], \quad s = \frac{\beta}{r} [w(1 - t^*) + I], \quad c = (1 - \alpha - \beta) [w(1 - t^*) + I] \quad (21)$$

where $t^* = \max\left\{\left(\frac{r\delta\Gamma}{w}\right)^{\frac{1}{1-\delta}}, 0\right\}$. Observe that the time spent in household production depends on the ratio r/w . The higher the wage, the less time she spends producing household services, and the more likely she is a net demander of services. Moreover, because of the cost K , those with high enough wages will choose not to produce services at all. Finally, the market clearing conditions (including in the market for services) pin down equilibrium prices and close the model.

We cannot solve the model analytically. We have therefore performed various quantitative exercises to get an idea of the properties of the model. In particular, we want to find parameter configurations under which we obtain fat tails. We use the parameters $\alpha = 0.24, \beta = 0.2, \delta = 0.3, \gamma = 0.8, \Gamma = 1, K = 0.2$, and from the data $M_1 = 21,644,289, M_2 = 62,544,627, M_3 = 21,644,289, C_1 = 21, C_2 = 204$, and $H = 110,016.5$, which is based on the observed mean number of housing units. Then we use the technology parameters generated by the exercise in section 7.3. The objective is to obtain distributional properties that are consistent with fat tails.

First, we can robustly reproduce the fat tails results in this model with services whenever there are extreme-skill complementarities in the market technology. This confirms that our approach in the baseline model is robust to the introduction of low skilled services. At the same time, this may not be all that surprising especially whenever the mechanism of extreme-skill complementarities is strong enough. More challenging is whether fat tails obtain without extreme-skill complementarities. Our *second* finding is that with a CES market technology and without the quasi fixed costs K , the distributions with services are identical across cities. With $K > 0$ and CES, the distributions differ across cities, and results in FOSD of the small city: there are relatively more low skilled workers in the large city, relatively more middle skilled workers in the small city and the same density of high skilled workers in both cities; the average skills are lower in the large cities. *Third*, the model generates fat tails if preferences for services are combined with top-skill complementarity. The logic is that the top-skill complementarity generates the fat upper tail, whereas the demand for services generates the fat lower tail.

Table 7.4 shows this third result in a quantitative exercise. To obtain fat tails, the income share of services β must be

Table 3: Preferences for Services and Home Production.

Assumed production technology:								
γ	λ	A_1	A_2	y_1	y_2	y_3	C_1	C_2
0.8	1.0193	19,118	9,065	0.3189	1	1.4733	21	204
Observed model outcomes:								
city j	w_{1j}	w_{2j}	w_{3j}	pdf_{1j}	pdf_{2j}	pdf_{3j}	p_j	r_j
1	430	1,315	2,330	0.2128	0.5693	0.2178	4473.43	653.88
2	261	774	1,419	0.2016	0.5986	0.1998	763.33	372.82

large enough. When it drops below 20%, the lower tail disappears.²⁷ This means that households must spend nearly as much on low skilled services as on housing. Second, the fixed cost K must also be large enough ($K = 0.2$ is a big barrier), which effectively inflates the price of services. Observe that there is no such entry barrier in the formal sector, where one would expect those to be at least as big. Finally, the top skill complementarity must not be too strong.

Our simulations suggest that demand for services can indeed contribute to the fat lower tail and that it is broadly consistent with extreme-skill complementarity. To generate fat tails without extreme-skill complementarity, however, the required parameter are somewhat extreme. In particular, it requires a strong non-homotheticity in the services technology, and the expenditure share on services must be unrealistically high. Many low skilled services are demanded *indirectly* because they are inputs in production: cooks in restaurants, administrative staff in firms, etc. We find it therefore justified to model their role through the production technology. Finally, a prime advantage of our basic model with complementarities in the production technology is that we can solve and study it analytically.

8 Conclusion

We propose a tractable theory of spatially dispersed production with perfectly mobile heterogeneous inputs, i.e. skilled labor. Differences in TFP lead to differences in demand for skills across cities. In general equilibrium, wages and housing prices clear the labor and housing markets. Perfect mobility of citizens leads to utility equalization by skill. We show that cities with a higher TFP are larger and that a CES production technology entails identical skill distributions across cities with different productivity. We consider two alternative hypotheses concerning differential complementarities/substitutabilities between skills and derive the implication for the equilibrium skill distribution across cities. First, when there are complementarities between extreme skills, the firm size distribution in larger cities has fatter tails. Instead, when there are complementarities between the top skills, there is first order stochastic dominance of the skill distribution in large cities.

We also find robust empirical evidence from US data for fat tails in the skill distribution. Adjusting wages for housing prices by means of a hedonic price index, we find that average skills are constant, but the standard deviation increases with city size. Big cities have big real inequality. Given the theory, this provides empirical support for the extreme-skill complementarity hypothesis: the productivity of the high-skilled is enhanced most by the providers of low-skilled services.

These findings contribute to our understanding of the urban wage premium. Not only do we establish robustly that higher wages are not due to higher average skill, but we also find that there is an urban inequality “premium”. In the presence of extreme skill complementarities, this indicates that extreme skills multiply total factor productivity differences.

Finally, our method and results can provide new insights into the role of complementarities within firms. At the economy wide level, we know remarkably little about the skill composition across firms of different sizes, for example, and even less about the pattern of complementarities between differentially skilled workers within firms. Understanding the patterns of complementarities is not only important for the efficient allocation of resources. As we have demonstrated in this paper, they are also key for the equitable distribution of the output of production.

²⁷In the CEX, the direct expenditure on low skilled services is around 5%.

Appendix A: Theory

Preliminaries

The full system of equations that pins down the equilibrium allocation can be written as, for $j \in \{1, 2\}$:

$$\begin{cases} \lambda A_j [m_{3j}^\gamma y_3 + m_{1j}^\gamma y_1]^{\lambda-1} \gamma m_{1j}^{\gamma-1} y_1 - w_{1j} = 0 \\ \gamma A_j m_{2j}^{\gamma-1} y_2 - w_{2j} = 0 \\ \lambda A_j [m_{3j}^\gamma y_3 + m_{1j}^\gamma y_1]^{\lambda-1} \gamma m_{3j}^{\gamma-1} y_3 - w_{3j} = 0 \\ \left(\frac{w_{i1}}{w_{i2}}\right) = \left(\frac{p_1}{p_2}\right)^\alpha, \forall i \in \{1, 2, 3\} \\ C_1 m_{i1} + C_2 m_{i2} = M_i, \forall i \in \{1, 2, 3\} \\ h_{ij} = \frac{\alpha w_{ij}}{p_j}, \forall i \in \{1, 2, 3\} \\ \sum_{i=1}^3 h_{ij} m_{ij} = H \end{cases} \quad (22)$$

Since $w_{i2} = \left(\frac{p_2}{p_1}\right)^\alpha w_{i1}$, we can equate the first-order conditions to obtain:

$$\begin{cases} A_1 [m_{31}^\gamma y_3 + m_{11}^\gamma y_1]^{\lambda-1} m_{11}^{\gamma-1} = \left(\frac{p_1}{p_2}\right)^\alpha A_2 [m_{32}^\gamma y_3 + m_{12}^\gamma y_1]^{\lambda-1} m_{12}^{\gamma-1} \\ A_1 m_{21}^{\gamma-1} = \left(\frac{p_1}{p_2}\right)^\alpha A_2 m_{22}^{\gamma-1} \\ A_1 [m_{31}^\gamma y_3 + m_{11}^\gamma y_1]^{\lambda-1} m_{31}^{\gamma-1} = \left(\frac{p_1}{p_2}\right)^\alpha A_2 [m_{32}^\gamma y_3 + m_{12}^\gamma y_1]^{\lambda-1} m_{32}^{\gamma-1} \\ C_1 m_{i1} + C_2 m_{i2} = M_i, \forall i \in \{1, 2, 3\} \\ m_{2j}^\gamma y_2 + \lambda [m_{3j}^\gamma y_3 + m_{1j}^\gamma y_1]^\lambda = H \frac{p_j}{\alpha \gamma A_j} \end{cases} \quad (23)$$

From the first and the third equation, we obtain:

$$\frac{A_1 [m_{31}^\gamma y_3 + m_{11}^\gamma y_1]^{\lambda-1} m_{11}^{\gamma-1}}{A_1 [m_{31}^\gamma y_3 + m_{11}^\gamma y_1]^{\lambda-1} m_{31}^{\gamma-1}} = \frac{\left(\frac{p_1}{p_2}\right)^\alpha A_2 [m_{32}^\gamma y_3 + m_{12}^\gamma y_1]^{\lambda-1} m_{12}^{\gamma-1}}{\left(\frac{p_1}{p_2}\right)^\alpha A_2 [m_{32}^\gamma y_3 + m_{12}^\gamma y_1]^{\lambda-1} m_{32}^{\gamma-1}} \quad (24)$$

After rearranging and using market clearing ($C_1 m_{i1} + C_2 m_{i2} = M_i$) we can write this as:

$$m_{11} = \frac{M_1}{M_3} m_{31}, \quad (25)$$

and we can write the first equation in (23) as:

$$\frac{[m_{31}^\gamma y_3 + m_{11}^\gamma y_1]^{\lambda-1} m_{11}^{\gamma-1}}{m_{21}^{\gamma-1}} = \frac{[m_{32}^\gamma y_3 + m_{12}^\gamma y_1]^{\lambda-1} m_{12}^{\gamma-1}}{m_{22}^{\gamma-1}}. \quad (26)$$

Now given the symmetry assumption $m_{11} = m_{31}$ and $m_{12} = m_{32}$, this then implies:

$$m_{21} = \left(\frac{m_{11}}{m_{12}}\right)^{\frac{\lambda\gamma-1}{\gamma-1}} m_{22}, \quad (27)$$

and we substitute it back in (23) and rearrange to get:

$$\left(\frac{m_{11}}{m_{12}}\right)^{\lambda\gamma-1} = \left(\frac{p_1}{p_2}\right)^\alpha \frac{A_2}{A_1} \quad (28)$$

Using the fact that $m_{12} = \frac{M_1}{C_2} - \frac{C_1}{C_2} m_{11}$, we have:

$$m_{11} = \frac{\left[\left(\frac{p_1}{p_2}\right)^\alpha \frac{A_2}{A_1}\right]^{\frac{1}{\lambda\gamma-1}} \frac{M_1}{C_2}}{1 + \frac{C_1}{C_2} \left[\left(\frac{p_1}{p_2}\right)^\alpha \frac{A_2}{A_1}\right]^{\frac{1}{\lambda\gamma-1}}} \quad \text{and} \quad m_{12} = \frac{\frac{M_1}{C_2}}{1 + \frac{C_1}{C_2} \left[\left(\frac{p_1}{p_2}\right)^\alpha \frac{A_2}{A_1}\right]^{\frac{1}{\lambda\gamma-1}}} \quad (29)$$

and likewise for the other expressions for m_{2j} and m_{3j} :

$$m_{21} = \frac{\left[\left(\frac{p_1}{p_2}\right)^\alpha \frac{A_2}{A_1}\right]^{\frac{1}{\gamma-1}} \frac{M_2}{C_2}}{1 + \frac{C_1}{C_2} \left[\left(\frac{p_1}{p_2}\right)^\alpha \frac{A_2}{A_1}\right]^{\frac{1}{\gamma-1}}} \quad \text{and} \quad m_{22} = \frac{\frac{M_2}{C_2}}{1 + \frac{C_1}{C_2} \left[\left(\frac{p_1}{p_2}\right)^\alpha \frac{A_2}{A_1}\right]^{\frac{1}{\gamma-1}}} \quad (30)$$

$$m_{31} = \frac{\left[\left(\frac{p_1}{p_2}\right)^\alpha \frac{A_2}{A_1}\right]^{\frac{1}{\lambda\gamma-1}} \frac{M_3}{C_2}}{1 + \frac{C_1}{C_2} \left[\left(\frac{p_1}{p_2}\right)^\alpha \frac{A_2}{A_1}\right]^{\frac{1}{\lambda\gamma-1}}} \quad \text{and} \quad m_{32} = \frac{\frac{M_3}{C_2}}{1 + \frac{C_1}{C_2} \left[\left(\frac{p_1}{p_2}\right)^\alpha \frac{A_2}{A_1}\right]^{\frac{1}{\lambda\gamma-1}}} \quad (31)$$

Substituting the m_{ij} 's in the last equation in (23), and rearranging, we get:

$$\left\{ \begin{aligned} & \left[\left(\frac{p_2}{p_1}\right)^{\frac{1-\lambda\gamma(1-\alpha)}{1-\lambda\gamma}} \left(\frac{A_1}{A_2}\right)^{\frac{1}{1-\lambda\gamma}} - 1 \right] \lambda \left(\frac{\frac{M_1}{C_2}}{1 + \frac{C_1}{C_2} \left[\left(\frac{p_1}{p_2}\right)^\alpha \frac{A_2}{A_1}\right]^{\frac{1}{\lambda\gamma-1}}} \right)^{\lambda\gamma} [y_3 + y_1]^\lambda \\ & + \left[\left(\frac{p_2}{p_1}\right)^{\frac{1-\gamma(1-\alpha)}{1-\gamma}} \left(\frac{A_1}{A_2}\right)^{\frac{1}{1-\gamma}} - 1 \right] \left(\frac{\frac{M_2}{C_2}}{\left\{ 1 + \frac{C_1}{C_2} \left[\left(\frac{p_1}{p_2}\right)^\alpha \frac{A_2}{A_1}\right]^{\frac{1}{\gamma-1}} \right\}} \right)^\gamma y_2 \end{aligned} \right\} \left(\frac{p_1}{p_2} \frac{A_2}{A_1} \right) = 0 \quad (\star)$$

where we have used the fact that $\gamma < 1$, $\lambda > 1$, and $\lambda\gamma < 1$. We can now establish Lemma 1.

Lemma 1 *Let $A_1 > A_2$ and $\lambda\gamma < 1, \gamma < 1$. Then housing prices in the more productive city are larger, $p_1 > p_2$.*

Proof. In order to satisfy the equality $(\star)$, the only terms that can be negative are the ones in between squared brackets. Since $\frac{A_1}{A_2} > 1$ and $\min \left\{ \frac{1}{1-\lambda\gamma}, \frac{1}{1-\gamma} \right\} > 1$, the only way one of these terms is negative is if

$$\min \left\{ \left(\frac{p_2}{p_1}\right)^{\frac{1-\lambda\gamma(1-\alpha)}{1-\lambda\gamma}} \left(\frac{A_1}{A_2}\right)^{\frac{1}{1-\lambda\gamma}}, \left(\frac{p_2}{p_1}\right)^{\frac{1-\gamma(1-\alpha)}{1-\gamma}} \left(\frac{A_1}{A_2}\right)^{\frac{1}{1-\gamma}} \right\} < 1.$$

However, since $\frac{1-\lambda\gamma(1-\alpha)}{1-\lambda\gamma}$ and $\frac{1-\gamma(1-\alpha)}{1-\gamma}$ are positive, this is only possible if $\frac{p_2}{p_1} < 1 \Rightarrow p_2 < p_1$. ■

Proof of Theorem 1

Theorem 1 *City Size and TFP. Let $A_1 > A_2$ and $\lambda\gamma < 1, \gamma < 1$. Then the more productive city is larger, $S_1 > S_2$.*

Proof. Based on Lemma 1, we know that $p_1 > p_2$. Since $\lambda > 1$ and $\lambda\gamma < 1$, we have that $\frac{1}{1-\lambda\gamma} > \frac{1}{1-\gamma}$ and $\frac{1-\lambda\gamma(1-\alpha)}{1-\lambda\gamma} > \frac{1-\gamma(1-\alpha)}{1-\gamma} > 1$. Since we know that $A_1 > A_2$, we have that the first term in squared brackets in $(\star)$ is positive if

$$\frac{p_2}{p_1} > \left(\frac{A_2}{A_1}\right)^{\frac{1}{1-\lambda\gamma(1-\alpha)}} \quad (32)$$

while the second term in squared brackets is positive if:

$$\frac{p_2}{p_1} > \left(\frac{A_2}{A_1}\right)^{\frac{1}{1-\gamma(1-\alpha)}}. \quad (33)$$

Since $\frac{A_2}{A_1} < 1$, we have that:

$$\left(\frac{p_2}{p_1}\right)^\alpha \frac{A_1}{A_2} \in \left(\left(\frac{A_1}{A_2}\right)^{\frac{(1-\lambda\gamma)(1-\alpha)}{1-\lambda\gamma(1-\alpha)}}, \left(\frac{A_1}{A_2}\right)^{\frac{(1-\gamma)(1-\alpha)}{1-\gamma(1-\alpha)}} \right) > 1. \quad (34)$$

From the expressions for m_{ij} :

$$m_{11} = \frac{\left[\left(\frac{p_1}{p_2}\right)^\alpha \frac{A_2}{A_1}\right]^{\frac{1}{\lambda\gamma-1}} \frac{M_1}{C_2}}{1 + \frac{C_1}{C_2} \left[\left(\frac{p_1}{p_2}\right)^\alpha \frac{A_2}{A_1}\right]^{\frac{1}{\lambda\gamma-1}}} \quad (35)$$

$$m_{12} = \frac{\frac{M_1}{C_2}}{1 + \frac{C_1}{C_2} \left[\left(\frac{p_1}{p_2}\right)^\alpha \frac{A_2}{A_1}\right]^{\frac{1}{\lambda\gamma-1}}}, \quad (36)$$

and $\left(\frac{p_2}{p_1}\right)^\alpha \frac{A_1}{A_2} > 1$, we have that $m_{11} > m_{12}$, and likewise $m_{21} > m_{22}$ and $m_{31} > m_{32}$. Finally, since:

$$S_j = m_{1j} + m_{2j} + m_{3j} \quad (37)$$

it immediately follows that $S_1 > S_2$. ■

Proof of Theorem 2

Theorem 2 Fat Tails. *Given $A_1 > A_2$, $\lambda > 1$ and $\lambda\gamma < 1$, the skill distribution in the larger city has fatter tails.*

Proof. Consider the distributions, denoted by $pdf_{ij} = \frac{m_{ij}}{S_j}$, where we denote by $Z = \left(\frac{p_1}{p_2}\right)^\alpha \frac{A_2}{A_1} < 1$. Then we can write

$$pdf_{11} = \frac{\frac{Z^{\frac{1}{\lambda\gamma-1}} \frac{M_1}{C_2}}{1 + \frac{C_1}{C_2} Z^{\frac{1}{\lambda\gamma-1}}}}{\frac{Z^{\frac{1}{\lambda\gamma-1}} \frac{M_1+M_3}{C_2}}{1 + \frac{C_1}{C_2} Z^{\frac{1}{\lambda\gamma-1}}} + \frac{Z^{\frac{1}{\gamma-1}} \frac{M_2}{C_2}}{1 + \frac{C_1}{C_2} Z^{\frac{1}{\gamma-1}}}} \quad (38)$$

$$pdf_{12} = \frac{\frac{\frac{M_1}{C_2}}{1 + \frac{C_1}{C_2} Z^{\frac{1}{\lambda\gamma-1}}}}{\frac{\frac{M_1+M_3}{C_2}}{1 + \frac{C_1}{C_2} Z^{\frac{1}{\lambda\gamma-1}}} + \frac{\frac{M_2}{C_2}}{1 + \frac{C_1}{C_2} Z^{\frac{1}{\gamma-1}}}} \quad (39)$$

Then:

$$\frac{pdf_{11}}{pdf_{12}} = \frac{Z^{\frac{1}{\lambda\gamma-1}} \left\{ (M_1 + M_3) \times \left[C_2 + C_1 Z^{\frac{1}{\gamma-1}} \right] + M_2 \times \left[C_2 + C_1 Z^{\frac{1}{\lambda\gamma-1}} \right] \right\}}{Z^{\frac{1}{\lambda\gamma-1}} (M_1 + M_3) \times \left[C_2 + C_1 Z^{\frac{1}{\gamma-1}} \right] + \left[C_2 + C_1 Z^{\frac{1}{\lambda\gamma-1}} \right] \times Z^{\frac{1}{\gamma-1}} M_2} > 1 \quad (40)$$

Recall that $Z < 1$, and therefore $Z^{\frac{1}{\lambda\gamma-1}} = \left(\frac{1}{Z}\right)^{\frac{1}{1-\lambda\gamma}}$, then since $\frac{1}{Z} > 1$, the larger the exponent, the larger is $\left(\frac{1}{Z}\right)^{\frac{1}{1-\lambda\gamma}}$. Since $\lambda > 1$ and $\lambda\gamma < 1$, $\frac{1}{1-\lambda\gamma} > \frac{1}{1-\lambda}$, it follows that $pdf_{11} > pdf_{12}$.

Similarly we can show that $pdf_{31} > pdf_{32}$:

$$\frac{pdf_{31}}{pdf_{32}} = \frac{Z^{\frac{1}{\lambda\gamma-1}} \left\{ (M_1 + M_3) \times \left[C_2 + C_1 Z^{\frac{1}{\gamma-1}} \right] + M_2 \times \left[C_2 + C_1 Z^{\frac{1}{\lambda\gamma-1}} \right] \right\}}{Z^{\frac{1}{\lambda\gamma-1}} (M_1 + M_3) \times \left[C_2 + C_1 Z^{\frac{1}{\gamma-1}} \right] + \left[C_2 + C_1 Z^{\frac{1}{\lambda\gamma-1}} \right] \times Z^{\frac{1}{\gamma-1}} M_2} > 1 \quad (41)$$

Finally:

$$pdf_{21} = \frac{\left[C_2 + C_1 Z^{\frac{1}{\lambda\gamma-1}} \right] Z^{\frac{1}{\gamma-1}} M_2}{Z^{\frac{1}{\lambda\gamma-1}} (M_1 + M_3) \times \left[C_2 + C_1 Z^{\frac{1}{\lambda-1}} \right] + Z^{\frac{1}{\gamma-1}} M_2 \times \left[C_2 + C_1 Z^{\frac{1}{\lambda\gamma-1}} \right]}$$

$$pdf_{22} = \frac{\left[C_2 + C_1 Z^{\frac{1}{\lambda\gamma-1}} \right] M_2}{(M_1 + M_3) \left[C_2 + C_1 Z^{\frac{1}{\gamma-1}} \right] + M_2 \left[C_2 + C_1 Z^{\frac{1}{\lambda\gamma-1}} \right]}$$

Then:

$$\frac{pdf_{21}}{pdf_{22}} = \frac{Z^{\frac{1}{\gamma-1}} (M_1 + M_3) \left[C_2 + C_1 Z^{\frac{1}{\lambda-1}} \right] + M_2 \left[C_2 + C_1 Z^{\frac{1}{\lambda\gamma-1}} \right]}{Z^{\frac{1}{\lambda\gamma-1}} (M_1 + M_3) \times \left[C_2 + C_1 Z^{\frac{1}{\lambda-1}} \right] + Z^{\frac{1}{\lambda-1}} M_2 \times \left[C_2 + C_1 Z^{\frac{1}{\lambda\gamma-1}} \right]} \quad (42)$$

Again, since $Z^{\frac{1}{\gamma-1}} < Z^{\frac{1}{\lambda\gamma-1}}$, now we have that $pdf_{21} < pdf_{22}$. ■

Proof of Theorem 3

Theorem 3 Top-Skill Complementarity. *Given $A_1 > A_2$, $\lambda > 1$ and $\lambda\gamma < 1$, the skill distribution in the larger city first order stochastically dominates.*

Proof. The proof follows closely the logic of Theorem 2.

$$\begin{aligned}
pdf_{11} &= \frac{\left[C_2 + C_1 Z^{\frac{1}{\lambda\gamma-1}} \right] Z^{\frac{1}{\gamma-1}} M_1}{Z^{\frac{1}{\lambda\gamma-1}} (M_2 + M_3) \times \left[C_2 + C_1 Z^{\frac{1}{\lambda-1}} \right] + Z^{\frac{1}{\gamma-1}} M_1 \times \left[C_2 + C_1 Z^{\frac{1}{\lambda\gamma-1}} \right]} \\
pdf_{12} &= \frac{\left[C_2 + C_1 Z^{\frac{1}{\lambda\gamma-1}} \right] M_1}{(M_2 + M_3) \left[C_2 + C_1 Z^{\frac{1}{\gamma-1}} \right] + M_1 \left[C_2 + C_1 Z^{\frac{1}{\lambda\gamma-1}} \right]}
\end{aligned}$$

Then:

$$\frac{pdf_{11}}{pdf_{12}} = \frac{Z^{\frac{1}{\gamma-1}} (M_2 + M_3) \left[C_2 + C_1 Z^{\frac{1}{\lambda-1}} \right] + M_1 \left[C_2 + C_1 Z^{\frac{1}{\lambda\gamma-1}} \right]}{Z^{\frac{1}{\lambda\gamma-1}} (M_2 + M_3) \times \left[C_2 + C_1 Z^{\frac{1}{\lambda-1}} \right] + Z^{\frac{1}{\lambda-1}} M_1 \times \left[C_2 + C_1 Z^{\frac{1}{\lambda\gamma-1}} \right]} < 1, \quad (43)$$

since $Z^{\frac{1}{\gamma-1}} < Z^{\frac{1}{\lambda\gamma-1}}$.

$$\begin{aligned}
pdf_{21} &= \frac{\left[C_2 + C_1 Z^{\frac{1}{\gamma-1}} \right] Z^{\frac{1}{\lambda\gamma-1}} M_2}{Z^{\frac{1}{\lambda\gamma-1}} (M_2 + M_3) \times \left[C_2 + C_1 Z^{\frac{1}{\gamma-1}} \right] + \left[C_2 + C_1 Z^{\frac{1}{\lambda\gamma-1}} \right] \times Z^{\frac{1}{\gamma-1}} M_1} \\
pdf_{22} &= \frac{\left[C_2 + C_1 Z^{\frac{1}{\gamma-1}} \right] M_2}{(M_2 + M_3) \times \left[C_2 + C_1 Z^{\frac{1}{\gamma-1}} \right] + M_1 \times \left[C_2 + C_1 Z^{\frac{1}{\lambda\gamma-1}} \right]}
\end{aligned}$$

Then:

$$\frac{pdf_{21}}{pdf_{22}} = \frac{Z^{\frac{1}{\lambda\gamma-1}} (M_2 + M_3) \times \left[C_2 + C_1 Z^{\frac{1}{\gamma-1}} \right] + M_1 \times \left[C_2 + C_1 Z^{\frac{1}{\lambda\gamma-1}} \right]}{Z^{\frac{1}{\lambda\gamma-1}} (M_2 + M_3) \times \left[C_2 + C_1 Z^{\frac{1}{\gamma-1}} \right] + \left[C_2 + C_1 Z^{\frac{1}{\lambda\gamma-1}} \right] \times Z^{\frac{1}{\gamma-1}} M_1} > 1 \quad (44)$$

Finally, analogously to $\frac{pdf_{21}}{pdf_{22}}$, we can derive $\frac{pdf_{31}}{pdf_{32}}$:

$$\frac{pdf_{31}}{pdf_{32}} = \frac{Z^{\frac{1}{\lambda\gamma-1}} (M_1 + M_3) \times \left[C_2 + C_1 Z^{\frac{1}{\gamma-1}} \right] + M_2 \times \left[C_2 + C_1 Z^{\frac{1}{\lambda\gamma-1}} \right]}{Z^{\frac{1}{\lambda\gamma-1}} (M_1 + M_3) \times \left[C_2 + C_1 Z^{\frac{1}{\gamma-1}} \right] + \left[C_2 + C_1 Z^{\frac{1}{\lambda\gamma-1}} \right] \times Z^{\frac{1}{\gamma-1}} M_2} > 1 \quad (45)$$

■

Appendix B: Data

Wage Data

Table 4: Rank of cities by 2009 population.

	City	Population
1	New York-Northern New Jersey-Long Island, NY-NJ-PA	19,069,796
2	Los Angeles-Long Beach-Santa Ana, CA	12,874,797
3	Chicago-Naperville-Joliet, IL-IN-WI	9,580,567
4	Dallas-Fort Worth-Arlington, TX	6,447,615
5	Philadelphia-Camden-Wilmington, PA-NJ-DE-MD	5,968,252
6	Houston-Sugar Land-Baytown, TX	5,867,489
7	Miami-Fort Lauderdale-Pompano Beach, FL	5,547,051
8	Washington-Arlington-Alexandria, DC-VA-MD-WV	5,476,241
9	Atlanta-Sandy Springs-Marietta, GA	5,475,213
10	Boston-Cambridge-Quincy, MA-NH	4,588,680
...		
245	Farmington, NM	124,131
246	Bowling Green, KY	120,595
247	Harrisonburg, VA	120,271
248	Lawrence, KS	116,383
249	Victoria, TX	115,396
250	Anniston-Oxford, AL	114,081
251	Lawton, OK	113,228
252	Kankakee-Bradley, IL	113,215
253	Michigan City-La Porte, IN	111,063
254	Decatur, IL	108,204

Notes: cities are defined as core based statistical areas (CBSA). The Office of Management and Budget (OMB) defines 940 metropolitan and micropolitan areas of which we use the ones with population above 100,000 and where housing prices are observed.

Wage data is taken from the Current Population Survey (CPS), a joint effort between the Bureau of Labor Statistics (BLS) and the Census Bureau.²⁸ The CPS is a monthly survey and used by the U.S. Government to calculate the official unemployment and labor force participation figures. We use the 2009 merged outgoing rotation groups (MORG) as provided by the National Bureau of Economic Research (NBER)²⁹. The MORG are extracts of the basic monthly data during the household's fourth and eighth month in the survey, when usual weekly hours/earnings are asked.

We use the variable 'earnwke' as created by the NBER.³⁰ This variable reports earnings per week in the current job. It includes overtime, tips and commissions. For hourly workers, Item 25a ("How many hours per week does...usually work at this job?") times Item 25c ("How much does ...earn per hour?") appears here. For weekly workers, Item 25d ("How much does...usually earn per week at this job before deductions?") appears here.

We restrict the sample to full time workers (between 36 and 60 usual hours per week). We also drop the lowest 0.5% of wages as a pragmatic way of eliminating likely misreported wages close to zero. Our final wage sample includes 102,599 workers out of the 320,941 surveyed persons. CPS wage data is in 2009 top-coded at a weekly wage of 2884.61 USD which applies to 2616 or 2.5% of workers. All estimations use the weights in variable 'earnwt' provided by the NBER.

The NBER version of the CPS identifies the core-based statistical area (CBSA) of the observation. It uses the New England city and town areas (NECTA) definition and codes for metro areas in the 6 New England states and the Federal Information Processing Standards (FIPS) definition and codes for all other states.

Our baseline results use CPS wage data because they are generally considered of higher quality than Census data (see e.g. Baum-Snow and Neal, 2009). However, the CPS has two disadvantages: it has relatively low top codes and it does not identify the location of the household *within* cities. We therefore alternatively use wage data from the 2009 American Community Survey (ACS). We use the variable 'incwage' which measures yearly wage and salary income. We restrict our sample to full-time (between 36 and 60 usual hours per week) and full-year (between 48 and 52 weeks per year) workers. The yearly wage is divided by the

²⁸See <http://www.bls.gov/cps/>

²⁹Stata data file available at <http://www.nber.org/morg/annual/morg09.dta>

³⁰See details of the variable creation at the NBER website <http://www.nber.org/cps/>

number of weeks worked to get weakly wages comparable to the CPS data. ACS are top-coded at the 99.5 percentile of each state. We also drop the lowest 0.1% of wages as a pragmatic way of eliminating likely misreported wages close to zero.

Local house and commodity price indices

We use the 2009 American Community Survey (ACS) collected by the U.S. Census Bureau. The ACS samples a small percentage of the population every year.³¹ The data is provided by the Minnesota Population Center in its Integrated Public Use Microdata Series (IPUMS).³²

The variable ‘rent’ reports the monthly contract rent for rental units in contemporary dollars. We also use all the reported housing characteristics of the unit: ‘rooms’ is the number of rooms, ‘unitsstr’ is the units in structure (in 8 groups), and ‘builtyr’ is the age of structure (in 13 age groups).

We drop housing units in group quarters, farmhouses, drop mobile homes, trailers, boats, and tents and only use data from housing units in identified metropolitan or micropolitan core based statistical areas (CBSA).

The ACS discloses the co-called Public Use Microdata Area (PUMA). PUMA’s are areas with a maximum of 179,405 housing units and only partly overlap with political borders of towns and counties. We use the Geographic Correspondence Engine with Census 2000 Geography from the Missouri Census Data Center(MCDC) ³³ to link PUMA areas to CBSAs. The MCDC data matches every urban PUMA code to one or more CBSA codes and reports the fraction of housing units that are matched. We assign a PUMA to a CBSA if this fraction is bigger than 33%. In cases where the PUMA does not fully belong to a CBSA, we assign the PUMA to the CBSA where most of its housing units belong to. Our final sample contains data from 533 metropolitan or micropolitan core based statistical areas (CBSA) out of a total of 940 existing CBSAs. Not that we do *not* use the metropolitan area code provided in the PUMS in variable ‘metaread’. This variable reports a mixture of metropolitan area codes (MSA, PMSA, central city or county) which is difficult to match with the CBSA definition. Our final sample contains 273,761 rental units in 533 CBSAs and 1884 PUMA areas.

For robustness checks, we also purchased the ACCRA Cost of Living Index from C2ER (The Council for Community and Economic Research). ACCRA data are collected by local chambers of commerce and similar organization who have volunteered to participate. They are reported for 269 core-based statistical areas (CBSA) and 80 metropolitan divisions for the 33 largest CBSAs. The ACCRA Cost of Living Index consists of six major categories: grocery items, housing, utilities, transportation, health care, and miscellaneous goods and services. These major categories in turn are composed of subcategories, each of which is represented by one or more items in the Index. In total, local prices of 60 items are reported, e.g. tbone steak (item 1), phone (31), gasoline (33), Lipitor (38), pizza (40) haircut (42), movie (52). Indices for major categories and an overall composite index are calculated as weighted averages where weights come from the Consumer Expenditures Survey conducted by the U.S. Bureau of Labor Statistics. We use the average of quarterly data from Q2.2008 to Q2.2009 in order to minimize the number of missing cities from non-reporting places. We use the average across metropolitan divisions to match ACCRA data to our wage data.

For further robustness checks, we use data from the National Association of Realtors for the 4th quarter in 2009. We use the median sales price of existing single-family homes for metropolitan areas. MSAs are as defined by the U.S. Office of Management and Budget and include the specified city or cities and surrounding suburban areas.

Hedonic Regression to calculate housing price index

We model housing as a homogenous good h with a location specific per unit price p_j . In practice, however, housing differs in many observable dimensions. Observed housing prices therefore reflect both the location and the physical characteristics of the unit. Sieg et al. (2002) show the conditions under which housing can be treated as if it were homogenous and how to construct a price index for it. Take our Cobb-Douglas utility function

$$u(c, h(z)) = c^{1-\alpha} h^\alpha(z) \quad (46)$$

and assume that housing $h(z)$ is a function, for simplicity of exposition only, of two characteristics $z = (z_1, z_2)$ with a nested Cobb-Douglas structure

$$h(z) = z_1^\delta z_2^{1-\delta}. \quad (47)$$

The indirect utility given the market prices q_1 and q_2 for, respectively, characteristic z_1 and z_2 is then

$$U_i = \alpha^\alpha (1 - \alpha)^{1-\alpha} \left[L q_1^\delta q_2^{1-\delta} \right]^{-\alpha} w \quad (48)$$

where $L = 1/[\delta^\delta (1 - \delta)^{1-\delta}]$. Defining the price index $p = L q_1^\delta q_2^{1-\delta}$ the indirect utility is

$$U_i = \alpha^\alpha (1 - \alpha)^{1-\alpha} \frac{w}{p^\alpha} \quad (49)$$

³¹See <http://www.census.gov/acs/www/> for more information on the survey.

³²See Ruggles et al. (2010) for the data source and <http://usa.ipums.org/usa/> for a detailed description of data and variables.

³³Available at <http://mc2c2.missouri.edu/websas/geocorr2k.html>.

Table 5: Hedonic regressions for rental units.

	CBSA level		PUMA level	
Number of rooms				
1	-0.2314***	(0.0056)	-0.2238***	(0.0055)
2	-0.1658***	(0.0050)	-0.1863***	(0.0049)
3	-0.1329***	(0.0031)	-0.1386***	(0.0030)
4	0		0	
5	0.0760***	(0.0033)	0.0798***	(0.0031)
6	0.1614***	(0.0041)	0.1592***	(0.0039)
7	0.2405***	(0.0057)	0.2313***	(0.0055)
8	0.2877***	(0.0077)	0.2717***	(0.0074)
9+	0.3341***	(0.0082)	0.3049***	(0.0079)
Age of structure				
1939 or earlier	-0.3068***	(0.0053)	-0.2700***	(0.0053)
1940-1949	-0.3603***	(0.0062)	-0.3219***	(0.0061)
1950-1959	-0.3167***	(0.0055)	-0.2970***	(0.0054)
1960-1969	-0.2887***	(0.0053)	-0.2793***	(0.0052)
1970-1979	-0.2553***	(0.0050)	-0.2542***	(0.0049)
1980-1989	-0.1758***	(0.0052)	-0.1838***	(0.0050)
1990-1999	-0.0780***	(0.0054)	-0.0838***	(0.0052)
2000-2004	0		0	
2005	0.0122	(0.0097)	0.0223**	(0.0094)
2006	0.0421***	(0.0099)	0.0537***	(0.0095)
2007	0.0548***	(0.0104)	0.0621***	(0.0100)
2008	0.1029***	(0.0135)	0.1139***	(0.0130)
2009	0.0343	(0.0444)	0.0347	(0.0427)
Units in structure				
1-family house detached	0		0	
1-family house attached	-0.0635***	(0.0050)	-0.0677***	(0.0049)
2-family building	-0.1257***	(0.0045)	-0.1289***	(0.0044)
3-4 family building	-0.1314***	(0.0042)	-0.1434***	(0.0041)
5-9 family building	-0.1239***	(0.0042)	-0.1532***	(0.0041)
10-19 family building	-0.0786***	(0.0043)	-0.1171***	(0.0042)
20-49 family building	-0.1023***	(0.0048)	-0.1354***	(0.0047)
50+ family building	-0.0929***	(0.0045)	-0.1413***	(0.0045)
Constant	6.5728***	(0.0481)	6.0277***	(0.0523)
CBSA Fixed Effects	yes		no	
PUMA Fixed Effects	no		yes	
N (rental units)	273,761		273,761	
Number of CBSAs	533		533	
Number of PUMA regions			1884	

Notes: * p<0.10, ** p<0.05, *** p<0.01. Reference groups are indicated by "0".

and thus identical to the one derived assuming homogenous housing h with market price p . The sub-expenditure function $e(q_1, q_2, h)$ is defined as the minimum expenditure necessary to obtain h units of housing and given by

$$e(q_1, q_2, h) = Lq_1^\delta q_2^{1-\delta} h = ph = pz_1^\delta z_2^{1-\delta}. \quad (50)$$

Taking logarithms and assuming that we observe z_1 but not z_2 yields a linear hedonic regression model

$$\log(e_{jn}) = \log(p_j) + \delta \log(z_{1jn}) + u_{jn} \quad (51)$$

where e_{jn} is the observed rental price of housing unit n and $\log(p_j)$ is city-specific common component of housing prices. We can therefore estimate the city specific price level as location-specific fixed effect in a simple hedonic regression of log rental prices on the physical characteristics.

Table 5 shows the results of the hedonic regressions for rental units using data from the 2009 American Community Survey (ACS). Column (1) shows the results with 533 fixed effects for cities (CBSA) and column (2) with 1844 fixed effects for neighbourhoods (PUMA areas). We use all relevant housing characteristics in the data and add all categories as dummy variables without functional form assumptions. All coefficients are highly significant with expected signs: housing prices increase with the number of rooms and

Table 6: Rank of cities by estimated housing price index.

	City	Population	Rent Index
1	San Jose-Sunnyvale-Santa Clara, CA	1,839,700	1.74
2	San Francisco-Oakland-Fremont, CA	4,317,853	1.64
3	Santa Barbara-Santa Maria-Goleta, CA	407,057	1.62
4	Oxnard-Thousand Oaks-Ventura, CA	802,983	1.62
5	Honolulu, HI	907,574	1.61
6	Los Angeles-Long Beach-Santa Ana, CA	12,874,797	1.55
7	San Diego-Carlsbad-San Marcos, CA	3,053,793	1.51
8	Washington-Arlington-Alexandria, DC-VA-MD-WV	5,476,241	1.46
9	Napa, CA	134,650	1.43
10	Santa Cruz-Watsonville, CA	256,218	1.43
11	New York-Northern New Jersey-Long Island, NY-NJ-PA	19,069,796	1.41
...			
245	McAllen-Edinburg-Mission, TX	741,152	.50
246	Lawton, OK	113,228	.50
247	Lake Charles, LA	194,138	.49
248	Huntington-Ashland, WV-KY-OH	285,624	.49
249	Monroe, LA	174,086	.47
250	Johnstown, PA	143,998	.47
251	Brownsville-Harlingen, TX	396,371	.47
252	Decatur, AL	151,399	.46
253	Joplin, MO	174,300	.45
254	Anniston-Oxford, AL	114,081	.36

Notes: Housing price indices based on hedonic regressions using the 2009 American Community Survey.

decrease with the age of the structure. We find a non-monotonic relationship in the numbers of units in the structure with highest prices for single-family detached homes and lowest prices for 3-4 family buildings.

We standardize the housing price index such that the weighted (by housing units) average equals 1. Table 6 shows the resulting housing price indices for the highest and lowest priced cities in our sample. The highest priced city is San Jose, CA with rental prices 74% above average urban prices; the lowest priced city with more than 100,000 inhabitants is Anniston, AL with prices 64% below average.

Expenditure Data for Estimation of Non-Linear Engel Curve

We use Public Use Microdata (PUMD) from the Consumer Expenditure Survey (CEX) which is provided by the U.S. Bureau of Labor Statistics.³⁴ In particular, our sample consists of interview data for 4581 households in the first quarter of 2011 in the data file “fmli111x”. The PUMD reports the exact city (MSA) for 2021 households living in one the of the 21 largest MSAs. We merge these data with our hedonic price indices from the corresponding CBSAs. The housing expenditure shares, s_i , are measured as “expenditures on shelter this quarter” (variable SHELTCQ) divided by “total expenditures this quarter” (TOTEXPCQ). Weekly wages, w_i are measured as “income before taxes in past 12 months” (FINCBTAX) divided by 52. Housing prices, p_j , are measured as the hedonic price index using the 2009 American Community Survey. We restrict our sample to weekly wage incomes above \$175 because very low wages become extremely large inverse values which would almost fully determine the regression. The limit of \$175 is also the lower bound in our CPS wage data (see the data section on wages) and guarantees that the indirect utility is defined for all observations. The regression with 1569 observations results in: $\hat{\alpha} = 0.224$ (s.e.= 0.005), $\hat{\beta} = 21.5$ (3.05), $\hat{h} = 27.7$ (3.79 using the delta method). As a robustness check, we also use a values for $\hat{h}$ different from the estimated value. As an extreme example, for $\hat{h} = 250$ we find that even though the shape of the distribution changes dramatically – especially at for the low income workers – the fat tails are still prominently present, as illustrated in Figure 16.

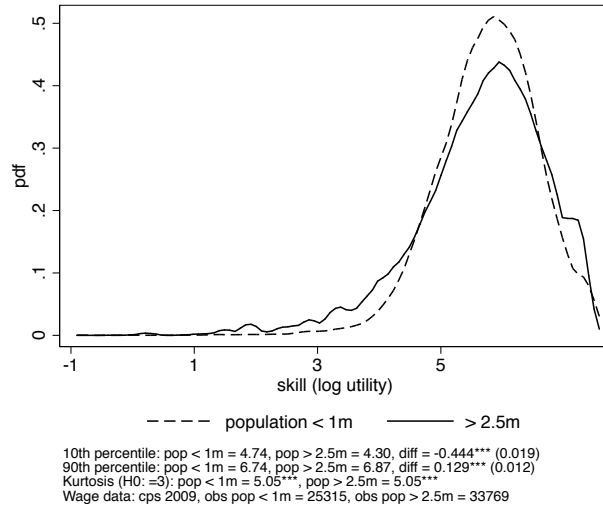


Figure 16: Expenditure Share using Stone-Geary preferences, $\alpha = 0.22$, $\hat{h} = 250$.

³⁴See <http://www.bls.gov/ce/> for details on the CEX and its public use individual data version. The CEX allows us to calculate expenditure share as a ratio of total expenditures. The ACS does not provide total expenditures of individuals or households. Housing shares as a ratio of reported income are extremely noisy with housing expenditure shares above 100% for a large fraction of low income households. We did not get any reasonable Stone-Geary parameters based on ACS data.

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Additional Results – Online Appendix

I. General Technology: N skill types

The firm's problem with N skills is given by:

$$\pi(m_{1j}, \dots, m_{jN}) = A_j F(m_{1j}, \dots, m_{jN}) - \sum_{i=1}^N w_{ij} m_{ij} \quad (\text{A.1})$$

Then, the system becomes:

$$\begin{cases} A_1 F_i(m_{11}, \dots, m_{N1}) = \left(\frac{p_1}{p_2}\right)^\alpha A_2 F_i(m_{12}, \dots, m_{N2}), & \forall i \in \{1, \dots, N\} \\ \sum_{i=1}^N F_i(m_{11}, \dots, m_{N1}) m_{i1} = H \frac{p_1}{\alpha A_1} \\ \sum_{i=1}^N F_i(m_{12}, \dots, m_{N2}) m_{i2} = H \frac{p_2}{\alpha A_2} \\ C_1 m_{i1} + C_2 m_{i2} = M_i, & \forall i \in \{1, \dots, N\} \end{cases} \quad (\text{A.2})$$

Now, define $F(\cdot)$ as (assuming without loss that N is even):

$$F(\cdot) = (m_{11}^\gamma y_1 + m_{N1}^\gamma y_N)^{\lambda_1} + (m_{21}^\gamma y_2 + m_{N-1,1}^\gamma y_{N-1})^{\lambda_2} + \dots + \left(m_{\frac{N}{2},1}^\gamma y_{\frac{N}{2}} + m_{\frac{N}{2}+1,1}^\gamma y_{\frac{N}{2}+1}\right)^{\lambda_{\frac{N}{2}}} \quad (\text{A.3})$$

Substituting this back into the system, we have:

$$\begin{cases} \frac{A_1 (m_{i,1}^\gamma y_i + m_{N-(i-1),1}^\gamma y_{N-(i-1)})^{\lambda_{\min\{i, N-(i-1)\}_i} m_{i,1}^{\gamma-1}}{A_2 (m_{i,2}^\gamma y_i + m_{N-(i-1),2}^\gamma y_{N-(i-1)})^{\lambda_{\min\{i, N-(i-1)\}_i} m_{i,2}^{\gamma-1}}} = \left(\frac{p_1}{p_2}\right)^\alpha, & \forall i \in \{1, \dots, N\} & (1), \dots, (N) \\ \sum_{i=1}^N \lambda_{\min\{i, N-(i-1)\}_i} \left(m_{i,1}^\gamma y_i + m_{N-(i-1),1}^\gamma y_{N-(i-1)}\right)^{\lambda_{\min\{i, N-(i-1)\}_i} - 1} m_{i,1}^\gamma y_i = H \frac{p_1}{\alpha \beta \gamma A_1} & (N+1) \\ \sum_{i=1}^N \lambda_{\min\{i, N-(i-1)\}_i} \left(m_{i,2}^\gamma y_i + m_{N-(i-1),2}^\gamma y_{N-(i-1)}\right)^{\lambda_{\min\{i, N-(i-1)\}_i} - 1} m_{i,2}^\gamma y_i = H \frac{p_2}{\alpha \beta \gamma A_2} & (N+2) \\ C_1 m_{i1} + C_2 m_{i2} = M_i, & \forall i \in \{1, \dots, N\} & (N+3), \dots, (2N+2) \end{cases} \quad (\text{A.4})$$

From the first N equations, dividing the expressions for i and $N-(i-1)$, we have:

$$m_{i,1} = \frac{M_i}{M_{N-(i-1)}} m_{N-(i-1),1}, \text{ for } i \in \left\{1, \dots, \frac{N}{2}\right\} \quad (\text{A.5})$$

Considering a symmetric distribution (so $M_i = M_{N-(i-1)}$, for $i \in \{1, \dots, \frac{N}{2}\}$), we have that $m_{i,1} = m_{N-(i-1),1}$. Similarly $m_{i2} = m_{N-(i-1),2} = \frac{M_i}{N_2} - \frac{N_1}{N_2} m_{i1}$, for $i \in \{1, \dots, \frac{N}{2}\}$.

From equations for i and j for $i \neq j$ from the first N equations, we have:

$$\left[\frac{m_{i,1}}{m_{N-(i-1),1}}\right]^{\gamma-1} = \left[\frac{m_{i,2}}{m_{N-(i-1),2}}\right]^{\gamma-1}, \text{ for } i \in \left\{1, \dots, \frac{N}{2}\right\} \quad (\text{A.6})$$

Using equations $(N+3)$ to $(2N+2)$, we have:

$$m_{i,1} = \frac{M_i}{M_{N-(i-1)}} m_{N-(i-1),1}, \text{ for } i \in \left\{1, \dots, \frac{N}{2}\right\}$$

Considering a symmetric distribution (so $M_i = M_{N-(i-1)}$, for $i \in \{1, \dots, \frac{N}{2}\}$), we have that $m_{i,1} = m_{N-(i-1),1}$. Similarly $m_{i2} = m_{N-(i-1),2} = \frac{M_i}{C_2} - \frac{C_1}{C_2} m_{i1}$, for $i \in \{1, \dots, \frac{N}{2}\}$.

From the first N equations, we have:

$$m_{i,1} = \frac{\left[\left(\frac{p_1}{p_2}\right)^\alpha \frac{A_2}{A_1}\right]^{\frac{1}{\lambda_{\min\{i, N-(i-1)\}_i} \gamma - 1}} M_i}{C_2 + \left[\left(\frac{p_1}{p_2}\right)^\alpha \frac{A_2}{A_1}\right]^{\frac{1}{\lambda_{\min\{i, N-(i-1)\}_i} \gamma - 1}} C_1} \quad (\text{A.7})$$

Similarly:

$$m_{i2} = \frac{M_i}{C_2 + \left[\left(\frac{p_1}{p_2}\right)^\alpha \frac{A_2}{A_1}\right]^{\frac{1}{\lambda_{\min\{i, N-(i-1)\}_i} \gamma - 1}} C_1} \quad (\text{A.8})$$

Then, from $(N + 1)$, we have:

$$\frac{A_1}{p_1} \sum_{i=1}^N \left\{ \left[\left(\frac{p_1}{p_2} \right)^\alpha \frac{A_2}{A_1} \right]^{\lambda_{\min\{i, N-(i-1)\}_i} \gamma} \frac{1}{C_2 + \left[\left(\frac{p_1}{p_2} \right)^\alpha \frac{A_2}{A_1} \right]^{\lambda_{\min\{i, N-(i-1)\}_i} \gamma - 1} C_1} \frac{M_i}{\lambda_{\min\{i, N-(i-1)\}_i} \gamma} \right)^{\lambda_{\min\{i, N-(i-1)\}_i} \gamma} \times \lambda_{\min\{i, N-(i-1)\}_i} (y_i + y_{N-(i-1)})^{\lambda_{\min\{i, N-(i-1)\}_i} - 1} y_i \right\} = \frac{H}{\alpha \beta \gamma} \quad (\text{A.9})$$

Similarly, from $(N + 2)$, we have:

$$\frac{A_2}{p_2} \sum_{i=1}^N \left\{ \left(\frac{M_i}{C_2 + \left[\left(\frac{p_1}{p_2} \right)^\alpha \frac{A_2}{A_1} \right]^{\lambda_{\min\{i, N-(i-1)\}_i} \gamma - 1} C_1} \right)^{\lambda_{\min\{i, N-(i-1)\}_i} \gamma} \times \lambda_{\min\{i, N-(i-1)\}_i} (y_i + y_{N-(i-1)})^{\lambda_{\min\{i, N-(i-1)\}_i} - 1} y_i \right\} = \frac{H}{\alpha \beta \gamma} \quad (\text{A.10})$$

Combining these expressions and rearranging, we have:

$$\sum_{i=1}^N \left\{ \left[\left(\frac{p_2}{p_1} \right)^{\frac{1-(1-\alpha)\lambda_{\min\{i, N-(i-1)\}_i} \gamma}{1-\lambda_{\min\{i, N-(i-1)\}_i} \gamma}} \left(\frac{A_1}{A_2} \right)^{\frac{1}{1-\lambda_{\min\{i, N-(i-1)\}_i} \gamma} - 1} \times \right. \right. \\ \left. \left. \times \left(\frac{M_i}{C_2 + \left[\left(\frac{p_1}{p_2} \right)^\alpha \frac{A_2}{A_1} \right]^{\lambda_{\min\{i, N-(i-1)\}_i} \gamma - 1} C_1} \right)^{\lambda_{\min\{i, N-(i-1)\}_i} \gamma} \times \lambda_{\min\{i, N-(i-1)\}_i} (y_i + y_{N-(i-1)})^{\lambda_{\min\{i, N-(i-1)\}_i} - 1} y_i \right] \right\} = 0 \quad (\star) \quad (\text{A.11})$$

Lemma A.1: Let $\lambda_i > 1, \lambda_i \gamma < 1$, for every $i \in \{1, 2, \dots, \frac{N}{2}\}$ and $\{\lambda_i\}_{i=1}^{\frac{N}{2}}$ be a decreasing sequence. If $A_1 > A_2$, then house prices are higher in the city with higher TFP, $p_1 > p_2$.

Proof: In order to satisfy the equality $(\star)$, the only terms that can be negative are the ones in between squared brackets. Since $\frac{A_1}{A_2} > 1$ and $\min_i \left\{ \frac{1}{1-\lambda_{\min\{i, N-(i-1)\}_i} \gamma} \right\} > 1$, the only way one of these terms is negative is if:

$$\min_i \left\{ \left(\frac{p_2}{p_1} \right)^{\frac{1-(1-\alpha)\lambda_{\min\{i, N-(i-1)\}_i} \gamma}{1-\lambda_{\min\{i, N-(i-1)\}_i} \gamma}} \left(\frac{A_1}{A_2} \right)^{\frac{1}{1-\lambda_{\min\{i, N-(i-1)\}_i} \gamma} - 1} \right\} < 1 \quad (\text{A.12})$$

But, since $\min_i \left\{ \left(\frac{p_2}{p_1} \right)^{\frac{1-(1-\alpha)\lambda_{\min\{i, N-(i-1)\}_i} \gamma}{1-\lambda_{\min\{i, N-(i-1)\}_i} \gamma}} \left(\frac{A_1}{A_2} \right)^{\frac{1}{1-\lambda_{\min\{i, N-(i-1)\}_i} \gamma} - 1} \right\} > 1$, the only way that the above inequality is satisfied is if $\frac{p_2}{p_1} < 1 \Rightarrow p_2 < p_1$. ■

Theorem A.1: City Size and TFP. Let $A_1 > A_2$, $\lambda_i > 1, \lambda_i \gamma < 1$, for every $i \in \{1, 2, \dots, \frac{N}{2}\}$ and $\{\lambda_i\}_{i=1}^{\frac{N}{2}}$ be a decreasing sequence. Then, the more productive city is larger, $S_1 > S_2$.

Proof: Based on Lemma A.1, we know that $p_1 > p_2$. Since $\lambda_i > 1, \lambda_i \gamma < 1$, for every $i \in \{1, 2, \dots, \frac{N}{2}\}$ and $\{\lambda_i\}_{i=1}^{\frac{N}{2}}$ is a decreasing sequence, we know that $\frac{1}{1-\lambda_1 \gamma} > \frac{1}{1-\lambda_2 \gamma} > \dots > \frac{1}{1-\lambda_{\frac{N}{2}} \gamma} > 1$ and $\frac{1-(1-\alpha)\lambda_1 \gamma}{1-\lambda_1 \gamma} > \frac{1-(1-\alpha)\lambda_1 \gamma}{1-\lambda_1 \gamma} > \dots > \frac{1-(1-\alpha)\lambda_{\frac{N}{2}} \gamma}{1-\lambda_{\frac{N}{2}} \gamma} > 1$. But then, in order to satisfy $(\star)$, we must have some positive and negative terms. The term with respect to $i = \frac{N}{2}$ is positive if:

$$\frac{p_2}{p_1} > \left(\frac{A_2}{A_1} \right)^{\frac{1}{1-(1-\alpha)\lambda_{\frac{N}{2}} \gamma}} \quad (\text{A.13})$$

While the term with respect to $i = 1$ is positive if:

$$\frac{p_2}{p_1} > \left(\frac{A_2}{A_1} \right)^{\frac{1}{1-(1-\alpha)\lambda_1 \gamma}} \quad (\text{A.14})$$

But notice that $\frac{A_2}{A_1} < 1$. Then, we have that:

$$\left(\frac{A_2}{A_1} \right)^{\frac{1}{1-(1-\alpha)\lambda_{\frac{N}{2}} \gamma}} > \left(\frac{A_2}{A_1} \right)^{\frac{1}{1-(1-\alpha)\lambda_1 \gamma}} \quad (\text{A.15})$$

Therefore, in order to satisfy (★), we must have that:

$$\frac{p_2}{p_1} \in \left(\left(\frac{A_2}{A_1} \right)^{\frac{1}{1-(1-\alpha)\lambda_1\gamma}}, \left(\frac{A_2}{A_1} \right)^{\frac{1}{1-(1-\alpha)\lambda\frac{N}{2}\gamma}} \right) \quad (\text{A.16})$$

But this implies that:

$$\left(\frac{p_2}{p_1} \right)^\alpha \frac{A_1}{A_2} \in \left(\left(\frac{A_2}{A_1} \right)^{\frac{\alpha}{1-(1-\alpha)\lambda_1\gamma}-1}, \left(\frac{A_2}{A_1} \right)^{\frac{\alpha}{1-(1-\alpha)\lambda\frac{N}{2}\gamma}-1} \right) \quad (\text{A.17})$$

Rearranging it, we have:

$$\left(\frac{p_2}{p_1} \right)^\alpha \frac{A_1}{A_2} \in \left(\left(\frac{A_1}{A_2} \right)^{\frac{(1-\alpha)(1-\lambda_1\gamma)}{1-(1-\alpha)\lambda_1\gamma}}, \left(\frac{A_1}{A_2} \right)^{\frac{(1-\alpha)(1-\lambda\frac{N}{2}\gamma)}{1-(1-\alpha)\lambda\frac{N}{2}\gamma}} \right) \quad (\text{A.18})$$

Since $A_1 > A_2$, we have that:

$$\left(\frac{p_2}{p_1} \right)^\alpha \frac{A_1}{A_2} > 1 \quad (\text{A.19})$$

From the expressions for m_{ij} :

$$m_{i,1} = \frac{\left[\left(\frac{p_1}{p_2} \right)^\alpha \frac{A_2}{A_1} \right]^{\frac{1}{\lambda_{\min\{i, N-(i-1)\}_i} \gamma - 1}} M_i}{C_2 + \left[\left(\frac{p_1}{p_2} \right)^\alpha \frac{A_2}{A_1} \right]^{\frac{1}{\lambda_{\min\{i, N-(i-1)\}_i} \gamma - 1}} C_1} \quad (\text{A.20})$$

$$m_{i,2} = \frac{M_i}{C_2 + \left[\left(\frac{p_1}{p_2} \right)^\alpha \frac{A_2}{A_1} \right]^{\frac{1}{\lambda_{\min\{i, N-(i-1)\}_i} \gamma - 1}} C_1} \quad (\text{A.21})$$

and $\left(\frac{p_2}{p_1} \right)^\alpha \frac{A_1}{A_2} > 1$, we have that $m_{i,1} > m_{i,2}$, for every $i \in \{1, 2, \dots, N\}$. Finally, since:

$$S_j = \sum_{i=1}^N m_{ij} \quad (\text{A.22})$$

it immediately follows that $S_1 > S_2$. ■

Theorem A.2: Fat Tails. Given that $A_1 > A_2$, $\lambda_i > 1$, $\lambda_i \gamma < 1$, for every $i \in \{1, 2, \dots, \frac{N}{2}\}$ and $\{\lambda_i\}_{i=1}^{\frac{N}{2}}$ is a decreasing sequence, the skill distribution in the larger city has fatter tails.

Proof:

$$pdf_{11} = \frac{\left[\left(\frac{p_2}{p_1} \right)^\alpha \frac{A_1}{A_2} \right]^{\frac{1}{1-\lambda_1\gamma}} M_1}{C_2 + \left[\left(\frac{p_2}{p_1} \right)^\alpha \frac{A_1}{A_2} \right]^{\frac{1}{1-\lambda_1\gamma}} C_1} \quad (\text{A.23})$$

$$= \frac{1}{\sum_{i=1}^N \frac{M_i}{M_1} \left\{ \left[\left(\frac{p_2}{p_1} \right)^\alpha \frac{A_1}{A_2} \right]^{\frac{(\lambda_{\min\{i, N-(i-1)\}_i - \lambda_1)\gamma}{(1-\lambda_{\min\{i, N-(i-1)\}_i)\gamma} - 1}} \times \right.} \quad (\text{A.24})$$

$$\left. \times \frac{\left[\left(\frac{p_2}{p_1} \right)^\alpha \frac{A_1}{A_2} \right]^{\frac{1}{1-\lambda_1\gamma}} C_1}{C_2 + \left[\left(\frac{p_2}{p_1} \right)^\alpha \frac{A_1}{A_2} \right]^{\frac{1}{1-\lambda_{\min\{i, N-(i-1)\}_i}\gamma} C_1}} \right\}}$$

while:

$$pdf_{12} = \frac{\frac{M_1}{C_2 + \left[\left(\frac{p_2}{p_1}\right)^\alpha \frac{A_1}{A_2}\right]^{\frac{1}{1-\lambda_1\gamma}} C_1}}{\sum_{i=1}^N \frac{\frac{M_i}{C_2 + \left[\left(\frac{p_2}{p_1}\right)^\alpha \frac{A_1}{A_2}\right]^{\frac{1}{1-\lambda_{\min\{i, N-(i-1)\}_i}\gamma}} C_1}}{M_i}} \quad (\text{A.25})$$

$$= \frac{1}{\sum_{i=1}^N \frac{M_i}{M_1} \frac{C_2 + \left[\left(\frac{p_2}{p_1}\right)^\alpha \frac{A_1}{A_2}\right]^{\frac{1}{1-\lambda_1\gamma}} C_1}{C_2 + \left[\left(\frac{p_2}{p_1}\right)^\alpha \frac{A_1}{A_2}\right]^{\frac{1}{1-\lambda_{\min\{i, N-(i-1)\}_i}\gamma}} C_1}} \quad (\text{A.26})$$

But then, since $\lambda_1 = \max\{\lambda_i\}_{i=1}^N$ and $\left(\frac{p_2}{p_1}\right)^\alpha \frac{A_1}{A_2} > 1$, we have that:

$$\sum_{i=1}^N \frac{M_i}{M_1} \left\{ \begin{aligned} & \left[\left(\frac{p_2}{p_1}\right)^\alpha \frac{A_1}{A_2}\right]^{\frac{(\lambda_{\min\{i, N-(i-1)\}_i - \lambda_1)\gamma}{(1-\lambda_{\min\{i, N-(i-1)\}_i)\gamma} (1-\lambda_1\gamma)}} \times \\ & \times \frac{C_2 + \left[\left(\frac{p_2}{p_1}\right)^\alpha \frac{A_1}{A_2}\right]^{\frac{1}{1-\lambda_1\gamma}} C_1}{C_2 + \left[\left(\frac{p_2}{p_1}\right)^\alpha \frac{A_1}{A_2}\right]^{\frac{1}{1-\lambda_{\min\{i, N-(i-1)\}_i}\gamma}} C_1} \end{aligned} \right\} \quad (\text{A.27})$$

$$< \sum_{i=1}^N \frac{M_i}{M_1} \frac{C_2 + \left[\left(\frac{p_2}{p_1}\right)^\alpha \frac{A_1}{A_2}\right]^{\frac{1}{1-\lambda_1\gamma}} C_1}{C_2 + \left[\left(\frac{p_2}{p_1}\right)^\alpha \frac{A_1}{A_2}\right]^{\frac{1}{1-\lambda_{\min\{i, N-(i-1)\}_i}\gamma}} C_1} \quad (\text{A.28})$$

Therefore, $pdf_{11} > pdf_{12}$. Since the distributions are symmetric, we also have $pdf_{N1} > pdf_{N2}$. ■

II. Nested CES and Free Entry of firms

We now consider a technology with gross complementarities β and 3 skill types:

$$Y = A_1 \left[m_{21}^\gamma y_2 + [m_{31}^\gamma y_3 + m_{11}^\gamma y_1]^\lambda \right]^\beta. \quad (\text{A.29})$$

In this model we simultaneously consider the additional extension that firms are perfectly mobile. Firms can relocate instantaneously and at no cost to another city. To establish itself in a city, a firm must buy a amount k of land. Given that firms can freely enter and exit cities, we have that in equilibrium, firms must generate zero profits, i.e.:

$$A_j F(m_{1j}, m_{2j}, m_{3j}) - \sum_i^3 w_{ij} m_{ij} - k p_j = 0, \forall j \in \{1, 2\} \quad (\text{A.30})$$

We will assume that there are only two cities, 1 and 2, while city i has a measure N_i of firms, that will be pin down in equilibrium. Since $w_{i2} = \left(\frac{p_2}{p_1}\right)^\alpha w_{i1}$, the system then becomes:

$$\left\{ \begin{array}{l} A_1 \frac{\left[\frac{[m_{21}^\gamma y_2 + [m_{31}^\gamma y_3 + m_{11}^\gamma y_1]^\lambda]^{\beta-1} \times [m_{31}^\gamma y_3 + m_{11}^\gamma y_1]^{\lambda-1}}{[m_{22}^\gamma y_2 + [m_{32}^\gamma y_3 + m_{12}^\gamma y_1]^\lambda]^{\beta-1} \times [m_{32}^\gamma y_3 + m_{12}^\gamma y_1]^{\lambda-1}} \right]}{m_{11}^{\gamma-1}} = \left(\frac{p_1}{p_2}\right)^\alpha A_2 m_{12}^{\gamma-1} \quad (1) \\ A_1 \frac{[m_{21}^\gamma y_2 + [m_{31}^\gamma y_3 + m_{11}^\gamma y_1]^\lambda]^{\beta-1}}{[m_{22}^\gamma y_2 + [m_{32}^\gamma y_3 + m_{12}^\gamma y_1]^\lambda]^{\beta-1}} m_{21}^{\gamma-1} = \left(\frac{p_1}{p_2}\right)^\alpha A_2 [m_{22}^\gamma y_2 + [m_{32}^\gamma y_3 + m_{12}^\gamma y_1]^\lambda]^{\beta-1} m_{22}^{\gamma-1} \quad (2) \\ A_1 \frac{\left[\frac{[m_{21}^\gamma y_2 + [m_{31}^\gamma y_3 + m_{11}^\gamma y_1]^\lambda]^{\beta-1} \times [m_{31}^\gamma y_3 + m_{11}^\gamma y_1]^{\lambda-1}}{2 [m_{22}^\gamma y_2 + [m_{32}^\gamma y_3 + m_{12}^\gamma y_1]^\lambda]^{\beta-1} \times [m_{32}^\gamma y_3 + m_{12}^\gamma y_1]^{\lambda-1}} \right]}{m_{31}^{\gamma-1}} = \left(\frac{p_1}{p_2}\right)^\alpha A_2 m_{32}^{\gamma-1} \quad (3) \\ N_1 m_{i1} + N_2 m_{i2} = M_i, \forall i \in \{1, 2, 3\} \quad (4, 5, 6) \\ [m_{21}^\gamma y_2 + [m_{31}^\gamma y_3 + m_{11}^\gamma y_1]^\lambda]^{\beta-1} \left\{ \lambda [m_{31}^\gamma y_3 + m_{11}^\gamma y_1]^\lambda + m_{21}^\gamma y_2 \right\} = \left[\frac{H}{N_1} - k \right] \frac{p_1}{\alpha \gamma \beta A_1} \quad (7) \\ [m_{22}^\gamma y_2 + [m_{32}^\gamma y_3 + m_{12}^\gamma y_1]^\lambda]^{\beta-1} \left\{ \lambda [m_{32}^\gamma y_3 + m_{12}^\gamma y_1]^\lambda + m_{22}^\gamma y_2 \right\} = \left[\frac{H}{N_2} - k \right] \frac{p_2}{\alpha \gamma \beta A_2} \quad (8) \\ [m_{21}^\gamma y_2 + [m_{31}^\gamma y_3 + m_{11}^\gamma y_1]^\lambda]^{\beta-1} \left\{ (1 - \lambda \gamma \beta) [m_{31}^\gamma y_3 + m_{11}^\gamma y_1]^\lambda + (1 - \gamma \beta) m_{21}^\gamma y_2 \right\} = \frac{k}{A_1} p_1 \quad (9) \\ [m_{22}^\gamma y_2 + [m_{32}^\gamma y_3 + m_{12}^\gamma y_1]^\lambda]^{\beta-1} \left\{ (1 - \lambda \gamma \beta) [m_{32}^\gamma y_3 + m_{12}^\gamma y_1]^\lambda + (1 - \gamma \beta) m_{22}^\gamma y_2 \right\} = \frac{k}{A_2} p_2 \quad (10) \end{array} \right. \quad (\text{A.31})$$

From eq. (1) and (3), we have:

$$\begin{aligned} \left[\frac{m_{11}}{m_{31}} \right]^{\gamma-1} &= \left[\frac{m_{12}}{m_{32}} \right]^{\gamma-1} \\ \frac{m_{11}}{m_{31}} &= \frac{m_{12}}{m_{32}} \end{aligned}$$

Since:

$$m_{12} = \frac{M_1}{N_2} - \frac{N_1}{N_2} m_{11} \quad (\text{A.32})$$

$$m_{32} = \frac{M_3}{N_2} - \frac{N_1}{N_2} m_{31} \quad (\text{A.33})$$

Substituting it, we have:

$$\frac{m_{11}}{m_{31}} = \frac{M_1 - N_1 m_{11}}{M_3 - N_1 m_{31}} \quad (\text{A.34})$$

Rearranging:

$$m_{11} = \frac{M_1}{M_3} m_{31} \quad (\text{A.35})$$

Considering a symmetric distribution (so $M_1 = M_3$), we have that $m_{11} = m_{31}$. Similarly $m_{12} = m_{32} = \frac{M_1}{N_2} - \frac{N_1}{N_2} m_{11}$.

From (1) and (2), we have:

$$\frac{[m_{31}^\gamma y_3 + m_{11}^\gamma y_1]^{\lambda-1} m_{11}^{\gamma-1}}{m_{21}^{\gamma-1}} = \frac{[m_{32}^\gamma y_3 + m_{12}^\gamma y_1]^{\lambda-1} m_{12}^{\gamma-1}}{m_{22}^{\gamma-1}} \quad (\text{A.36})$$

Using the symmetry of the distribution and consequentially that $m_{11} = m_{31}$ and $m_{12} = m_{32}$, we have:

$$m_{11}^{\gamma(\lambda-1)} \left(\frac{m_{11}}{m_{21}} \right)^{\gamma-1} = m_{12}^{\gamma(\lambda-1)} \left(\frac{m_{12}}{m_{22}} \right)^{\gamma-1} \quad (\text{A.37})$$

Then:

$$m_{21} = \left(\frac{m_{11}}{m_{12}} \right)^{\frac{\lambda\gamma-1}{\gamma-1}} m_{22} \quad (\text{A.38})$$

Then, from (7) and (9), we have:

$$\frac{\left\{ \lambda [m_{31}^\gamma y_3 + m_{11}^\gamma y_1]^\lambda + m_{21}^\gamma y_2 \right\}}{\left\{ (1 - \lambda\gamma\beta) [m_{31}^\gamma y_3 + m_{11}^\gamma y_1]^\lambda + (1 - \gamma\beta) m_{21}^\gamma y_2 \right\}} = \frac{\left[\frac{H}{N_1} - k \right]}{k\alpha\gamma\beta} \quad (\text{A.39})$$

Using symmetry and again that $m_{11} = m_{31}$, we have:

$$m_{21}^\gamma y_2 = \frac{\left\{ (1 - \lambda\gamma\beta) \left[\frac{H}{N_1 k\alpha\gamma\beta} - \frac{k}{k\alpha\gamma\beta} \right] - \lambda \right\}}{\left\{ 1 - (1 - \gamma\beta) \left[\frac{H}{N_1 k\alpha\gamma\beta} - \frac{k}{k\alpha\gamma\beta} \right] \right\}} m_{11}^{\lambda\gamma} [y_3 + y_1]^\lambda \quad (\text{A.40})$$

Similarly, from (8) and (10), we have:

$$\frac{\left\{ \lambda [m_{32}^\gamma y_3 + m_{12}^\gamma y_1]^\lambda + m_{22}^\gamma y_2 \right\}}{\left\{ (1 - \lambda\gamma\beta) [m_{32}^\gamma y_3 + m_{12}^\gamma y_1]^\lambda + (1 - \gamma\beta) m_{22}^\gamma y_2 \right\}} = \frac{\left[\frac{H}{N_2} - k \right]}{k\alpha\gamma\beta} \quad (\text{A.41})$$

Using symmetry and again that $m_{12} = m_{32}$, we have:

$$m_{22}^\gamma y_2 = \frac{\left\{ (1 - \lambda\gamma\beta) \left[\frac{H}{N_2 k\alpha\gamma\beta} - \frac{k}{k\alpha\gamma\beta} \right] - \lambda \right\}}{\left\{ 1 - (1 - \gamma\beta) \left[\frac{H}{N_2 k\alpha\gamma\beta} - \frac{k}{k\alpha\gamma\beta} \right] \right\}} m_{12}^{\lambda\gamma} [y_3 + y_1]^\lambda \quad (\text{A.42})$$

Then, from equaiton (1), we have - again using symmetry:

$$\left[m_{21}^\gamma y_2 + m_{11}^{\lambda\gamma} [y_3 + y_1]^\lambda \right]^{\beta-1} m_{11}^{\lambda\gamma-1} = \left(\frac{p_1}{p_2} \right)^\alpha \frac{A_2}{A_1} \left[m_{22}^\gamma y_2 + m_{12}^{\lambda\gamma} [y_3 + y_1]^\lambda \right]^{\beta-1} m_{12}^{\lambda\gamma-1} \quad (\text{A.43})$$

Substituting $m_{21}^\gamma y_2$ and $m_{22}^\gamma y_2$, we have:

$$\begin{aligned} & \left[\frac{\beta\gamma(\lambda-1)[(1-\alpha)kN_1 - H]}{[1 - (1-\alpha)\beta\gamma]kN_1 - (1-\beta\gamma)H} \right]^{\beta-1} m_{11}^{\lambda\gamma\beta-1} = \\ & = \left(\frac{p_1}{p_2} \right)^\alpha \frac{A_2}{A_1} \left[\frac{\beta\gamma(\lambda-1)[(1-\alpha)kN_2 - H]}{[1 - (1-\alpha)\beta\gamma]kN_2 - (1-\beta\gamma)H} \right]^{\beta-1} m_{12}^{\lambda\gamma\beta-1} \end{aligned}$$

Assuming $\lambda \neq 1$, we have:

$$\left(\frac{m_{11}}{m_{12}} \right) = \left\{ \left(\frac{p_1}{p_2} \right)^\alpha \frac{A_2}{A_1} \left[\frac{[1-(1-\alpha)\beta\gamma]kN_1 - (1-\beta\gamma)H}{[1-(1-\alpha)\beta\gamma]kN_2 - (1-\beta\gamma)H} \times \frac{(1-\alpha)kN_2 - H}{(1-\alpha)kN_1 - H} \right]^{\beta-1} \right\}^{\frac{1}{\lambda\gamma\beta-1}} \quad (\text{A.44})$$

Substituting $m_{12} = \frac{M_1}{N_2} - \frac{N_1}{N_2} m_{11}$, we have:

$$m_{11} = \frac{\left\{ \left(\frac{p_1}{p_2} \right)^\alpha \frac{A_2}{A_1} \left[\frac{[1-(1-\alpha)\beta\gamma]kN_1 - (1-\beta\gamma)H}{[1-(1-\alpha)\beta\gamma]kN_2 - (1-\beta\gamma)H} \times \frac{(1-\alpha)kN_2 - H}{(1-\alpha)kN_1 - H} \right]^{\beta-1} \right\}^{\frac{1}{\lambda\gamma\beta-1}}}{\left[N_2 + N_1 \left\{ \left(\frac{p_1}{p_2} \right)^\alpha \frac{A_2}{A_1} \left[\frac{[1-(1-\alpha)\beta\gamma]kN_1 - (1-\beta\gamma)H}{[1-(1-\alpha)\beta\gamma]kN_2 - (1-\beta\gamma)H} \times \frac{(1-\alpha)kN_2 - H}{(1-\alpha)kN_1 - H} \right]^{\beta-1} \right\}^{\frac{1}{\lambda\gamma\beta-1}} \right]} M_1 \quad (\text{A.45})$$

Since the distribution is symmetric, we have:

$$m_{31} = \frac{\left\{ \left(\frac{p_1}{p_2} \right)^\alpha \frac{A_2}{A_1} \left[\frac{[1-(1-\alpha)\beta\gamma]kN_1-(1-\beta\gamma)H}{[1-(1-\alpha)\beta\gamma]kN_2-(1-\beta\gamma)H} \times \frac{(1-\alpha)kN_2-H}{(1-\alpha)kN_1-H} \right]^{\beta-1} \right\}^{\frac{1}{\lambda\gamma\beta-1}}}{\left[N_2 + N_1 \left\{ \left(\frac{p_1}{p_2} \right)^\alpha \frac{A_2}{A_1} \left[\frac{[1-(1-\alpha)\beta\gamma]kN_1-(1-\beta\gamma)H}{[1-(1-\alpha)\beta\gamma]kN_2-(1-\beta\gamma)H} \times \frac{(1-\alpha)kN_2-H}{(1-\alpha)kN_1-H} \right]^{\beta-1} \right\}^{\frac{1}{\lambda\gamma\beta-1}} \right]} M_3 \quad (\text{A.46})$$

Finally, from our expression for $m_{21}^\gamma y_2$, we have:

$$m_{21}^\gamma y_2 = \frac{\left\{ \frac{(1-\lambda\gamma\beta)[H-N_1k]-\lambda N_1 k \alpha \gamma \beta}{N_1 k \alpha \gamma \beta} \right\}}{\left\{ \frac{N_1 k \alpha \gamma \beta - (1-\gamma\beta)[H-N_1k]}{N_1 k \alpha \gamma \beta} \right\}} m_{11}^{\lambda\gamma} [y_3 + y_1]^\lambda \quad (\text{A.47})$$

Rearranging it, we have:

$$m_{21} = \left[\frac{H(1-\beta\lambda\gamma) - [1-(1-\alpha)\beta\lambda\gamma]kN_1}{[1-(1-\alpha)\beta\gamma]kN_1 - (1-\beta\gamma)H} \right]^{\frac{1}{\gamma}} m_{11}^\lambda \left(\frac{[y_3 + y_1]^\lambda}{y_2} \right)^{\frac{1}{\gamma}} \quad (\text{A.48})$$

Substituting m_{11} , we have:

$$m_{21} = \left\{ \frac{\left[\frac{H(1-\beta\lambda\gamma) - [1-(1-\alpha)\beta\lambda\gamma]kN_1}{[1-(1-\alpha)\beta\gamma]kN_1 - (1-\beta\gamma)H} \right]^{\frac{1}{\gamma}} \left(\frac{[y_3 + y_1]^\lambda}{y_2} \right)^{\frac{1}{\gamma}} \times \left\{ \left(\frac{p_1}{p_2} \right)^\alpha \frac{A_2}{A_1} \left[\frac{[1-(1-\alpha)\beta\gamma]kN_1-(1-\beta\gamma)H}{[1-(1-\alpha)\beta\gamma]kN_2-(1-\beta\gamma)H} \times \frac{(1-\alpha)kN_2-H}{(1-\alpha)kN_1-H} \right]^{\beta-1} \right\}^{\frac{1}{\lambda\gamma\beta-1}}}{\left[N_2 + N_1 \left\{ \left(\frac{p_1}{p_2} \right)^\alpha \frac{A_2}{A_1} \left[\frac{[1-(1-\alpha)\beta\gamma]kN_1-(1-\beta\gamma)H}{[1-(1-\alpha)\beta\gamma]kN_2-(1-\beta\gamma)H} \times \frac{(1-\alpha)kN_2-H}{(1-\alpha)kN_1-H} \right]^{\beta-1} \right\}^{\frac{1}{\lambda\gamma\beta-1}} \right]^\lambda} (M_1)^\lambda \right\}} \quad (\text{A.49})$$

Then, also notice that:

$$m_{12} = \frac{M_1}{N_2 + N_1 \left\{ \left(\frac{p_1}{p_2} \right)^\alpha \frac{A_2}{A_1} \left[\frac{[1-(1-\alpha)\beta\gamma]kN_1-(1-\beta\gamma)H}{[1-(1-\alpha)\beta\gamma]kN_2-(1-\beta\gamma)H} \times \frac{(1-\alpha)kN_2-H}{(1-\alpha)kN_1-H} \right]^{\beta-1} \right\}^{\frac{1}{\lambda\gamma\beta-1}}} \quad (\text{A.50})$$

and:

$$m_{32} = \frac{M_3}{\left[N_2 + N_1 \left\{ \left(\frac{p_1}{p_2} \right)^\alpha \frac{A_2}{A_1} \left[\frac{[1-(1-\alpha)\beta\gamma]kN_1-(1-\beta\gamma)H}{[1-(1-\alpha)\beta\gamma]kN_2-(1-\beta\gamma)H} \times \frac{(1-\alpha)kN_2-H}{(1-\alpha)kN_1-H} \right]^{\beta-1} \right\}^{\frac{1}{\lambda\gamma\beta-1}} \right]} \quad (\text{A.51})$$

and

$$m_{22} = \left\{ \frac{\left[\frac{H(1-\beta\lambda\gamma) - [1-(1-\alpha)\beta\lambda\gamma]kN_2}{[1-(1-\alpha)\beta\gamma]kN_2 - (1-\beta\gamma)H} \right]^{\frac{1}{\gamma}} \left(\frac{[y_3 + y_1]^\lambda}{y_2} \right)^{\frac{1}{\gamma}} \times \left(\frac{M_1}{N_2 + N_1 \left\{ \left(\frac{p_1}{p_2} \right)^\alpha \frac{A_2}{A_1} \left[\frac{[1-(1-\alpha)\beta\gamma]kN_1-(1-\beta\gamma)H}{[1-(1-\alpha)\beta\gamma]kN_2-(1-\beta\gamma)H} \times \frac{(1-\alpha)kN_2-H}{(1-\alpha)kN_1-H} \right]^{\beta-1} \right\}^{\frac{1}{\lambda\gamma\beta-1}}} \right)^\lambda}{\left(\frac{M_1}{N_2 + N_1 \left\{ \left(\frac{p_1}{p_2} \right)^\alpha \frac{A_2}{A_1} \left[\frac{[1-(1-\alpha)\beta\gamma]kN_1-(1-\beta\gamma)H}{[1-(1-\alpha)\beta\gamma]kN_2-(1-\beta\gamma)H} \times \frac{(1-\alpha)kN_2-H}{(1-\alpha)kN_1-H} \right]^{\beta-1} \right\}^{\frac{1}{\lambda\gamma\beta-1}}} \right)^\lambda} \right\}} \quad (\text{A.52})$$

Proposition A. 1 *If $\lambda > 1$, $\lambda\gamma < 1$, and $\lambda\gamma\beta < 1$, there is no equilibrium in which $A_2 > A_1$, and $m_{i1} \geq m_{i2}$.*

Assume $A_2 > A_1$. Before we continue, we prove the following Lemma:

Lemma A. 1 *If $m_{11} > m_{12}$, then $p_1 > p_2$, $N_2 > N_1$, and $m_{21} > m_{22}$*

Proof. Going back to the system, we have:

$$\begin{cases}
 A_1 \left[\frac{\left[m_{21}^\gamma y_2 + [m_{31}^\gamma y_3 + m_{11}^\gamma y_1]^\lambda \right]^{\beta-1} \times [m_{31}^\gamma y_3 + m_{11}^\gamma y_1]^{\lambda-\Gamma}}{\left[m_{22}^\gamma y_2 + [m_{32}^\gamma y_3 + m_{12}^\gamma y_1]^\lambda \right]^{\beta-1} \times [m_{32}^\gamma y_3 + m_{12}^\gamma y_1]^{\lambda-\Gamma}} \right] m_{11}^{\gamma-1} = \left(\frac{p_1}{p_2} \right)^\alpha A_2 m_{12}^{\gamma-1} & (1') \\
 A_1 \left[\frac{\left[m_{21}^\gamma y_2 + [m_{31}^\gamma y_3 + m_{11}^\gamma y_1]^\lambda \right]^{\beta-1}}{\left[m_{22}^\gamma y_2 + [m_{32}^\gamma y_3 + m_{12}^\gamma y_1]^\lambda \right]^{\beta-1}} \right] m_{21}^{\gamma-1} = \left(\frac{p_1}{p_2} \right)^\alpha A_2 \left[m_{22}^\gamma y_2 + [m_{32}^\gamma y_3 + m_{12}^\gamma y_1]^\lambda \right]^{\beta-1} m_{22}^{\gamma-1} & (2') \\
 A_1 \left[\frac{\left[m_{21}^\gamma y_2 + [m_{31}^\gamma y_3 + m_{11}^\gamma y_1]^\lambda \right]^{\beta-1} \times [m_{31}^\gamma y_3 + m_{11}^\gamma y_1]^{\lambda-\Gamma}}{\left[m_{22}^\gamma y_2 + [m_{32}^\gamma y_3 + m_{12}^\gamma y_1]^\lambda \right]^{\beta-1} \times [m_{32}^\gamma y_3 + m_{12}^\gamma y_1]^{\lambda-\Gamma}} \right] m_{31}^{\gamma-1} = \left(\frac{p_1}{p_2} \right)^\alpha A_2 m_{32}^{\gamma-1} & (3') \\
 N_1 m_{i1} + N_2 m_{i2} = M_i, \forall i \in \{1, 2, 3\} & (4', 5', 6') \\
 \left[m_{21}^\gamma y_2 + [m_{31}^\gamma y_3 + m_{11}^\gamma y_1]^\lambda \right]^{\beta-1} \left\{ \lambda [m_{31}^\gamma y_3 + m_{11}^\gamma y_1]^\lambda + m_{21}^\gamma y_2 \right\} = \left[\frac{H}{N_1} - k \right] \frac{p_1}{\alpha \gamma \beta A_1} & (7') \\
 \left[m_{22}^\gamma y_2 + [m_{32}^\gamma y_3 + m_{12}^\gamma y_1]^\lambda \right]^{\beta-1} \left\{ \lambda [m_{32}^\gamma y_3 + m_{12}^\gamma y_1]^\lambda + m_{22}^\gamma y_2 \right\} = \left[\frac{H}{N_2} - k \right] \frac{p_2}{\alpha \gamma \beta A_2} & (8') \\
 \left[m_{21}^\gamma y_2 + [m_{31}^\gamma y_3 + m_{11}^\gamma y_1]^\lambda \right]^{\beta-1} \left\{ (1 - \lambda \gamma \beta) [m_{31}^\gamma y_3 + m_{11}^\gamma y_1]^\lambda + (1 - \gamma \beta) m_{21}^\gamma y_2 \right\} = \frac{k}{A_1} p_1 & (9') \\
 \left[m_{22}^\gamma y_2 + [m_{32}^\gamma y_3 + m_{12}^\gamma y_1]^\lambda \right]^{\beta-1} \left\{ (1 - \lambda \gamma \beta) [m_{32}^\gamma y_3 + m_{12}^\gamma y_1]^\lambda + (1 - \gamma \beta) m_{22}^\gamma y_2 \right\} = \frac{k}{A_2} p_2 & (10')
 \end{cases} \quad (A.53)$$

From the last two equations, we have:

$$\begin{aligned}
 & \left[\frac{\left[m_{21}^\gamma y_2 + [m_{31}^\gamma y_3 + m_{11}^\gamma y_1]^\lambda \right]^{\beta-1} \times \left\{ (1 - \lambda \gamma \beta) [m_{31}^\gamma y_3 + m_{11}^\gamma y_1]^\lambda + (1 - \gamma \beta) m_{21}^\gamma y_2 \right\}}{\left[m_{22}^\gamma y_2 + [m_{32}^\gamma y_3 + m_{12}^\gamma y_1]^\lambda \right]^{\beta-1} \times \left\{ (1 - \lambda \gamma \beta) [m_{32}^\gamma y_3 + m_{12}^\gamma y_1]^\lambda + (1 - \gamma \beta) m_{22}^\gamma y_2 \right\}} \right] \frac{p_2}{p_1} \frac{A_1}{A_2} = \frac{k}{A_2} p_2 \\
 & \left[\frac{\left[m_{21}^\gamma y_2 + [m_{31}^\gamma y_3 + m_{11}^\gamma y_1]^\lambda \right]^{\beta-1} \times \left\{ (1 - \lambda \gamma \beta) [m_{31}^\gamma y_3 + m_{11}^\gamma y_1]^\lambda + (1 - \gamma \beta) m_{21}^\gamma y_2 \right\}}{\left[m_{22}^\gamma y_2 + [m_{32}^\gamma y_3 + m_{12}^\gamma y_1]^\lambda \right]^{\beta-1} \times \left\{ (1 - \lambda \gamma \beta) [m_{32}^\gamma y_3 + m_{12}^\gamma y_1]^\lambda + (1 - \gamma \beta) m_{22}^\gamma y_2 \right\}} \right] = \frac{k}{A_2} p_2
 \end{aligned} \quad (A.54)$$

Equating this two expressions, we have:

$$\left[\begin{aligned} & \left[\frac{\left[m_{21}^\gamma y_2 + [m_{31}^\gamma y_3 + m_{11}^\gamma y_1]^\lambda \right]^{\beta-1} \times \left\{ (1 - \lambda \gamma \beta) [m_{31}^\gamma y_3 + m_{11}^\gamma y_1]^\lambda + (1 - \gamma \beta) m_{21}^\gamma y_2 \right\}}{\left[m_{22}^\gamma y_2 + [m_{32}^\gamma y_3 + m_{12}^\gamma y_1]^\lambda \right]^{\beta-1} \times \left\{ (1 - \lambda \gamma \beta) [m_{32}^\gamma y_3 + m_{12}^\gamma y_1]^\lambda + (1 - \gamma \beta) m_{22}^\gamma y_2 \right\}} \right] \frac{p_2}{p_1} \frac{A_1}{A_2} \\ & - \left[\frac{\left[m_{21}^\gamma y_2 + [m_{31}^\gamma y_3 + m_{11}^\gamma y_1]^\lambda \right]^{\beta-1} \times \left\{ (1 - \lambda \gamma \beta) [m_{31}^\gamma y_3 + m_{11}^\gamma y_1]^\lambda + (1 - \gamma \beta) m_{21}^\gamma y_2 \right\}}{\left[m_{22}^\gamma y_2 + [m_{32}^\gamma y_3 + m_{12}^\gamma y_1]^\lambda \right]^{\beta-1} \times \left\{ (1 - \lambda \gamma \beta) [m_{32}^\gamma y_3 + m_{12}^\gamma y_1]^\lambda + (1 - \gamma \beta) m_{22}^\gamma y_2 \right\}} \right] \end{aligned} \right] = 0 \quad (A.55)$$

since $M_1 = M_3$, we have that $m_{31} = m_{11}$ and $m_{32} = m_{12}$. Based on these results, we have:

$$\left[\begin{aligned} & \left[m_{21}^\gamma y_2 + m_{11}^{\lambda \gamma} [y_3 + y_1]^\lambda \right]^{\beta-1} \left\{ (1 - \lambda \gamma \beta) m_{11}^{\lambda \gamma} [y_3 + y_1]^\lambda + (1 - \gamma \beta) m_{21}^\gamma y_2 \right\} \frac{p_2}{p_1} \frac{A_1}{A_2} \\ & - \left[m_{22}^\gamma y_2 + m_{12}^{\lambda \gamma} [y_3 + y_1]^\lambda \right]^{\beta-1} \left\{ (1 - \lambda \gamma \beta) m_{12}^{\lambda \gamma} [y_3 + y_1]^\lambda + (1 - \gamma \beta) m_{22}^\gamma y_2 \right\} \end{aligned} \right] = 0 \quad (A.56)$$

Then, from equation (1), we have - again using symmetry:

$$\left[m_{21}^\gamma y_2 + m_{11}^{\lambda \gamma} [y_3 + y_1]^\lambda \right]^{\beta-1} = \left(\frac{p_1}{p_2} \right)^\alpha \frac{A_2}{A_1} \left[m_{22}^\gamma y_2 + m_{12}^{\lambda \gamma} [y_3 + y_1]^\lambda \right]^{\beta-1} \frac{m_{12}^{\lambda \gamma-1}}{m_{11}^{\lambda \gamma-1}} \quad (A.57)$$

Substituting it back, we have:

$$\left[m_{22}^\gamma y_2 + m_{12}^{\lambda \gamma} [y_3 + y_1]^\lambda \right]^{\beta-1} \left[\begin{aligned} & (1 - \lambda \gamma \beta) [y_3 + y_1]^\lambda \left[\left(\frac{p_2}{p_1} \right)^{1-\alpha} m_{11} - m_{12} \right] m_{12}^{\lambda \gamma-1} \\ & + (1 - \gamma \beta) y_2 \left[\left(\frac{p_2}{p_1} \right)^{1-\alpha} \left(\frac{m_{12}}{m_{11}} \right)^{\lambda \gamma-1} m_{21}^\gamma - m_{22}^\gamma \right] \end{aligned} \right] = 0 \quad (\star) \quad (A.58)$$

Since:

$$\begin{aligned} \left(\frac{m_{11}}{m_{12}} \right)^{\lambda\gamma-1} &= \left(\frac{m_{21}}{m_{22}} \right)^{\gamma-1} \\ &\Downarrow \\ \left(\frac{m_{12}}{m_{11}} \right)^{\lambda\gamma-1} &= \left(\frac{m_{22}}{m_{21}} \right)^{\gamma-1} \end{aligned}$$

we have:

$$\left[m_{22}^{\gamma} y_2 + m_{12}^{\lambda\gamma} [y_3 + y_1]^{\lambda} \right]^{\beta-1} \left\{ \begin{aligned} &(1 - \lambda\gamma\beta) [y_3 + y_1]^{\lambda} \left[\left(\frac{p_2}{p_1} \right)^{1-\alpha} \frac{m_{11}}{m_{12}} - 1 \right] m_{12}^{\lambda\gamma} \\ &+ (1 - \gamma\beta) y_2 \left[\left(\frac{p_2}{p_1} \right)^{1-\alpha} \frac{m_{21}}{m_{22}} - 1 \right] m_{22}^{\gamma} \end{aligned} \right\} = 0 \quad (\text{A.59})$$

Since:

$$\frac{m_{21}}{m_{22}} = \left(\frac{m_{11}}{m_{12}} \right)^{\frac{\lambda\gamma-1}{\gamma-1}} \quad (\text{A.60})$$

we have:

$$\left[m_{22}^{\gamma} y_2 + m_{12}^{\lambda\gamma} [y_3 + y_1]^{\lambda} \right]^{\beta-1} \left\{ \begin{aligned} &(1 - \lambda\gamma\beta) [y_3 + y_1]^{\lambda} \left[\left(\frac{p_2}{p_1} \right)^{1-\alpha} \frac{m_{11}}{m_{12}} - 1 \right] m_{12}^{\lambda\gamma} \\ &(1 - \gamma\beta) y_2 \left[\left(\frac{p_2}{p_1} \right)^{1-\alpha} \left(\frac{m_{11}}{m_{12}} \right)^{\frac{\lambda\gamma-1}{\gamma-1}} - 1 \right] m_{22}^{\gamma} \end{aligned} \right\} = 0 \quad (\text{A.61})$$

Assuming that $\lambda\gamma\beta < 1$, we have that the only terms that can be negative are the ones inside the squared brackets inside the curly brackets.

Since $\frac{\lambda\gamma-1}{\gamma-1} \in (0, 1)$:

$$\begin{aligned} &\left[\left(\frac{p_2}{p_1} \right)^{1-\alpha} \frac{m_{11}}{m_{12}} - 1 \right] - \left[\left(\frac{p_2}{p_1} \right)^{1-\alpha} \left(\frac{m_{11}}{m_{12}} \right)^{\frac{\lambda\gamma-1}{\gamma-1}} - 1 \right] = \\ &= \left(\frac{p_2}{p_1} \right)^{1-\alpha} \frac{m_{11}}{m_{12}} \left[1 - \left(\frac{m_{12}}{m_{11}} \right)^{\frac{\gamma(\lambda-1)}{1-\gamma}} \right] \end{aligned}$$

Since $\frac{\gamma(\lambda-1)}{1-\gamma} \in (0, 1)$, the sign will depend on $\frac{m_{12}}{m_{11}}$. Since

$$\frac{m_{12}}{m_{11}} < 1 \Rightarrow \left[\left(\frac{p_2}{p_1} \right)^{1-\alpha} \frac{m_{11}}{m_{12}} - 1 \right] > \left[\left(\frac{p_2}{p_1} \right)^{1-\alpha} \left(\frac{m_{11}}{m_{12}} \right)^{\frac{\lambda\gamma-1}{\gamma-1}} - 1 \right].$$

In order to keep the equality, we must have:

$$\begin{aligned} &\left(\frac{p_2}{p_1} \right)^{1-\alpha} \frac{m_{11}}{m_{12}} - 1 > 0 \\ &\frac{m_{11}}{m_{12}} > \left(\frac{p_1}{p_2} \right)^{1-\alpha} \end{aligned}$$

and

$$\begin{aligned} &\left(\frac{p_2}{p_1} \right)^{1-\alpha} \left(\frac{m_{11}}{m_{12}} \right)^{\frac{\lambda\gamma-1}{\gamma-1}} - 1 < 0 \\ &\left(\frac{m_{11}}{m_{12}} \right)^{\frac{1-\lambda\gamma}{1-\gamma}} < \left(\frac{p_1}{p_2} \right)^{1-\alpha} \end{aligned}$$

since $\frac{1-\lambda\gamma}{1-\gamma} \in (0, 1)$ and $\alpha \in (0, 1)$, we have that:

$$\left(\frac{p_1}{p_2} \right)^{1-\alpha} \in \left(\left(\frac{m_{11}}{m_{12}} \right)^{\frac{1-\lambda\gamma}{1-\gamma}}, \frac{m_{11}}{m_{12}} \right) \quad (\text{A.62})$$

since $\frac{m_{11}}{m_{12}} > 1$, we have that $p_1 > p_2$.

We also showed earlier that:

$$\frac{m_{21}}{m_{22}} = \left(\frac{m_{11}}{m_{12}} \right)^{\frac{1-\lambda\gamma}{1-\gamma}} \quad (\text{A.63})$$

since $\frac{m_{11}}{m_{12}} > 1$, we have that $m_{21} > m_{22}$.

Finally, from equations (7') and (8'), we have:

$$\begin{aligned} N_1 &= \frac{H}{\left\{ \frac{\alpha\gamma\beta A_1}{p_1} [m_{21}^\gamma y_2 + [m_{31}^\gamma y_3 + m_{11}^\gamma y_1]^\lambda]^{\beta-1} \left\{ \lambda [m_{31}^\gamma y_3 + m_{11}^\gamma y_1]^\lambda + m_{21}^\gamma y_2 \right\} + k \right\}} \\ N_2 &= \frac{H}{\left\{ \frac{\alpha\gamma\beta A_2}{p_2} [m_{22}^\gamma y_2 + [m_{32}^\gamma y_3 + m_{12}^\gamma y_1]^\lambda]^{\beta-1} \left\{ \lambda [m_{32}^\gamma y_3 + m_{12}^\gamma y_1]^\lambda + m_{22}^\gamma y_2 \right\} + k \right\}} \end{aligned} \quad (\text{A.64})$$

Since, from (9') and (10'):

$$\begin{aligned} \frac{A_1}{p_1} &= \frac{k}{\left[\left[m_{21}^\gamma y_2 + [m_{31}^\gamma y_3 + m_{11}^\gamma y_1]^\lambda \right]^{\beta-1} \times \right.} \\ &\quad \left. \times \left\{ (1-\beta\gamma) m_{21}^\gamma y_2 + (1-\lambda\gamma\beta) [m_{31}^\gamma y_3 + m_{11}^\gamma y_1]^\lambda \right\} \right] \\ \frac{A_2}{p_2} &= \frac{k}{\left[\left[m_{22}^\gamma y_2 + [m_{32}^\gamma y_3 + m_{12}^\gamma y_1]^\lambda \right]^{\beta-1} \times \right.} \\ &\quad \left. \times \left\{ (1-\beta\gamma) m_{22}^\gamma y_2 + (1-\lambda\gamma\beta) [m_{32}^\gamma y_3 + m_{12}^\gamma y_1]^\lambda \right\} \right] \end{aligned}$$

Substituting it back, we have:

$$N_1 = \frac{H}{k} \frac{(1-\beta\gamma) m_{21}^\gamma y_2 + (1-\lambda\gamma\beta) m_{11}^{\lambda\gamma} [y_3 + y_1]^\lambda}{[1 - (1-\alpha)\beta\gamma] m_{21}^\gamma y_2 + [1 - (1-\alpha)\lambda\gamma\beta] m_{11}^{\lambda\gamma} [y_3 + y_1]^\lambda} \quad (\text{A.65})$$

and

$$N_2 = \frac{H}{k} \frac{(1-\beta\gamma) m_{22}^\gamma y_2 + (1-\lambda\gamma\beta) m_{12}^{\lambda\gamma} [y_3 + y_1]^\lambda}{[1 - (1-\alpha)\beta\gamma] m_{22}^\gamma y_2 + [1 - (1-\alpha)\lambda\gamma\beta] m_{12}^{\lambda\gamma} [y_3 + y_1]^\lambda} \quad (\text{A.66})$$

Then:

$$\frac{N_1}{N_2} = 1 + \frac{\alpha\beta\gamma y_2 [y_3 + y_1]^\lambda (\lambda - 1) \left[\left(\frac{m_{12}}{m_{11}} \right)^{\frac{(\lambda-1)\gamma}{1-\gamma}} - 1 \right] m_{22}^\gamma m_{11}^{\lambda\gamma}}{\left[\begin{aligned} &[1 - (1-\alpha)\beta\gamma] (1-\beta\gamma) (y_2)^2 m_{22}^\gamma m_{21}^\gamma \\ &+ [1 - (1-\alpha)\beta\gamma] (1-\lambda\gamma\beta) y_2 [y_3 + y_1]^\lambda m_{21}^\gamma m_{12}^{\lambda\gamma} \\ &+ [1 - (1-\alpha)\lambda\gamma\beta] (1-\beta\gamma) [y_3 + y_1]^\lambda y_2 m_{22}^\gamma m_{11}^{\lambda\gamma} \\ &+ [1 - (1-\alpha)\lambda\gamma\beta] (1-\lambda\gamma\beta) [y_3 + y_1]^{2\lambda} m_{11}^{\lambda\gamma} m_{12}^{\lambda\gamma} \end{aligned} \right]} \quad (\star\star) \quad (\text{A.67})$$

Since $\frac{m_{12}}{m_{11}} < 1$, we have that $\frac{N_1}{N_2} < 1 \Rightarrow N_1 < N_2$.

Then, back in the system, rearranging it, we have:

$$\left\{ \left[\left(\frac{M_1}{N_2 + N_1 \left\{ \left(\frac{p_1}{p_2} \right)^\alpha \frac{A_2}{A_1} Z^{\beta-1} \right\}^{\frac{1}{\lambda\gamma\beta-1}}} \right)^\lambda \left(\frac{[y_3 + y_1]^\lambda}{y_2} \right)^{\frac{1}{\gamma}} \times \right. \right. \right. \quad (1'') \\
 \left. \times \left[N_1 \left\{ \left[\frac{H(1-\beta\lambda\gamma) - [1-(1-\alpha)\beta\lambda\gamma]kN_1}{[1-(1-\alpha)\beta\gamma]kN_1 - (1-\beta\gamma)H} \right]^{\frac{1}{\gamma}} \times \right. \right. \right. \quad (2'') \\
 \left. \left. \left. \times \left\{ \left(\frac{p_1}{p_2} \right)^\alpha \frac{A_2}{A_1} Z^{\beta-1} \right\}^{\frac{\lambda}{\lambda\gamma\beta-1}} \right\} \right] \right. \right. \quad (3'') \\
 \left. \left. \left. + N_2 \left[\frac{H(1-\beta\lambda\gamma) - [1-(1-\alpha)\beta\lambda\gamma]kN_2}{[1-(1-\alpha)\beta\gamma]kN_2 - (1-\beta\gamma)H} \right]^{\frac{1}{\gamma}} \right] \right] \right\} = M_2 \quad (A.68) \\
 \left\{ \left[\left\{ \left(\frac{p_1}{p_2} \right)^\alpha \frac{A_2}{A_1} Z^{\beta-1} \right\}^{\frac{\lambda-1}{1-\lambda\gamma\beta}} \times \right. \right. \quad (4'') \\
 \left. \left. \times Z^{\frac{\gamma-1}{\gamma}} \right] \right] = 1 \quad (2'') \\
 \left[\left[\frac{[H-(1-\alpha)kN_1]\beta\gamma(\lambda-1)}{H(1-\beta\gamma) - [1-(1-\alpha)\beta\gamma]kN_1} \right]^{\beta-1} \left[\frac{(\lambda-1)}{H(1-\beta\gamma) - [1-(1-\alpha)\beta\gamma]kN_1} \right] \times \right. \quad (3'') \\
 \left. \times \left(\frac{\left\{ \left(\frac{p_1}{p_2} \right)^\alpha \frac{A_2}{A_1} Z^{\beta-1} \right\}^{\frac{1}{\lambda\gamma\beta-1}}}{\left[N_2 + N_1 \left\{ \left(\frac{p_1}{p_2} \right)^\alpha \frac{A_2}{A_1} Z^{\beta-1} \right\}^{\frac{1}{\lambda\gamma\beta-1}} \right] M_1} \right) [y_3 + y_1]^{\lambda\beta} \right] = \frac{1}{N_1} \frac{p_1}{\alpha\gamma\beta A_1} \quad (3'') \\
 \left(\left[\frac{(\lambda-1)}{H(1-\beta\gamma) - [1-(1-\alpha)\beta\gamma]kN_2} \right] \left[\frac{[H-(1-\alpha)kN_2]\beta\gamma(\lambda-1)}{H(1-\beta\gamma) - [1-(1-\alpha)\beta\gamma]kN_2} \right]^{\beta-1} \times \right. \quad (4'') \\
 \left. \times \left(\frac{M_1}{N_2 + N_1 \left\{ \left(\frac{p_1}{p_2} \right)^\alpha \frac{A_2}{A_1} Z^{\beta-1} \right\}^{\frac{1}{\lambda\gamma\beta-1}}} \right)^\lambda [y_3 + y_1]^{\lambda\beta} \right) = \frac{1}{N_2} \frac{p_2}{\alpha\gamma\beta A_2} \quad (4'')$$

where $Z = \frac{[1-(1-\alpha)\beta\gamma]kN_1 - (1-\beta\gamma)H}{[1-(1-\alpha)\beta\gamma]kN_2 - (1-\beta\gamma)H} \times \frac{(1-\alpha)kN_2 - H}{(1-\alpha)kN_1 - H}$

Then, from (3'') and (4''), we have:

$$\left\{ \left(\frac{m_{11}}{m_{12}} \right)^{\lambda\gamma\beta} \left[\frac{H-(1-\alpha)kN_1}{H-(1-\alpha)kN_2} \right]^{\beta-1} \right\} \frac{N_1}{N_2} = \frac{A_2}{A_1} \frac{p_1}{p_2} \quad (A.69)$$

once

$$\frac{m_{11}}{m_{12}} = \left\{ \left(\frac{p_2}{p_1} \right)^\alpha \frac{A_1}{A_2} \left[\frac{(1-\beta\gamma)H - [1-(1-\alpha)\beta\gamma]kN_2}{(1-\beta\gamma)H - [1-(1-\alpha)\beta\gamma]kN_1} \right]^{\beta-1} \times \right\}^{\frac{1}{1-\lambda\gamma\beta}} \quad (A.70)$$

Substituting it back, we have:

$$\left[\left[\frac{H(1-\beta\gamma) - [1-(1-\alpha)\beta\gamma]kN_2}{H(1-\beta\gamma) - [1-(1-\alpha)\beta\gamma]kN_1} \right]^{\frac{\beta(1-\lambda\gamma)}{1-\lambda\gamma\beta}} \times \frac{N_1}{N_2} = \left(\frac{A_2}{A_1} \right)^{\frac{1}{1-\lambda\gamma\beta}} \left(\frac{p_1}{p_2} \right)^{\frac{1-(1-\alpha)\lambda\gamma\beta}{1-\lambda\gamma\beta}} \right] \quad (\star\star\star) \quad (A.71)$$

Notice that:

$$\left[\frac{H(1-\beta\gamma) - [1-(1-\alpha)\beta\gamma]kN_2}{H(1-\beta\gamma) - [1-(1-\alpha)\beta\gamma]kN_1} \times \frac{H-(1-\alpha)kN_1}{H-(1-\alpha)kN_2} \right] - 1 = \frac{Hk\alpha(N_1 - N_2)}{\left\{ [H(1-\beta\gamma) - [1-(1-\alpha)\beta\gamma]kN_1] \times [H-(1-\alpha)kN_2] \right\}} \quad (A.72)$$

Since:

$$m_{21} = \left[-\frac{H(1-\beta\lambda\gamma) - [1-(1-\alpha)\beta\lambda\gamma]kN_1}{H(1-\beta\gamma) - [1-(1-\alpha)\beta\gamma]kN_1} \right]^{\frac{1}{\gamma}} m_{11}^\lambda \left(\frac{[y_3 + y_1]^\lambda}{y_2} \right)^{\frac{1}{\gamma}} \quad (A.73)$$

and $m_{21} > 0$, we must have that:

$$-\frac{H(1-\beta\lambda\gamma) - [1-(1-\alpha)\beta\lambda\gamma]kN_1}{H(1-\beta\gamma) - [1-(1-\alpha)\beta\gamma]kN_1} > 0 \quad (A.74)$$

Since $H(1-\beta\lambda\gamma) - [1-(1-\alpha)\beta\lambda\gamma]kN_1$ is decreasing in λ , we must have:

$$H(1-\beta\gamma) - [1-(1-\alpha)\beta\gamma]kN_1 > 0 \quad (A.75)$$

and

$$H(1-\beta\lambda\gamma) - [1-(1-\alpha)\beta\lambda\gamma]kN_1 < 0 \quad (A.76)$$

but them, we have that:

$$\left\{ \begin{array}{l} [H(1-\beta\gamma) - [1-(1-\alpha)\beta\gamma]kN_1] \times \\ \times [H - (1-\alpha)kN_2] \end{array} \right\} > 0 \quad (\text{A.77})$$

Since $N_1 < N_2$, this implies that:

$$\left[\begin{array}{l} \frac{H(1-\beta\gamma) - [1-(1-\alpha)\beta\gamma]kN_2}{H(1-\beta\gamma) - [1-(1-\alpha)\beta\gamma]kN_1} \\ \times \frac{H - (1-\alpha)kN_1}{H - (1-\alpha)kN_2} \end{array} \right] < 1 \quad (\text{A.78})$$

Then, from (★★★), we have:

$$\begin{aligned} \left[\begin{array}{l} \frac{H(1-\beta\gamma) - [1-(1-\alpha)\beta\gamma]kN_2}{H(1-\beta\gamma) - [1-(1-\alpha)\beta\gamma]kN_1} \\ \times \frac{H - (1-\alpha)kN_1}{H - (1-\alpha)kN_2} \end{array} \right]^{\frac{\beta(1-\lambda\gamma)}{1-\lambda\gamma\beta}} &< 1 \\ \left[\frac{H - (1-\alpha)kN_2}{H - (1-\alpha)kN_1} \right] &< 1 \\ \frac{N_1}{N_2} &< 1 \end{aligned}$$

Therefore $LHS < 1$. We also know that $\left(\frac{p_1}{p_2}\right)^{\frac{1-(1-\alpha)\lambda\gamma\beta}{1-\lambda\gamma\beta}} > 1$. Given $A_2 > A_1$, $RHS > 1$ and we have a contradiction

In order to complete our proof, assume that $\frac{m_{11}}{m_{12}} = 1 \Rightarrow m_{11} = m_{12}$. Given that $\frac{m_{21}}{m_{22}} = \left(\frac{m_{11}}{m_{12}}\right)^{\frac{1-\lambda\gamma}{1-\gamma}}$, we have that $m_{21} = m_{22}$. Then, from (★★) we have $N_1 = N_2$ and from (★) we have $p_1 = p_2$. But, combining these results and (★★★), we again have a contradiction, once $LHS = 1$ while $RHS > 1$ once $A_2 > A_1$. ■

Corollary A. 1 *There is no equilibrium in which $A_1 > A_2$ and $m_{i2} > m_{i1}$, $\forall i \in \{1, 2, 3\}$.*

Theorem A. 1 *City Size and TFP. Let $A_1 > A_2$, $\beta > 1$, $\lambda\gamma\beta < 1$, and $\gamma < 1$. Then the more productive city is larger, $S_1 > S_2$.*

Proof. Before we start, define:

$$Z = \left(\frac{p_1}{p_2}\right)^\alpha \frac{A_2}{A_1} \left[\begin{array}{l} \frac{[1-(1-\alpha)\beta\gamma]kN_1 - (1-\beta\gamma)H}{[1-(1-\alpha)\beta\gamma]kN_2 - (1-\beta\gamma)H} \\ \times \frac{(1-\alpha)kN_2 - H}{(1-\alpha)kN_1 - H} \end{array} \right]^{\beta-1} \quad (\text{A.79})$$

Notice that:

$$\frac{m_{11}}{m_{12}} = Z^{\frac{1}{\lambda\gamma\beta-1}} \quad (\text{A.80})$$

Since $A_1 > A_2$, from Corollary 1 we have $m_{11} > m_{12}$. From Lemma 1 and $\lambda\gamma\beta < 1$, we have that $Z < 1$.

Notice that:

$$\begin{aligned} S_1 &= N_1 (2 * m_{11} + m_{21}) \\ S_1 &= N_2 \left(\begin{array}{l} 2 * \frac{N_1}{N_2} \frac{Z^{\frac{1}{\lambda\gamma\beta-1}}}{[N_2 + N_1 Z^{\frac{1}{\lambda\gamma\beta-1}}]} M_1 \\ + \frac{N_1}{N_2} \left\{ \left[\frac{H(1-\beta\lambda\gamma) - [1-(1-\alpha)\beta\lambda\gamma]kN_1}{[1-(1-\alpha)\beta\gamma]kN_2 - (1-\beta\gamma)H} \right]^{\frac{1}{\gamma}} \right. \\ \times \left(\frac{[y_3 + y_1]^\lambda}{y_2} \right)^{\frac{1}{\gamma}} \left(\frac{Z^{\frac{1}{\lambda\gamma\beta-1}}}{[N_2 + N_1 Z^{\frac{1}{\lambda\gamma\beta-1}}]} M_1 \right)^\lambda \left. \right\} \end{array} \right) \end{aligned}$$

while:

$$\begin{aligned} S_2 &= N_2 (2 * m_{12} + m_{22}) \\ &= N_2 \left(\begin{array}{l} 2 * \frac{M_1}{N_2 + N_1 Z^{\frac{1}{\lambda\gamma\beta-1}}} \\ + \left\{ \left[\frac{H(1-\beta\lambda\gamma) - [1-(1-\alpha)\beta\lambda\gamma]kN_2}{[1-(1-\alpha)\beta\gamma]kN_2 - (1-\beta\gamma)H} \right]^{\frac{1}{\gamma}} \left(\frac{[y_3 + y_1]^\lambda}{y_2} \right)^{\frac{1}{\gamma}} \left(\frac{M_1}{N_2 + N_1 Z^{\frac{1}{\lambda\gamma\beta-1}}} \right)^\lambda \right\} \end{array} \right) \end{aligned}$$

then:

$$S_2 - S_1 = N_2 \left\{ \begin{aligned} & 2 \frac{\left[1 - \frac{N_1}{N_2} Z^{\frac{1}{\lambda\gamma\beta-1}} \right] M_1}{N_2 + N_1 Z^{\frac{1}{\lambda\gamma\beta-1}}} + \\ & + \left[\left[1 - \frac{N_1}{N_2} Z^{\frac{1}{\lambda\gamma\beta-1}} \right] \left[\frac{H(1-\beta\lambda\gamma) - [1-(1-\alpha)\beta\lambda\gamma]kN_2}{[1-(1-\alpha)\beta\gamma]kN_2 - (1-\beta\gamma)H} \right]^{\frac{1}{\gamma}} \times \right. \\ & \quad \left. \times \left(\frac{[y_3+y_1]^\lambda}{y_2} \right)^{\frac{1}{\gamma}} \left(\frac{M_1}{N_2 + N_1 Z^{\frac{1}{\lambda\gamma\beta-1}}} \right)^\lambda \right] \end{aligned} \right\} \quad (\text{A.81})$$

Since:

$$\left\{ \begin{aligned} & \left[\frac{H-(1-\alpha)kN_1}{H-(1-\alpha)kN_2} \right]^{\beta-1} \\ & \times \left[\frac{H(1-\beta\gamma) - [1-(1-\alpha)\beta\gamma]kN_2}{H(1-\beta\gamma) - [1-(1-\alpha)\beta\gamma]kN_1} \right]^\beta \end{aligned} \right\} Z^{\frac{\lambda\gamma\beta}{\lambda\gamma\beta-1}} = \frac{N_2}{N_1} \frac{p_1}{p_2} \frac{A_2}{A_1} \quad (\text{A.82})$$

Then, from $\frac{(3'')}{(4'')}$, we have:

$$\frac{N_1}{N_2} = \frac{\frac{p_1}{p_2} \frac{A_2}{A_1}}{\left[\frac{H-(1-\alpha)kN_1}{H-(1-\alpha)kN_2} \right]^{\beta-1} \left[\frac{H(1-\beta\gamma) - [1-(1-\alpha)\beta\gamma]kN_2}{H(1-\beta\gamma) - [1-(1-\alpha)\beta\gamma]kN_1} \right]^\beta Z^{\frac{\lambda\gamma\beta}{\lambda\gamma\beta-1}}} \quad (\text{A.83})$$

so:

$$\begin{aligned} \frac{N_1}{N_2} Z^{\frac{1}{\lambda\gamma\beta-1}} &= \frac{\frac{p_1}{p_2} \frac{A_2}{A_1}}{\left[\frac{H-(1-\alpha)kN_1}{H-(1-\alpha)kN_2} \right]^{\beta-1} \left[\frac{H(1-\beta\gamma) - [1-(1-\alpha)\beta\gamma]kN_2}{H(1-\beta\gamma) - [1-(1-\alpha)\beta\gamma]kN_1} \right]^\beta} \left(\frac{1}{Z} \right) \\ &= \left(\frac{p_1}{p_2} \right)^{1-\alpha} \left[\frac{H(1-\beta\gamma) - [1-(1-\alpha)\beta\gamma]kN_1}{H(1-\beta\gamma) - [1-(1-\alpha)\beta\gamma]kN_2} \right] > 1 \end{aligned}$$

Therefore, since $\frac{N_1}{N_2} Z^{\frac{1}{\lambda\gamma\beta-1}} > 1$, we have that $\left[1 - \frac{N_1}{N_2} Z^{\frac{1}{\lambda\gamma\beta-1}} \right] < 0$. Since $\lambda > 1$ and $\frac{N_1}{N_2} Z^{\frac{\lambda}{\lambda\gamma\beta-1}} \cdot \frac{N_1}{N_2} Z^{\frac{1}{\lambda\gamma\beta-1}}$, we also have that $\left[1 - \frac{N_1}{N_2} Z^{\frac{\lambda}{\lambda\gamma\beta-1}} \right] < 0$. Therefore:

$$S_2 - S_1 < 0 \quad (\text{A.84})$$

and we have that the city with the highest TFP is also the largest city. ■

Theorem A. 2 Fat Tails. Let $A_1 > A_2, \beta > 1, \lambda > 1$, and $\lambda\gamma\beta < 1$, the skill distribution in the larger city has fatter tails.

Proof. Consider the distributions, denoted by pdf_{ij} :

$$pdf_{11} = \frac{N_1 m_{11}}{S_1} = \frac{\frac{Z^{\frac{1}{\lambda\gamma\beta-1}}}{\left[N_2 + N_1 Z^{\frac{1}{\lambda\gamma\beta-1}} \right]} M_1}{\left(\begin{aligned} & 2 * \frac{Z^{\frac{1}{\lambda\gamma\beta-1}}}{\left[N_2 + N_1 Z^{\frac{1}{\lambda\gamma\beta-1}} \right]} M_1 \\ & + \left\{ \left[\frac{H(1-\beta\lambda\gamma) - [1-(1-\alpha)\beta\lambda\gamma]kN_1}{[1-(1-\alpha)\beta\gamma]kN_1 - (1-\beta\gamma)H} \right]^{\frac{1}{\gamma}} \right. \\ & \quad \left. \times \left(\frac{[y_3+y_1]^\lambda}{y_2} \right)^{\frac{1}{\gamma}} \left(\frac{Z^{\frac{1}{\lambda\gamma\beta-1}}}{\left[N_2 + N_1 Z^{\frac{1}{\lambda\gamma\beta-1}} \right]} M_1 \right)^\lambda \right\} \end{aligned} \right)} \quad (\text{A.85})$$

$$pdf_{12} = \frac{\frac{M_1}{N_2 + N_1 Z^{\frac{1}{\lambda\gamma\beta-1}}}}{\left(\begin{aligned} & 2 * \frac{M_1}{N_2 + N_1 Z^{\frac{1}{\lambda\gamma\beta-1}}} \\ & + \left\{ \left[\frac{H(1-\beta\lambda\gamma) - [1-(1-\alpha)\beta\lambda\gamma]kN_2}{[1-(1-\alpha)\beta\gamma]kN_2 - (1-\beta\gamma)H} \right]^{\frac{1}{\gamma}} \right. \\ & \quad \left. \times \left(\frac{[y_3+y_1]^\lambda}{y_2} \right)^{\frac{1}{\gamma}} \left(\frac{M_1}{N_2 + N_1 Z^{\frac{1}{\lambda\gamma\beta-1}}} \right)^\lambda \right\} \end{aligned} \right)} \quad (\text{A.86})$$

Since:

$$\begin{aligned} & \left(\frac{M_1}{N_2 + N_1 Z^{\frac{1}{\lambda\gamma\beta-1}}} \right)^\lambda \left(\frac{[y_3 + y_1]^\lambda}{y_2} \right)^{\frac{1}{\gamma}} \\ &= \frac{M_2}{\left[N_1 \left[\frac{H(1-\beta\lambda\gamma) - [1-(1-\alpha)\beta\lambda\gamma]kN_1}{[1-(1-\alpha)\beta\gamma]kN_1 - (1-\beta\gamma)H} \right]^{\frac{1}{\gamma}} Z^{\frac{\lambda}{\lambda\gamma\beta-1}} \right.} \\ & \quad \left. + N_2 \left[\frac{H(1-\beta\lambda\gamma) - [1-(1-\alpha)\beta\lambda\gamma]kN_2}{[1-(1-\alpha)\beta\gamma]kN_2 - (1-\beta\gamma)H} \right]^{\frac{1}{\gamma}} \right] \end{aligned}$$

we have:

$$pdf_{11} = \frac{Z^{\frac{1}{\lambda\gamma\beta-1}} M_1}{\left(\frac{2Z^{\frac{1}{\lambda\gamma\beta-1}} M_1}{M_2 [N_2 + N_1 Z^{\frac{1}{\lambda\gamma\beta-1}}]} + \left[N_1 Z^{\frac{\lambda}{\lambda\gamma\beta-1}} + N_2 \left[\frac{H(1-\beta\lambda\gamma) - [1-(1-\alpha)\beta\lambda\gamma]kN_2}{[1-(1-\alpha)\beta\gamma]kN_2 - (1-\beta\gamma)H} \right]^{\frac{1}{\gamma}} \times \frac{[1-(1-\alpha)\beta\gamma]kN_1 - (1-\beta\gamma)H}{H(1-\beta\lambda\gamma) - [1-(1-\alpha)\beta\lambda\gamma]kN_1} \right]^{\frac{1}{\gamma}} \right)} \quad (A.87)$$

and

$$pdf_{12} = \frac{M_1}{\left(\frac{2M_1}{M_2 [N_2 + N_1 Z^{\frac{1}{\lambda\gamma\beta-1}}]} + \left[N_1 Z^{\frac{\lambda}{\lambda\gamma\beta-1}} \left[\frac{H(1-\beta\lambda\gamma) - [1-(1-\alpha)\beta\lambda\gamma]kN_1}{[1-(1-\alpha)\beta\gamma]kN_1 - (1-\beta\gamma)H} \right]^{\frac{1}{\gamma}} \times \frac{[1-(1-\alpha)\beta\gamma]kN_2 - (1-\beta\gamma)H}{H(1-\beta\lambda\gamma) - [1-(1-\alpha)\beta\lambda\gamma]kN_2} \right]^{\frac{1}{\gamma}} + N_2 \right)} \quad (A.88)$$

$$\frac{pdf_{11}}{pdf_{12}} = \frac{\left(\left[\frac{2Z^{\frac{1}{\lambda\gamma\beta-1}} M_1 \times \left[\frac{H(1-\beta\lambda\gamma) - [1-(1-\alpha)\beta\lambda\gamma]kN_2}{H(1-\beta\lambda\gamma) - [1-(1-\alpha)\beta\lambda\gamma]kN_1} \times \frac{H(1-\beta\gamma) - [1-(1-\alpha)\beta\gamma]kN_1}{H(1-\beta\gamma) - [1-(1-\alpha)\beta\gamma]kN_2} \right]^{\frac{1}{\gamma}} \times \left[N_1 Z^{\frac{\lambda}{\lambda\gamma\beta-1}} \left[\frac{H(1-\beta\lambda\gamma) - [1-(1-\alpha)\beta\lambda\gamma]kN_1}{H(1-\beta\lambda\gamma) - [1-(1-\alpha)\beta\lambda\gamma]kN_2} \right]^{\frac{1}{\gamma}} + N_2 \right]^{\frac{1}{\gamma}} + M_2 [N_2 + N_1 Z^{\frac{1}{\lambda\gamma\beta-1}}] Z^{\frac{1}{\lambda\gamma\beta-1}} \right]}{\left(\left[\frac{2Z^{\frac{1}{\lambda\gamma\beta-1}} M_1 \times \left[\frac{H(1-\beta\lambda\gamma) - [1-(1-\alpha)\beta\lambda\gamma]kN_2}{H(1-\beta\lambda\gamma) - [1-(1-\alpha)\beta\lambda\gamma]kN_1} \times \frac{H(1-\beta\gamma) - [1-(1-\alpha)\beta\gamma]kN_1}{H(1-\beta\gamma) - [1-(1-\alpha)\beta\gamma]kN_2} \right]^{\frac{1}{\gamma}} \times \left[N_1 Z^{\frac{\lambda}{\lambda\gamma\beta-1}} \left[\frac{H(1-\beta\lambda\gamma) - [1-(1-\alpha)\beta\lambda\gamma]kN_1}{H(1-\beta\lambda\gamma) - [1-(1-\alpha)\beta\lambda\gamma]kN_2} \right]^{\frac{1}{\gamma}} + N_2 \right]^{\frac{1}{\gamma}} + M_2 [N_2 + N_1 Z^{\frac{1}{\lambda\gamma\beta-1}}] \right)} \right) \quad (A.89)$$

Since $Z < 1 \Rightarrow Z^{\frac{1}{\lambda\gamma\beta-1}} > 1$, we have that $\frac{pdf_{11}}{pdf_{12}} > 1$. Since the distribution is symmetric, we also have that $\frac{pdf_{31}}{pdf_{32}} > 1$ ■

III. Agglomeration Externalities

Since Marshall (1890), there is a broad consensus in the economics literature that the principal explanation for the existence of cities is the presence of agglomeration externalities (see Duranton and Puga, 2004 for a theoretical survey, and Rosenthal and Strange, 2004, and Combes, Duranton, Gobillon, Puga, and Roux, 2009 for the empirical evidence). Due to economies of scale and network effects, firms that cluster together may see a decline in the costs of production, due to the presence of competing multiple suppliers, greater specialization and the division of labor. Even direct competitors in the same sector may benefit because the cluster of firms in the same city attracts more suppliers and customers than a single firm in isolation. Alternatively, there may be demand-side agglomeration externalities due to the variety of goods and services provided. Of course, the size of the city is limited by diseconomies of agglomeration, for example congestion, and the limited availability of land which drives up the price of housing and office space. The latter is captured by the fixed amount of land in our baseline model above.

Because the key feature of agglomeration externalities is city size, we will assume that TFP is determined *endogenously* and increasing in city size $S_j : A_j = A(S_j)$, where $A'(S) > 0$. Cities are ex ante identical and there are no initial differences in TFP across different cities.

We analyze the case of Extreme-Skill Complementarities with free mobility of firms in a two-city model. The next Theorem characterizes the equilibrium allocation of skilled workers and of firms across cities. Firms in larger cities are more productive due to higher agglomeration externalities. Also real estate prices are higher. This may seem obvious, but as in the results on city size with exogenous TFP, this hinges on the fact that land supply is equal (or at least not too different). Once endogenous TFP due to agglomeration is higher, labor productivity is higher and therefore labor demand. As a result, the representative firm is larger and more firms enter. Finally, the same logic that explains the emergence of fat tails applies exactly as it does for the case of exogenous TFP.

Theorem A. 3 *Given endogenous agglomeration externalities and given $\lambda > 1$ and $\lambda\gamma < 1$, and provided cities of different size exist, the larger city has:*

- *higher TFP;*
- *higher real estate prices;*
- *more and larger firms;*
- *fatter tails in the skill distribution.*

Proof. See below. ■

Observe that with endogenous agglomeration externalities we can readily extend the proofs to the case of the technology with Top-Skill Complementarity.

An open question remains whether there actually exist equilibria with endogenous agglomeration externalities where cities are ex post heterogeneous, despite being ex ante identical. Of course, if there is heterogeneity in equilibrium city size, we expect there to be multiple equilibria since there is no ex ante advantage to any city ex ante: one equilibrium where city 1 is large and city 2 is small, another equilibrium where city 2 is large and city 1 is small, and finally an intermediate equilibrium where cities are identical.

For the case of a CES production technology, we show conditions under which cities are different in size, despite the ex ante identical technologies and agglomeration externalities. Mobility of workers and free entry of firms induces wages and housing prices to adjust such that workers are indifferent between locating in either city. When there are sufficiently large economies of scale of agglomeration, i.e. when the function A is sufficiently convex, we obtain that cities differ in equilibrium. We establish this result for the exponential function in conjunction with the CES technology.

Theorem A. 4 *Given the CES technology and endogenous agglomeration externalities of the form $A(S) = e^{\psi S}$, $\psi > 0$, cities of different size exist, provided $\psi > \frac{2(1-\gamma(1-\alpha))}{\bar{M}(1-\alpha)}$.*

Proof. See below. ■

This result indicates that agglomeration externalities in production alone can generate the coexistence of cities of different size and productivity. The qualifier requires that for a given size of the labor force $\bar{M}$, the externality must be strong enough. If ψ is high enough, the function $A = e^{\psi S}$ will be convex enough and as a result, there will be a large enough agglomeration effect that generates the existence of multiple equilibria.

Interestingly, a commonly assumed functional form in partial equilibrium, $A(S) = S^\phi$, does not generate heterogeneous cities in conjunction with the CES technology. This is true even if A is convex ($\phi > 1$) as shown in the following Corollary. The reason is that already under CES, there is proportionality in the equilibrium demand for labor (proportional across skills), and an externality of this form lifts each city's productivity, but again proportionally. As a result homotheticity, the size of the city is fully governed by the decreasing returns at each skill level. The returns to scale can never be sufficiently strong.

Corollary A. 2 *Given the CES technology and endogenous agglomeration externalities of the form $A(S) = S^\phi, \phi > 0$, generically cities are of identical size.*

Proof. See below. ■

Ideally we would like to solve the model and prove that multiple equilibria exist also in the presence of extreme-skill complementarities. Unfortunately, that problem is quite a bit more challenging due to the dimensionality of the skill distribution. Not surprisingly, under CES, the proportionality of labor demand implies that distributions are identical across cities. As a result, we only need to solve for the endogenous city size, and not each skill level individually. While we cannot prove any general results, we do conjecture that the nature of the results extends to the non-CES case.

Proofs Agglomeration Externalities

Going back to the system of five equations in the preliminaries, we can now substitute A_j for $A(S_j)$. Denote by $\bar{M} = S_1 + S_2 = \sum_i M_i$ as the economy wide population. Then we will write $S_2 = \bar{M} - S_1$.

From dividing the first by the second and rearranging, we obtain:

$$\begin{aligned} & \left\{ \begin{array}{l} [1 - \lambda\gamma(1 - \alpha)] \left[\left(\frac{p_1}{p_2} \right)^\alpha \frac{A(\bar{M} - S_1)}{A(S_1)} \right]^{\frac{\lambda\gamma}{\lambda\gamma - 1}} \\ - \frac{N_2}{N_1} \frac{p_1}{p_2} \frac{A(\bar{M} - S_1)}{A(S_1)} [1 - \lambda\gamma(1 - \alpha)] \end{array} \right\} \left(\frac{M_3}{N_2 + N_1 \left[\left(\frac{p_1}{p_2} \right)^\alpha \frac{A(\bar{M} - S_1)}{A(S_1)} \right]^{\frac{1}{\lambda\gamma - 1}}} \right)^{\lambda\gamma} \left[y_3 + \left(\frac{M_1}{M_3} \right)^\gamma y_1 \right]^\lambda \\ = & \left\{ \begin{array}{l} \frac{N_2}{N_1} \frac{p_1}{p_2} \frac{A(\bar{M} - S_1)}{A(S_1)} [1 - \gamma(1 - \alpha)] \\ - [1 - \gamma(1 - \alpha)] \left[\left(\frac{p_1}{p_2} \right)^\alpha \frac{A(\bar{M} - S_1)}{A(S_1)} \right]^{\frac{\gamma}{\gamma - 1}} \end{array} \right\} \left(\frac{M_2}{N_2 + N_1 \left[\left(\frac{p_1}{p_2} \right)^\alpha \frac{A(\bar{M} - S_1)}{A(S_1)} \right]^{\frac{1}{\gamma - 1}}} \right)^\gamma y_2, \end{aligned}$$

and from dividing the third by the fourth we have:

$$\begin{aligned} & \left\{ \begin{array}{l} (1 - \lambda\gamma) \left[\left(\frac{p_1}{p_2} \right)^\alpha \frac{A(\bar{M} - S_1)}{A(S_1)} \right]^{\frac{\lambda\gamma}{\lambda\gamma - 1}} \\ - (1 - \lambda\gamma) \frac{p_1}{p_2} \frac{A(\bar{M} - S_1)}{A(S_1)} \end{array} \right\} \left(\frac{M_3}{N_2 + N_1 \left[\left(\frac{p_1}{p_2} \right)^\alpha \frac{A(\bar{M} - S_1)}{A(S_1)} \right]^{\frac{1}{\lambda\gamma - 1}}} \right)^{\lambda\gamma} \left[y_3 + \left(\frac{M_1}{M_3} \right)^\gamma y_1 \right]^\lambda \\ = & \left\{ \begin{array}{l} (1 - \gamma) \frac{p_1}{p_2} \frac{A(\bar{M} - S_1)}{A(S_1)} \\ - (1 - \gamma) \left[\left(\frac{p_1}{p_2} \right)^\alpha \frac{A(\bar{M} - S_1)}{A(S_1)} \right]^{\frac{\gamma}{\gamma - 1}} \end{array} \right\} \left(\frac{M_2}{N_2 + N_1 \left[\left(\frac{p_1}{p_2} \right)^\alpha \frac{A(\bar{M} - S_1)}{A(S_1)} \right]^{\frac{1}{\gamma - 1}}} \right)^\gamma y_2 \end{aligned}$$

Jointly, these two equations give us

$$\frac{[1 - \lambda\gamma(1 - \alpha)]}{(1 - \lambda\gamma)} \frac{\left\{ \left[\left(\frac{p_1}{p_2} \right)^\alpha \frac{A(\bar{M} - S_1)}{A(S_1)} \right]^{\frac{\lambda\gamma}{\lambda\gamma - 1}} - \frac{N_2}{N_1} \frac{p_1}{p_2} \frac{A(\bar{M} - S_1)}{A(S_1)} \right\}}{\left\{ \left[\left(\frac{p_1}{p_2} \right)^\alpha \frac{A(\bar{M} - S_1)}{A(S_1)} \right]^{\frac{\lambda\gamma}{\lambda\gamma - 1}} - \frac{p_1}{p_2} \frac{A(\bar{M} - S_1)}{A(S_1)} \right\}} = \frac{[1 - \gamma(1 - \alpha)]}{(1 - \gamma)} \frac{\left\{ \frac{N_2}{N_1} \frac{p_1}{p_2} \frac{A(\bar{M} - S_1)}{A(S_1)} - \left[\left(\frac{p_1}{p_2} \right)^\alpha \frac{A(\bar{M} - S_1)}{A(S_1)} \right]^{\frac{\gamma}{\gamma - 1}} \right\}}{\left\{ \frac{p_1}{p_2} \frac{A(\bar{M} - S_1)}{A(S_1)} - \left[\left(\frac{p_1}{p_2} \right)^\alpha \frac{A(\bar{M} - S_1)}{A(S_1)} \right]^{\frac{\gamma}{\gamma - 1}} \right\}} \quad (\star)$$

(A.90)

We can now establish the following preliminary results. First, cities are not equal in the number of firms N_j .

Lemma A. 2 *If $\lambda > 1$ and $\lambda\gamma < 1$, then $\frac{N_2}{N_1} \neq 1$, and $Z \neq 1$.*

Proof. Assume $\frac{N_2}{N_1} = 1$, then from $(\star)$ we have:

$$\frac{[1 - \lambda\gamma(1 - \alpha)]}{(1 - \lambda\gamma)} = \frac{[1 - \gamma(1 - \alpha)]}{(1 - \gamma)} \quad (\text{A.91})$$

which is a contradiction, since $\lambda > 1 \Rightarrow \frac{[1 - \lambda\gamma(1 - \alpha)]}{(1 - \lambda\gamma)} > \frac{[1 - \gamma(1 - \alpha)]}{(1 - \gamma)}$.

Rewriting the equality (★) above, we obtain:

$$\frac{[1 - \lambda\gamma(1 - \alpha)]}{(1 - \lambda\gamma)} \frac{\left\{ \left[\left(\frac{p_1}{p_2} \right)^\alpha \frac{A(\overline{M} - S_1)}{A(S_1)} \right]^{\frac{\lambda\gamma}{\lambda\gamma - 1}} - \frac{N_2}{N_1} \frac{p_1}{p_2} \frac{A(\overline{M} - S_1)}{A(S_1)} \right\}}{\left\{ \left[\left(\frac{p_1}{p_2} \right)^\alpha \frac{A(\overline{M} - S_1)}{A(S_1)} \right]^{\frac{\gamma}{\gamma - 1}} - \frac{N_2}{N_1} \frac{p_1}{p_2} \frac{A(\overline{M} - S_1)}{A(S_1)} \right\}} = \frac{[1 - \gamma(1 - \alpha)]}{(1 - \gamma)} \frac{\left\{ \left[\left(\frac{p_1}{p_2} \right)^\alpha \frac{A(\overline{M} - S_1)}{A(S_1)} \right]^{\frac{\lambda\gamma}{\lambda\gamma - 1}} - \frac{p_1}{p_2} \frac{A(\overline{M} - S_1)}{A(S_1)} \right\}}{\left\{ \left[\left(\frac{p_1}{p_2} \right)^\alpha \frac{A(\overline{M} - S_1)}{A(S_1)} \right]^{\frac{\gamma}{\gamma - 1}} - \frac{p_1}{p_2} \frac{A(\overline{M} - S_1)}{A(S_1)} \right\}} \quad (\text{A.92})$$

Then, if $Z = 1$, we have $\left[\left(\frac{p_1}{p_2} \right)^\alpha \frac{A(\overline{M} - S_1)}{A(S_1)} \right]^{\frac{\lambda\gamma}{\lambda\gamma - 1}} = \left[\left(\frac{p_1}{p_2} \right)^\alpha \frac{A(\overline{M} - S_1)}{A(S_1)} \right]^{\frac{\gamma}{\gamma - 1}} = 1$. Therefore, we have:

$$\begin{aligned} \frac{[1 - \lambda\gamma(1 - \alpha)]}{(1 - \lambda\gamma)} \frac{\left\{ 1 - \frac{N_2}{N_1} \frac{p_1}{p_2} \frac{A(\overline{M} - S_1)}{A(S_1)} \right\}}{\left\{ 1 - \frac{N_2}{N_1} \frac{p_1}{p_2} \frac{A(\overline{M} - S_1)}{A(S_1)} \right\}} &= \frac{[1 - \gamma(1 - \alpha)]}{(1 - \gamma)} \frac{\left\{ 1 - \frac{p_1}{p_2} \frac{A(\overline{M} - S_1)}{A(S_1)} \right\}}{\left\{ 1 - \frac{p_1}{p_2} \frac{A(\overline{M} - S_1)}{A(S_1)} \right\}} \\ \frac{[1 - \lambda\gamma(1 - \alpha)]}{(1 - \lambda\gamma)} &= \frac{[1 - \gamma(1 - \alpha)]}{(1 - \gamma)} \end{aligned}$$

which as we saw before, it is a contradiction. ■

Given Z , we can now establish the main relations between the number of firms N_j , city size S_j , housing prices p_j and TFP $A(S_j)$.

Lemma A. 3 *If $Z < 1$, then:*

1. $N_1 > N_2$;
2. $S_1 > S_2$;
3. $A_1 > A_2$;
4. $p_1 > p_2$.

With opposite inequalities if $Z > 1$.

Proof. We establish each of the items in turn

1. Rearranging equality (★), we get:

$$\frac{[1 - \lambda\gamma(1 - \alpha)]}{(1 - \lambda\gamma)} \frac{\left\{ \left[\left(\frac{p_1}{p_2} \right)^\alpha \frac{A(\overline{M} - S_1)}{A(S_1)} \right]^{\frac{\lambda\gamma}{\lambda\gamma - 1}} - \frac{N_2}{N_1} \frac{p_1}{p_2} \frac{A(\overline{M} - S_1)}{A(S_1)} \right\}}{\left\{ \left[\left(\frac{p_1}{p_2} \right)^\alpha \frac{A(\overline{M} - S_1)}{A(S_1)} \right]^{\frac{\lambda\gamma}{\lambda\gamma - 1}} - \frac{p_1}{p_2} \frac{A(\overline{M} - S_1)}{A(S_1)} \right\}} = \frac{[1 - \gamma(1 - \alpha)]}{(1 - \gamma)} \frac{\left\{ \left[\left(\frac{p_1}{p_2} \right)^\alpha \frac{A(\overline{M} - S_1)}{A(S_1)} \right]^{\frac{\gamma}{\gamma - 1}} - \frac{N_2}{N_1} \frac{p_1}{p_2} \frac{A(\overline{M} - S_1)}{A(S_1)} \right\}}{\left\{ \left[\left(\frac{p_1}{p_2} \right)^\alpha \frac{A(\overline{M} - S_1)}{A(S_1)} \right]^{\frac{\gamma}{\gamma - 1}} - \frac{p_1}{p_2} \frac{A(\overline{M} - S_1)}{A(S_1)} \right\}} \quad (\text{A.93})$$

and further simplifying:

$$\frac{[1 - \lambda\gamma(1 - \alpha)]}{(1 - \lambda\gamma)} \frac{\left\{ \left[\left(\frac{p_1}{p_2} \right)^\alpha \frac{A(\overline{M} - S_1)}{A(S_1)} \right]^{\frac{\lambda\gamma}{\lambda\gamma - 1}} \frac{p_2}{p_1} \frac{A(S_1)}{A(\overline{M} - S_1)} - \frac{N_2}{N_1} \right\}}{\left\{ \left[\left(\frac{p_1}{p_2} \right)^\alpha \frac{A(\overline{M} - S_1)}{A(S_1)} \right]^{\frac{\gamma}{\gamma - 1}} \frac{p_2}{p_1} \frac{A(S_1)}{A(\overline{M} - S_1)} - \frac{N_2}{N_1} \right\}} = \frac{[1 - \gamma(1 - \alpha)]}{(1 - \gamma)} \frac{\left\{ \left[\left(\frac{p_1}{p_2} \right)^\alpha \frac{A(\overline{M} - S_1)}{A(S_1)} \right]^{\frac{\lambda\gamma}{\lambda\gamma - 1}} \frac{p_2}{p_1} \frac{A(S_1)}{A(\overline{M} - S_1)} - 1 \right\}}{\left\{ \left[\left(\frac{p_1}{p_2} \right)^\alpha \frac{A(\overline{M} - S_1)}{A(S_1)} \right]^{\frac{\gamma}{\gamma - 1}} \frac{p_2}{p_1} \frac{A(S_1)}{A(\overline{M} - S_1)} - 1 \right\}} \quad (\text{A.94})$$

Then:

$$\frac{d}{d \frac{N_2}{N_1}} (LHS) = \frac{[1 - \lambda\gamma(1 - \alpha)]}{(1 - \lambda\gamma)} \frac{\left\{ \left[\left(\frac{p_1}{p_2} \right)^\alpha \frac{A(\overline{M} - S_1)}{A(S_1)} \right]^{\frac{\lambda\gamma}{\lambda\gamma - 1}} - \left[\left(\frac{p_1}{p_2} \right)^\alpha \frac{A(\overline{M} - S_1)}{A(S_1)} \right]^{\frac{\gamma}{\gamma - 1}} \right\} \frac{p_2}{p_1} \frac{A(S_1)}{A(\overline{M} - S_1)}}{\left\{ \left[\left(\frac{p_1}{p_2} \right)^\alpha \frac{A(\overline{M} - S_1)}{A(S_1)} \right]^{\frac{\gamma}{\gamma - 1}} \frac{p_2}{p_1} \frac{A(S_1)}{A(\overline{M} - S_1)} - \frac{N_2}{N_1} \right\}^2} \quad (\text{A.95})$$

If $Z < 1$, we have: $\frac{d}{d \frac{N_2}{N_1}} (LHS) > 0$. Then, since $\frac{[1 - \lambda\gamma(1 - \alpha)]}{(1 - \lambda\gamma)} > \frac{[1 - \gamma(1 - \alpha)]}{(1 - \gamma)}$, if $Z < 1$ we must have $\frac{N_2}{N_1} < 1$. Similarly, if $Z > 1$, we have: $\frac{d}{d \frac{N_2}{N_1}} (LHS) < 0$. Then, since $\frac{[1 - \lambda\gamma(1 - \alpha)]}{(1 - \lambda\gamma)} > \frac{[1 - \gamma(1 - \alpha)]}{(1 - \gamma)}$, if $Z > 1$ we must have $\frac{N_2}{N_1} > 1$.

2. From the fifth equation, we have:

$$S_1 = (M_1 + M_3) \frac{Z^{\frac{1}{\lambda\gamma-1}}}{\frac{N_2}{N_1} + Z^{\frac{1}{\lambda\gamma-1}}} + \frac{Z^{\frac{1}{\gamma-1}} M_2}{\frac{N_2}{N_1} + Z^{\frac{1}{\gamma-1}}} \quad (\text{A.96})$$

If $Z < 1$, from the previous Lemma we know that $\frac{N_2}{N_1} < 1$. Since:

$$\begin{aligned} \frac{d}{d\lambda} \left(\frac{Z^{\frac{1}{\lambda\gamma-1}}}{\frac{N_2}{N_1} + Z^{\frac{1}{\lambda\gamma-1}}} \right) &= \frac{-\frac{\gamma}{(\lambda\gamma-1)^2} Z^{\frac{1}{\lambda\gamma-1}} \ln Z \times \left(\frac{N_2}{N_1} + Z^{\frac{1}{\lambda\gamma-1}} \right) + \frac{\gamma}{(\lambda\gamma-1)^2} Z^{\frac{1}{\lambda\gamma-1}} Z^{\frac{1}{\lambda\gamma-1}} \ln Z}{\left(\frac{N_2}{N_1} + Z^{\frac{1}{\lambda\gamma-1}} \right)^2} \\ &= -\frac{\frac{\gamma}{(\lambda\gamma-1)^2} \frac{N_2}{N_1} Z^{\frac{1}{\lambda\gamma-1}} \ln Z}{\left(\frac{N_2}{N_1} + Z^{\frac{1}{\lambda\gamma-1}} \right)^2} > 0 \text{ since } \ln Z < 0 \text{ as } Z < 1 \end{aligned}$$

We have:

$$S_1 > (M_1 + M_3 + M_2) \frac{Z^{\frac{1}{\gamma-1}}}{\frac{N_2}{N_1} + Z^{\frac{1}{\gamma-1}}} > \frac{\bar{M}}{2} \quad (\text{A.97})$$

The same logic establishes the opposite when $Z > 1$.

3. From the previous lemma, if $Z < 1$, we have that $S_1 > S_2$. Since $A'(\cdot) > 0$, $A(S_1) > A(\bar{M} - S_1) = A_2$.

4. But then, from (★):

$$\frac{N_1}{N_2} \frac{A(S_1)}{A(\bar{M} - S_1)} \frac{\left\{ \begin{aligned} &[1 - \lambda\gamma(1 - \alpha)] Z^{\frac{\lambda\gamma}{\lambda\gamma-1}} \left(\frac{M_3}{N_2 + N_1 Z^{\frac{1}{\lambda\gamma-1}}} \right)^{\lambda\gamma} \left[y_3 + \left(\frac{M_1}{M_3} \right)^\gamma y_1 \right]^\lambda \\ &+ [1 - \gamma(1 - \alpha)] Z^{\frac{\gamma}{\gamma-1}} \left(\frac{Z^{\frac{1}{\gamma-1}} M_2}{N_2 + N_1 Z^{\frac{1}{\gamma-1}}} \right)^\gamma y_2 \end{aligned} \right\}}{\left\{ \begin{aligned} &[1 - \lambda\gamma(1 - \alpha)] \left(\frac{M_3}{N_2 + N_1 Z^{\frac{1}{\lambda\gamma-1}}} \right)^{\lambda\gamma} \left(y_3 + \left(\frac{M_1}{M_3} \right)^\gamma y_1 \right)^\lambda \\ &+ [1 - \gamma(1 - \alpha)] \left(\frac{M_2}{N_2 + N_1 Z^{\frac{1}{\gamma-1}}} \right)^\gamma y_2 \end{aligned} \right\}} = \frac{p_1}{p_2} \quad (\text{A.98})$$

Since $Z < 1$, we showed that $\frac{N_1}{N_2} > 1$. Then:

$$\frac{p_1}{p_2} > \frac{N_1}{N_2} \frac{A(S_1)}{A(\bar{M} - S_1)} Z^{\frac{\gamma}{\gamma-1}}. \quad (\text{A.99})$$

Similarly for $Z > 1$.

■

Next, we establish the result for fatter tails for the case of endogenous TFP from agglomeration externalities.

Lemma A. 4 *Given $\lambda > 1$ and $\lambda\gamma < 1$, the larger city has fatter tails.*

Proof. If $Z < 1$, from Lemma A.3 we know that city 1 is larger than city 2, and that $A_1 > A_2$. Therefore we can apply Theorem 2: city 1 is larger and has fatter tails. Instead, if $Z > 1$, we know that city 2 is larger than city 1, and that $A_1 < A_2$. Now we can define $Z' = 1/Z$ (or relabel the cities) and again apply Theorem 2: city 2 is larger and has fatter tails. ■

Now our main result immediately follows from Lemmas A.2, A.3, and A.4:

Theorem A.3 *Given endogenous agglomeration externalities and given $\lambda > 1$ and $\lambda\gamma < 1$, and provided cities of different size exist, the larger city has:*

We now establish the proof of Theorem A.4

Theorem A.4 *Given the CES technology and endogenous agglomeration externalities of the form $A(S) = e^{\psi S}$, $\psi > 0$, cities of different size exist, provided $\psi > \frac{2(1-\gamma(1-\alpha))}{\bar{M}(1-\alpha)}$.*

Proof. In the case of CES ($\lambda = 1$) we can write the system of 9 equilibrium equations as:

$$\left\{ \begin{array}{l} m_{12} = \frac{M_1}{N_1 \left[\left(\frac{p_1}{p_2} \right)^\alpha \frac{A(S_2)}{A(S_1)} \right]^{\frac{1}{\gamma-1}} + N_2} \\ m_{22} = \frac{M_2}{N_1 \left[\left(\frac{p_1}{p_2} \right)^\alpha \frac{A(S_2)}{A(S_1)} \right]^{\frac{1}{\gamma-1}} + N_2} \\ m_{32} = \frac{M_3}{N_1 \left[\left(\frac{p_1}{p_2} \right)^\alpha \frac{A(S_2)}{A(S_1)} \right]^{\frac{1}{\gamma-1}} + N_2} \\ \left[\left(\frac{p_1}{p_2} \right)^\alpha \frac{A(S_2)}{A(S_1)} \right]^{\frac{\gamma}{\gamma-1}} \{ (m_{12})^\gamma y_1 + (m_{32})^\gamma y_3 + (m_{22})^\gamma y_2 \} = \left[\frac{H}{N_1} - k \right] \frac{p_1}{\alpha \gamma A(S_1)} \\ \{ (m_{12})^\gamma y_1 + (m_{32})^\gamma y_3 + (m_{22})^\gamma y_2 \} = \left[\frac{H}{N_2} - k \right] \frac{p_2}{\alpha \gamma A(S_2)} \\ \left[\left(\frac{p_1}{p_2} \right)^\alpha \frac{A(S_2)}{A(S_1)} \right]^{\frac{\gamma}{\gamma-1}} \{ (m_{12})^\gamma y_1 + (m_{32})^\gamma y_3 + (m_{22})^\gamma y_2 \} = \frac{k}{(1-\gamma)A(S_1)} p_1 \\ \{ (m_{12})^\gamma y_1 + (m_{32})^\gamma y_3 + (m_{22})^\gamma y_2 \} = \frac{k}{(1-\gamma)A(S_2)} p_2 \\ S_1 = \left[\left(\frac{p_1}{p_2} \right)^\alpha \frac{A(S_2)}{A(S_1)} \right]^{\frac{1}{\gamma-1}} [m_{12} + m_{22} + m_{32}] N_1 \\ S_2 = [m_{12} + m_{22} + m_{32}] N_2 \end{array} \right. \quad (\text{A.100})$$

From eqs. (6) and (7), we obtain:

$$\frac{\left[\left(\frac{p_1}{p_2} \right)^\alpha \frac{A(S_2)}{A(S_1)} \right]^{\frac{\gamma}{\gamma-1}} \{ (m_{12})^\gamma y_1 + (m_{32})^\gamma y_3 + (m_{22})^\gamma y_2 \}}{\{ (m_{12})^\gamma y_1 + (m_{32})^\gamma y_3 + (m_{22})^\gamma y_2 \}} = \frac{k p_1}{(1-\gamma) A(S_1)} \times \frac{(1-\gamma) A(S_2)}{k p_2}, \quad (\text{A.101})$$

and after rearranging:

$$\frac{p_1}{p_2} = \left(\frac{A(S_1)}{A(S_2)} \right)^{\frac{1}{1-\gamma(1-\alpha)}} \quad (\text{A.102})$$

From (4) and (6), and from (5) and (7) we have:

$$N_1 = \frac{H}{\left[1 + \frac{\alpha \gamma}{(1-\gamma)} \right] k} = N_2 \quad (\text{A.103})$$

Substituting (1), (2), and (3) into (8), and using the price ratio $\frac{p_1}{p_2}$ we get:

$$S_1 = \left\{ \frac{\left(\frac{A(S_1)}{A(S_2)} \right)^{\frac{(1-\alpha)}{1-\gamma(1-\alpha)}}}{1 + \left(\frac{A(S_1)}{A(S_2)} \right)^{\frac{(1-\alpha)}{1-\gamma(1-\alpha)}}} \right\} \bar{M} \quad \text{and} \quad S_2 = \left\{ \frac{1}{1 + \left(\frac{A(S_1)}{A(S_2)} \right)^{\frac{(1-\alpha)}{1-\gamma(1-\alpha)}}} \right\} \bar{M} \quad (\text{A.104})$$

Then:

$$\frac{S_1}{S_2} = \left(\frac{A(S_1)}{A(S_2)} \right)^{\frac{(1-\alpha)}{1-\gamma(1-\alpha)}} \quad (\text{A.105})$$

Since $S_2 = \bar{M} - S_1$, we have:

$$\frac{S_1}{\bar{M} - S_1} = \left(\frac{A(S_1)}{A(\bar{M} - S_1)} \right)^{\frac{(1-\alpha)}{1-\gamma(1-\alpha)}} \quad (\text{A.106})$$

Now consider the case where $A(S) = e^{\psi S}$ and denote the exponent on the RHS term by $K = \frac{\psi(1-\alpha)}{1-\gamma(1-\alpha)}$ and observe that it is positive. Then the equilibrium condition is:

$$\begin{aligned} \frac{S_1}{\bar{M} - S_1} &= \left(e^{2S_1 - \bar{M}} \right)^K \\ \log \left(\frac{S_1}{\bar{M} - S_1} \right) &= K (2S_1 - \bar{M}) \end{aligned}$$

First, there is always a symmetric equilibrium $S_1 = \frac{\bar{M}}{2}$. Substituting $S_1 = \frac{\bar{M}}{2}$ gives 0 both on the LHS and the RHS.

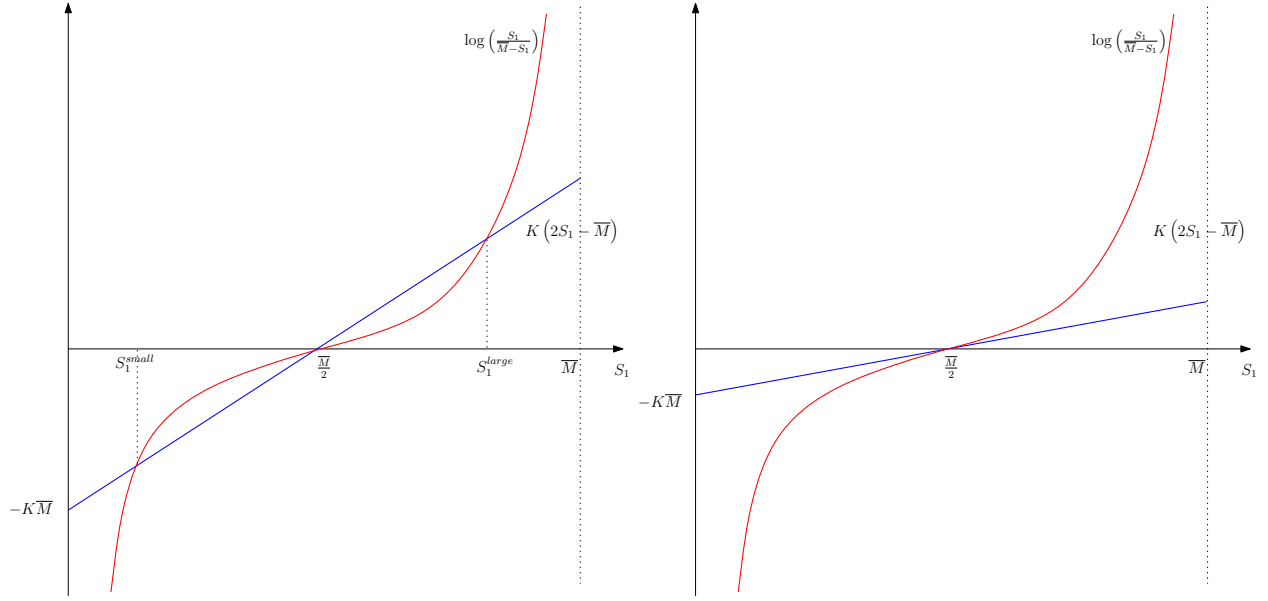


Figure 17: Proof of Theorem A.4: A. Multiple equilibria with cities of different sizes exist when K is large enough; B. a unique equilibrium exists with identical cities exists when K is small.

Next, we show that there are also two asymmetric equilibria, one where $S_1 > \frac{\overline{M}}{2} > S_2$ and the mirror image with $S_2 > \frac{\overline{M}}{2} > S_1$. To see this, observe that the RHS is linear with bounded support on $[0, \overline{M}]$ and takes values between $-K\overline{M}$ and $K\overline{M}$. The LHS takes values between $-\infty$ and $+\infty$: at $S_1 = 0$, the LHS is equal to $\log 0 = -\infty$ and at $S_1 = \overline{M}$, the LHS is equal to $\log \infty = +\infty$. The slope of the LHS is positive and given by

$$\frac{\overline{M}}{S_1(\overline{M} - S_1)}. \quad (\text{A.107})$$

We know that there is an intersection at $S_1 = \frac{\overline{M}}{2}$, and therefore, given the behavior at $S_1 = 0$ and ∞ and continuity of both LHS and RHS, there are at least two more intersections provided the slope at $S_1 = \frac{\overline{M}}{2}$ is flatter than the slope of the RHS, i.e. provided:

$$\frac{4}{\overline{M}} < 2K \quad \text{or} \quad \psi > \frac{2(1 - \gamma(1 - \alpha))}{\overline{M}(1 - \alpha)}. \quad (\text{A.108})$$

The logic is illustrated in Figure 17. ■

Corollary A.2 *Given the CES technology and endogenous agglomeration externalities of the form $A(S) = S^\phi, \phi > 1$, generically cities are of identical size.*

Proof. Now the equilibrium condition can be written as:

$$\frac{S_1}{\overline{M} - S_1} = \left(\frac{S_1}{\overline{M} - S_1} \right)^{\frac{\phi(1-\alpha)}{1-\gamma(1-\alpha)}}. \quad (\text{A.109})$$

which has a unique solution $S_1 = \overline{M} - S_1$ provided $\frac{\phi(1-\alpha)}{1-\gamma(1-\alpha)} - 1 \neq 0$. When $\frac{\phi(1-\alpha)}{1-\gamma(1-\alpha)} - 1 = 0$, there is indeterminacy in the size of both cities and $S_1 \in [0, \overline{M}]$. However, this configuration of parameters is non-generic, therefore generically $S_1 = \frac{\overline{M}}{2}$ and cities are identical. ■