

City Location Choice and Household Productivity

Tan Sein Jone

1 Introduction

The location choice of households is an important determinant of the spatial distribution of economic activity. The choice of location is influenced by a variety of factors such as the availability of jobs, the cost of living, and the quality of public services. In this paper, I develop a model of city location choice that incorporates the productivity of households as an important determinant of location choice. I show that the productivity of households is an important determinant of the spatial distribution of economic activity and that it can help explain the observed patterns of urbanization.

The model is based on the idea that households are more productive in cities because of the agglomeration of economic activity. In particular, households are more productive in certain cities due to the presence of occupations that are complementary to their skills. For example, a household with skills in finance may be more productive in a city with a large financial sector. Similarly, a household with skills in technology may be more productive in a city with a large technology sector. The model shows that households choose to locate in cities where they are most productive, leading to the agglomeration of economic activity in certain cities.

This leads to two key outcomes. First, larger cities will tend to have higher levels of economic activity because they are able to attract more households. Second, cities that specialize in specific occupations will tend to be more attractive to households with those skills. This leads to the agglomeration of economic activity in cities that specialize in specific occupations.

We achieve this by developing a model of city location choice that is based on Quantitative Spatial Models developed by Redding (2016) which loads city heterogeneity onto a city amenity term in order to avoid a trivial solution of all households choosing to live in one city. This model however comes with the independence of irrelevant alternatives (IIA) assumption, which makes cities perfect substitutes for each other. We relax this assumption by using a nested CES structure with correlation proposed by Lind and Ramondo (2023) to allow for correlated draws of productivity between cities, making cities imperfect substitutes for each other.

Both of these models are based off the class of discrete choice models proposed by Eaton and Kortum (2002) which determines production shares of different goods by taking probabilistic draws of productivity of different countries. Rather than having these productivities determine prices, we will draw productivities for households which determine wages and hence utility across different cities.

1.1 Literature Review

2 Model of Production

$$Y_c(\nu) = \prod_k Q_{ck}(\nu)^{\omega_{ck}} \quad (1)$$

Consider a closed economy consisting of N cities and a continuum of household types $\nu \in [0, 1]$. Each city c employs households of type ν in occupation k to produce output $Y_{ck}(\nu)$ using a Cobb-Douglas production function with technology $Z_{ck}(\nu)$. We assume no trade costs between cities, and that the price of good produced by occupation k is freely traded and priced under perfect competition.

The price index of city c is Φ_c . The wage of a household in occupation k in city c is $w_{ck}(\nu) = \Phi_c Z_{ck}(\nu)$. We assume that when a household chooses to work in a particular occupation k , they will be randomly allocated to a sector within a given city. As in EK, productivity is a random variable drawn from a max stable multivariate Fréchet distribution and is dependent on both the city and the occupation. Output produced by a specific occupation is also assumed to be produced by a random sector.

$$U(\nu) = \max_c \{\Phi_c Z_{ck}(\nu)\} \quad (2)$$

A household's utility is purely determined by wages and is given by the maximum wage across all cities. We assume that households are risk neutral and hence maximize expected utility. When choosing a particular city to maximize utility, households will simultaneously choose an occupation to work in. We assume that households are perfectly mobile and can move to any city at no cost.

3 Max Stable Multivariate Fréchet Distribution

$$P[Z_{1k}(\nu) < z, \dots, Z_{Nk}(\nu) < z] = \exp \left\{ \left[- \sum_c^N (T_{ck} H_k(\nu) z^{-\theta})^{\frac{1}{1-\rho_k}} \right]^{1-\rho_k} \right\} \quad (3)$$

We assume that productivity is distributed max stable multivariate Fréchet where T_{ck} is the scale parameter for city c and occupation k . $H_k(\nu)$ is the occupation specific productivity shifter for household of type ν in occupation k . The heterogeneity of this shifter reflects the difference in human capital across different household types. $\theta > 0$ is the shape parameter, characterizing the tail behaviour of the distribution. ρ_k is the occupation specific correlation parameter, which dictates the extent to which productivity draws are correlated across cities for occupation k .

$$T_{ck} = T_c T_k t_{ck} \quad (4)$$

Looking at the scale parameter T_{ck} , we can separate it into three components. T_c is the city specific scale parameter which captures the attractiveness of a city, shifting the distribution for all productivity draws within that city. T_k is the occupation specific scale parameter which is common across all cities, this captures the aggregate effect that occupation k has on productivity. An example shock to this parameter is the effect new computers have on an occupation that heavily relies on computation. t_{ck} is the city-occupation specific scale parameter which captures the idiosyncratic effect of city c on occupation k . The effect on new york on finance is an example of this.

$$Z_c(\nu) = \max_k \{Z_{ck}(\nu)\} \quad (5)$$

A household's schedule of productivities is characterized by a vector of draws from different Fréchet distributions for each city occupation pair. The realized productivity of a household of type ν in city c is the occupation that maximizes the productivity that particular household has in the city.

$$P[Z_1(\nu) < z, \dots, Z_N(\nu) < z] = \exp \left\{ - \sum_k \left[\sum_c^N (T_c H(\nu) z^{-\theta})^{\frac{1}{1-\rho_k}} \right]^{1-\rho_k} \right\} \quad (6)$$

Unlike sequential games where households might pick a city before picking an occupation, we assume that households pick both simultaneously. This is because the schedule of productivity already determines the ideal occupation of a household in a city. From here, we can obtain the joint distribution of all productivities being less than some value z for all cities and occupations.

$$Z(\nu) = \max_c \left\{ \frac{Z_c(\nu)}{\Phi_c} \right\} \quad (7)$$

The joint probability takes on the form of a max stable multivariate Fréchet distribution with a cross-nested CES correlation structure as proposed by Lind and Ramondo (2023). This distribution is a generalization of the Fréchet distribution to the multivariate case, and is used to model the joint distribution of extreme values. This is similar to the GEV distribution, but with the added flexibility of allowing for correlation between the draws of different cities across occupations. A household of type ν has the realized productivity that is hence characterized by the maximum of all productivity draws across all cities and occupations scaled by the inverse of that city's price index Φ_c .

3.1 Correlation Function

$$P[Z_1 < z, \dots, Z_N < z] = \exp \left\{ - \sum_k \left[\sum_c^N (T_c z^{-\theta})^{\frac{1}{1-\rho_k}} \right]^{1-\rho_k} \right\} \quad (8)$$

When we integrate over all household types for a particular household shifter, we get the average productivity shifter for that occupation which we assume to be 1 for all occupations $\int_0^1 H_k(\nu) d\nu = 1$. With the case of a cross-nested CES function, we can approximate a correlation function. Assuming that productivity is distributed max-stable multivariate Fréchet, with scale parameter T_{ck} shape parameter θ and correlation parameters ρ_k .

$$G(Z_1^{-\theta}, \dots, Z_N^{-\theta}) = \sum_c^N T_{ck} z^{-\theta} \quad (9)$$

$$G(Z_1^{-\theta}, \dots, Z_N^{-\theta}) = \sum_k \left[\sum_c^N (T_{ck} z^{-\theta})^{\frac{1}{1-\rho_k}} \right]^{1-\rho_k} \quad (10)$$

Where $Z_c^{-\theta} = (\gamma \Phi_c)^{-\theta}$ and $\gamma = \Gamma\left(\frac{\theta-1}{\theta}\right)$. $\Gamma(\cdot)$ is the gamma function. Expression 9 shows the standard Fréchet distribution with independent productivity in which the strength of comparative advantage is solely governed by the shape parameter θ . Once we abandon this assumption as in Lind and Ramondo (2023), we can obtain a correlation function that allows for correlated draws of productivity across cities as in expression 10. When there exists only one occupation, the correlation parameter will be 0 and expression 10 will reduce to expression 9.

3.2 Choice Shares

$$\pi_c = \frac{Z_c^{-\theta} G_c(Z_1^{-\theta}, \dots, Z_N^{-\theta})}{G(Z_1^{-\theta}, \dots, Z_N^{-\theta})} \quad (11)$$

The expression above gives us the city specific choice shares of households. Where $G_c(Z_1^{-\theta}, \dots, Z_N^{-\theta}) = \partial G(Z_1^{-\theta}, \dots, Z_N^{-\theta}) / \partial Z_c^{-\theta}$. In order to evaluate this expression, we make this simplifying assumption that the correlation parameter is the same across all occupations $\rho_k = \rho$. This allows us to obtain the following expression for the choice shares.

$$\pi_c = (Z_c^{-\theta})^{\frac{1}{1-\rho}} \left[\frac{\sum_k T_{ck}^{\frac{1}{1-\rho}} \lambda_k^{-\rho}}{\sum_k \lambda_k^{1-\rho}} \right] \quad (12)$$

We define $\lambda_k = \sum_c^N T_{ck}^{\frac{1}{1-\rho}} (Z_c^{-\theta})^{\frac{1}{1-\rho}}$. $Z_c^{-\theta}$ simply acts as a city level shifter that scales the productivity of all households in that city. The second term in brackets is a measure of a city c 's relative strength across

occupations. As any individual T_{ck} increases, the share of that city also increases. Conversely, as the strength of other cities in a given occupation λ_k increases, the share of that city decreases. This is because the city is less attractive relative to other cities in that occupation.

$$\pi_{ck} = \frac{Z_c^{-\theta} G_c^k(Z_1^{-\theta}, \dots, Z_N^{-\theta})}{G^k(Z_1^{-\theta}, \dots, Z_N^{-\theta})} \quad (13)$$

$$\pi_{ck} = \frac{(T_{ck} Z_c^{-\theta})^{\frac{1}{1-\rho_k}}}{\sum_c^N (T_{ck} Z_c^{-\theta})^{\frac{1}{1-\rho_k}}} \quad (14)$$

$G^k(Z_1^{-\theta}, \dots, Z_N^{-\theta}) = [\sum_c^N (T_{ck} Z_c^{-\theta})^{\frac{1}{1-\rho_k}}]^{1-\rho_k}$ is the occupation specific function that allows us to evaluate the city specific share of occupations. In this case, we can abandon the simplifying assumption of $\rho_k = \rho$ and obtain the expression for the choice shares of cities within a given occupation. This share is simply the share of productivities relative to all other city's productivities within a given occupation. Notice that as that occupation becomes more correlated across cities, the relative strength of that city starts to matter more.

3.3 Cross and Within City Elasticities

$$\epsilon_{cck} = \frac{\partial \ln \pi_{ck}}{\partial \ln T_{ck}} \approx \frac{1}{1-\rho} \phi_{ck} > 0 \quad (15)$$

$$\phi_{ck} = \frac{T_{ck}^{\frac{1}{1-\rho}} \lambda_k^{-\rho}}{\sum_k T_{ck}^{\frac{1}{1-\rho}} \lambda_k^{-\rho}} \quad (16)$$

We approximate this derivative by assuming that each city is small and therefore $\partial \ln \lambda_k / \partial \ln T_{ck} \approx 0$. This allows us to obtain the expression for the elasticity of a city's own price. Notice that a city's own price elasticity is positive, and increasing in the relevance of a given occupation for a given city. That is, as T_{ck} increases, the elasticity increases. If a given city is particularly productive in occupation k , then changes

in T_{ck} will have an outsized effect on that city's overall choice share. Put it another way: becoming more productive in occupations for which you are already everyone's last choice will not do much to alter the overall choice share of your city. ϕ_{ck} captures the extent to which this city is relatively more productive at occupation k than other cities compared to all other cities in every occupation.

$$\epsilon_{cc'k} = \frac{\partial \ln \pi_{ck}}{\partial \ln T_{c'k}} \approx -\pi_{c'} \phi_{c'k} \left[1 + \left(\frac{\rho}{1-\rho} \right) \left(\frac{\phi_{ck}}{\omega_k} \right) \right] < 0 \quad (17)$$

$$\omega_k = \frac{\lambda_k^{1-\rho}}{\sum_k \lambda_k^{1-\rho}} \quad (18)$$

We can approximate the cross-price elasticity in a similar fashion. The first term in this derivative simply captures the "CES" element: if city c' is large and has a particularly strong comparative advantage in occupation k , then technology shocks in this city-occupation pair will have large effects elsewhere. This is captured by the size $\pi_{c'k}$ and the comparative advantage $\phi_{c'k}$.

The second term captures the unbalanced substitution patterns associated with correlated choice probabilities. Notice first that if $\rho = 0$, this model is simple CES in substitution patterns. As $\rho \rightarrow 1$, the correlated choices dominate the CES element more and more. City c will be particularly effected by shocks to city c' in occupation k if city c is also productive in occupation k . In fact, it is the multiple of $\phi_{c'k} \phi_{ck}$ that dictates the strength of substitution.

But why is this substitution dampened by weight ω_k ? Notice that if occupation k is very attractive and $\omega_k \rightarrow 1$, this implies that there are many attractive cities for households productive in occupation k . That is, we cannot determine the cross-price elasticity without considering the environment in which both c and c' exist, and the strength of substitution between them is strongest when they are both productive in k and no other cities are even close, implying a small ω_k .

$$\epsilon_{ckck} = \frac{\partial \ln \pi_{ck}}{\partial \ln T_{ck}} = \frac{1}{1-\rho_k} [1 - \pi_{ck}] > 0 \quad (19)$$

$$\epsilon_{ckc'k} = \frac{\partial \ln \pi_{ck}}{\partial \ln T_{c'k}} = -\frac{1}{1-\rho_k} \pi_{c'k} < 0 \quad (20)$$

Elasticities within occupations can similarly be derived, this time without any approximations. Notice that both the within and cross-price elasticities are scaled by the $\frac{1}{1-\rho_k}$ parameter, with both increasing as ρ_k increases. This means that as occupations become more correlated across cities, the elasticities increase. For the second term in the within price elasticity, as π_{ck} increases, the elasticity decreases. This illustrates a diminishing returns effect where cities with high levels of city-occupation choice shares will have lower returns for any increases in productivity. In other words, when a city has a high level of choice shares in a given occupation, it has less to gain from further increases in productivity in that occupation relative to the shares it already has.

The opposite is true for cross-price elasticities, where the higher levels of $\pi_{c'k}$ will increase the elasticity. This is because the more productive a city is in a given occupation, the more it will affect another city's choice shares within that given occupation. $\pi_{c'k}$ neatly illustrates the gravity effect where large cities have larger effects on other cities.

$$\epsilon_{cc'} = \frac{\partial \ln \pi_c}{\partial \ln T_{c'}} = \frac{\sum_k \lambda_k^{1-\rho} \pi_{c'k}}{\sum_k \lambda_k^{1-\rho}} \quad (21)$$

$$\epsilon_{ck} = \frac{\partial \ln \pi_c}{\partial \ln T_k} = \phi_{ck} + \omega_k \quad (22)$$

4 Simulations

	Detriot	Chicago	New York
Trades	7	8	3
Services	2	1	8

Table 1: City Scale Parameters T_{ck}

Assume now that we have two occupations, trades and services. We will also assume three cities, Detriot,

Chicago and New York with Detroit and Chicago specializing in trades and New York specializing in services. The scale parameters for each city-occupation pair are as shown in Table 1. The correlation parameter ρ_k is set to 0.7 for services and 0.5 for trades and the shape parameter is set to 2.

For each household, they will draw a $K \times N$ matrix of productivities from specific Fréchet distributions where K is the number of occupations and N is the number of cities. The realized productivity of households is then the maximum productivity across all cities and occupations. The column index of this productivity determines the city at which the household chooses to locate, and the row index determines the occupation that the household chooses to work in. This will give us our choice shares for each city and occupation.

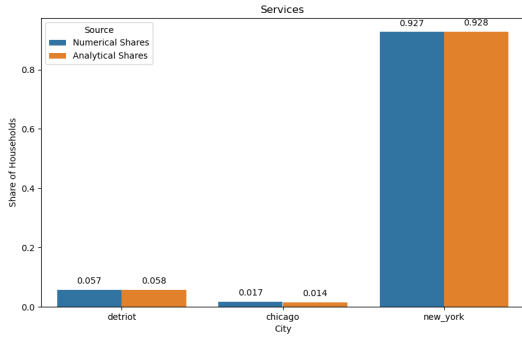


Figure 1: Service Choice Shares

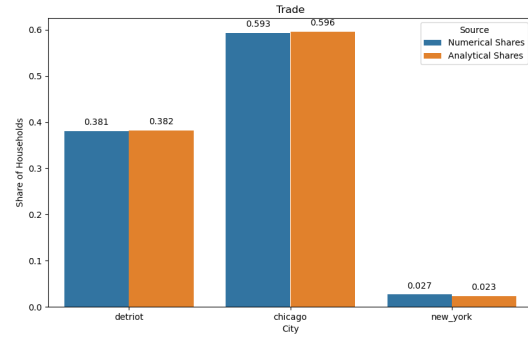


Figure 2: Trades Choice Shares

We now draw 10000 households, simulating the distribution of location choice shares across cities and occupations. This numerical solution will now be compared to our analytical solution for choice shares as discussed in the previous section. Figure 1 and Figure 2 show the simulated occupation specific choice shares for services and trades respectively. The analytical solution is given by expression 14. The same exercise is repeated for city choice shares as shown in Figure 3. Expression 12 gives us the analytical solution for city choice shares. Consistent with our simplifying assumption, $\rho_k = \rho$ for all and it is assumed to be the average of our two ρ_k values. The numerical results closely match the analytical results, validating our analytical solution.

Now that our analytical solutions have been verified, we will now begin to examine the behaviour of our model to ensure its consistency with initial intuitions. Figure 4 shows the initial population distribution across cities. New York has the highest population due to it being the only city specializing in services with Detroit and Chicago sharing trades focused households. The slight bias towards Chicago is expected due to its higher scale parameter for trades. We will now shock Detroit's trades scale parameter by 0.5 times its original value and observe the change in city populations. As shown in Figure 5, the population of Detroit

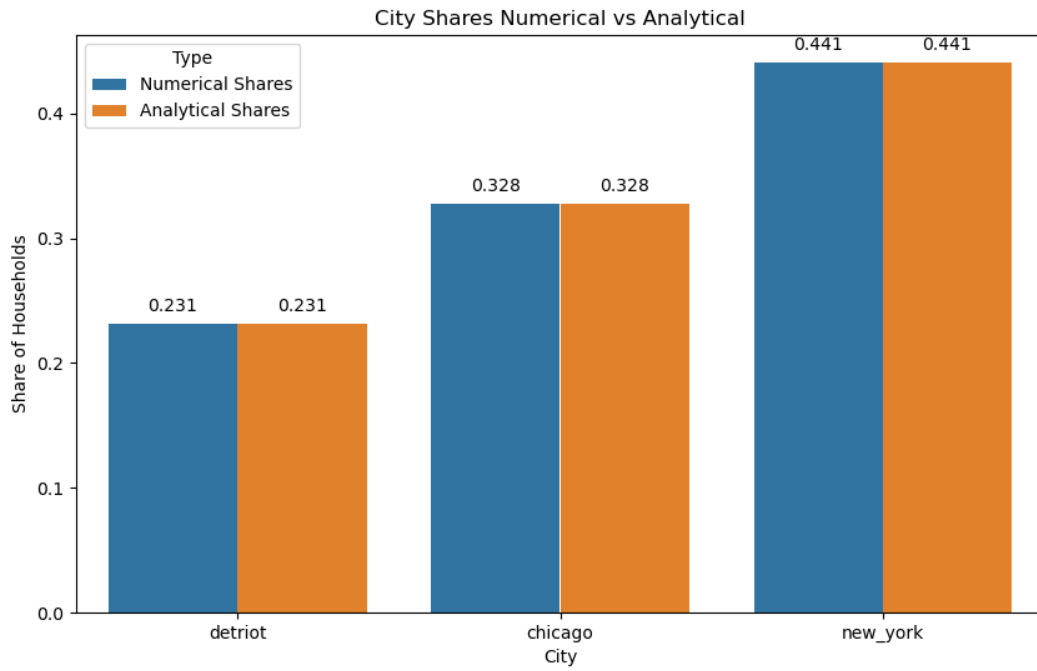


Figure 3: City Choice Shares

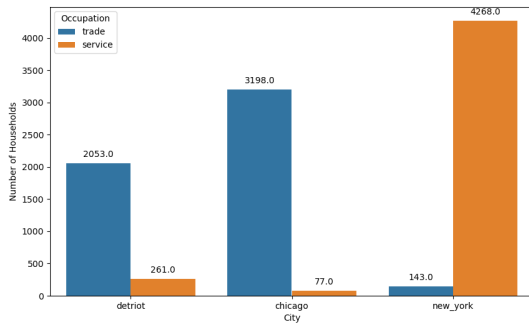


Figure 4: Initial City Population

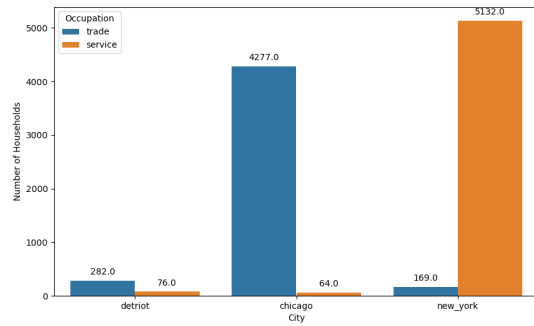


Figure 5: Post Detroit Shock City Population

decreases significantly, with Chicago and New York increasing in population. AS expected, the majority of the households working in trades have relocated to Chicago, with some moving to New York. New York meanwhile picks up the majority of households working in services from Detroit. This is consistent with our intuitions that households working in specific occupations will move to cities that specialize in those occupations.

5 Data

We now take our model to data. The data used is the 2019 American Community Survey (ACS) 1-year estimates. The data is at the metropolitan statistical area (MSA) level and consists of the number of employed individuals in each MSA by occupation. The data is aggregated into 22 occupations and 383 MSAs. Plotting the shares of employment across MSAs, we can see that there is a clear pattern of agglomeration of economic activity in certain MSAs. This is consistent with our model, where households choose to locate in cities where they are most productive. The model predicts that larger cities will tend to have higher levels of economic activity because they are able to attract more households. This is consistent with the data, where larger MSAs tend to have higher levels of employment.

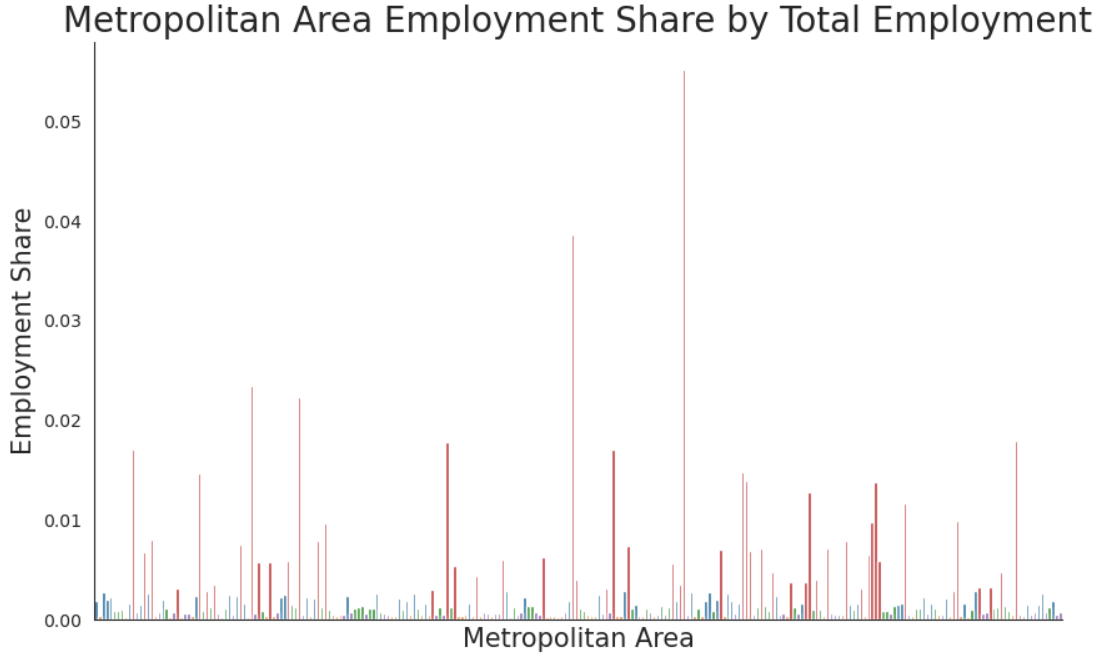


Figure 6: Metropolitan Employment Share

Zooming into the top 25 cities, Figure 7 continues to show concentration in certain cities for specific occupations, The notable example being the New York-New Jersey Metropolitan area which has a high concentration of occupation almost across the board. This illustrates the effect of the T_c shifter which makes a city more attractive overall regardless of occupation. Figure 8 meanwhile shows the composition of occupations in the top 25 cities. In other words, for any given city, which occupation does a person choose to work? We found that for the top 25 cities, the composition of occupations look very similar. This may be counterintuitive

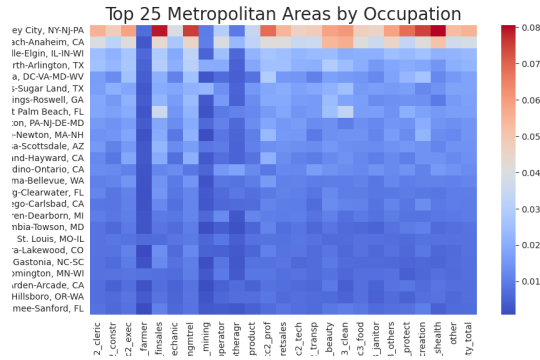


Figure 7: City Shares by Occupations

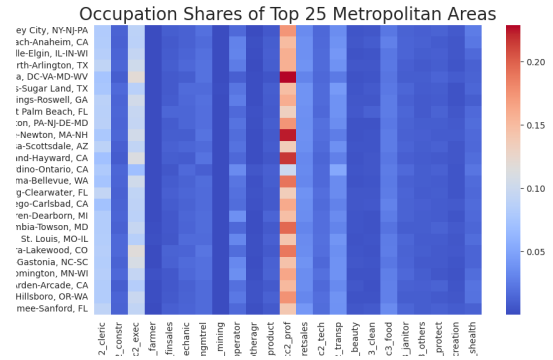


Figure 8: Occupation Shares by Cities

as cities should be specializing in different occupations. However, this may be explained by agglomeration effects where certain sectors tend to have a higher share of households overall, which leads to cities which specialize in those sectors having a higher overall share of households.

6 Proofs

6.1 City Choice Shares (Expression 12)

Begin with the following definitions:

$$G(Z_1^{-\theta}, \dots, Z_N^{-\theta}) = \sum_k \left[\sum_c^N (T_{ck} Z_c^{-\theta})^{\frac{1}{1-\rho_k}} \right]^{1-\rho_k}$$

$$G_c(Z_1^{-\theta}, \dots, Z_N^{-\theta}) = \frac{\partial G(\cdot)}{\partial Z_c^{-\theta}}$$

$$\pi_c = \frac{Z_c^{-\theta} G_c(Z_1^{-\theta}, \dots, Z_N^{-\theta})}{G(Z_1^{-\theta}, \dots, Z_N^{-\theta})}$$

Since we are summing across occupations k , we can move the derivative inside the summation:

$$\frac{\partial G(Z_1^{-\theta}, \dots, Z_N^{-\theta})}{\partial Z_c^{-\theta}} = \sum_k \frac{\partial}{\partial Z_c^{-\theta}} \left[\sum_c^N (T_{ck} Z_c^{-\theta})^{\frac{1}{1-\rho_k}} \right]^{1-\rho_k}$$

Now we define λ_k as the following:

$$\begin{aligned} \lambda_k &= \sum_c^N (T_{ck} Z_c^{-\theta})^{\frac{1}{1-\rho}} \\ &= \sum_c^N T_{ck}^{\frac{1}{1-\rho}} (Z_c^{-\theta})^{\frac{1}{1-\rho}} \end{aligned}$$

We can therefore simplify to the following:

$$\begin{aligned}
\frac{\partial G(Z_1^{-\theta}, \dots, Z_N^{-\theta})}{\partial Z_c^{-\theta}} &= \sum_k \left[(1-\rho) \lambda_k^{-\rho} \frac{\partial \lambda_k}{\partial Z_c^{-\theta}} \right] \\
&= \sum_k \left[(1-\rho) \lambda_k^{-\rho} \left(\frac{1}{1-\rho} \right) T_{ck}^{\frac{1}{1-\rho}} (Z_c^{-\theta})^{\frac{\rho}{1-\rho}} \right] \\
G_c(Z_1^{-\theta}, \dots, Z_N^{-\theta}) &= (Z_c^{-\theta})^{\frac{\rho}{1-\rho}} \sum_k T_{ck}^{\frac{1}{1-\rho}} \lambda_k^{-\rho} \\
\pi_c &= (Z_c^{-\theta})^{\frac{1}{1-\rho}} \left[\frac{\sum_k T_{ck}^{\frac{1}{1-\rho}} \lambda_k^{-\rho}}{\sum_k \lambda_k^{1-\rho}} \right]
\end{aligned}$$

6.2 City Occupation Choice Shares (Expression 14)

$$\begin{aligned}
G^k(Z_1^{-\theta}, \dots, Z_N^{-\theta}) &= \left[\sum_c^N (T_{ck} Z_c^{-\theta})^{\frac{1}{1-\rho_k}} \right]^{1-\rho_k} \\
G_c^k(Z_1^{-\theta}, \dots, Z_N^{-\theta}) &= \frac{\partial G(Z_1^{-\theta}, \dots, Z_N^{-\theta})}{\partial Z_c^{-\theta}} \\
&= (1-\rho_k) \left[\sum_c^N (T_{ck} Z_c^{-\theta})^{\frac{1}{1-\rho_k}} \right]^{-\rho_k} \left(\frac{1}{1-\rho_k} (T_{ck} Z_c^{-\theta})^{\frac{1}{1-\rho_k}-1} T_{ck} \right) \\
&= (1-\rho_k) \frac{1}{1-\rho_k} \frac{T_{ck}}{T_{ck} Z_c^{-\theta}} (T_{ck} Z_c^{-\theta})^{\frac{1}{1-\rho_k}} \left[\sum_c^N (T_{ck} Z_c^{-\theta})^{\frac{1}{1-\rho_k}} \right]^{-\rho_k} \\
Z_c^{-\theta} G_c^k(Z_1^{-\theta}, \dots, Z_N^{-\theta}) &= \frac{(T_{ck} Z_c^{-\theta})^{\frac{1}{1-\rho_k}}}{\sum_c^N (T_{ck} Z_c^{-\theta})^{\frac{1}{1-\rho_k}}} \left[\sum_c^N (T_{ck} Z_c^{-\theta})^{\frac{1}{1-\rho_k}} \right]^{1-\rho_k} \\
\frac{Z_c^{-\theta} G_c^k(Z_1^{-\theta}, \dots, Z_N^{-\theta})}{G^k(Z_1^{-\theta}, \dots, Z_N^{-\theta})} &= \frac{(T_{ck} Z_c^{-\theta})^{\frac{1}{1-\rho_k}}}{\sum_c^N (T_{ck} Z_c^{-\theta})^{\frac{1}{1-\rho_k}}} \\
\pi_{ck} &= \frac{(T_{ck} Z_c^{-\theta})^{\frac{1}{1-\rho_k}}}{\sum_c^N (T_{ck} Z_c^{-\theta})^{\frac{1}{1-\rho_k}}}
\end{aligned}$$

6.3 Within City Elasticity (Expression 15)

$$\ln \pi_c = \frac{1}{1-\rho} \ln(Z_c^{-\theta}) + \ln \left[\sum_k T_{ck}^{\frac{1}{1-\rho}} \lambda_k^{-\rho} \right] - \ln \left[\sum_k \lambda_k^{1-\rho} \right]$$

We assume that each city is small and therefore $\partial \ln \lambda_k / \partial \ln T_{ck} \approx 0$. This allows us to obtain the expression

for the elasticity of a city's own price:

$$\frac{\partial \ln \pi_c}{\partial \ln T_{ck}} \approx \frac{\partial \ln [\sum_k T_{ck}^{\frac{1}{1-\rho}} \lambda_k^{-\rho}]}{\partial \ln T_{ck}} = \left(\frac{\partial [\sum_k T_{ck}^{\frac{1}{1-\rho}} \lambda_k^{-\rho}]}{\partial T_{ck}} \right) \left(\frac{T_{ck}}{\sum_k T_{ck}^{\frac{1}{1-\rho}} \lambda_k^{-\rho}} \right)$$

$$\frac{\partial \ln \pi_c}{\partial \ln T_{ck}} \approx \left(\frac{1}{1-\rho} \right) \left(\frac{T_{ck}^{\frac{1}{1-\rho}} \lambda_k^{-\rho}}{T_{ck}} \right) \left(\frac{T_{ck}}{\sum_k T_{ck}^{\frac{1}{1-\rho}} \lambda_k^{-\rho}} \right)$$

$$\frac{\partial \ln \pi_c}{\partial \ln T_{ck}} \approx \left(\frac{1}{1-\rho} \right) \left[\frac{T_{ck}^{\frac{1}{1-\rho}} \lambda_k^{-\rho}}{\sum_k T_{ck}^{\frac{1}{1-\rho}} \lambda_k^{-\rho}} \right] = \frac{\phi_{ck}}{1-\rho}$$

Where $\phi_{ck} = \frac{T_{ck}^{\frac{1}{1-\rho}} \lambda_k^{-\rho}}{\sum_k T_{ck}^{\frac{1}{1-\rho}} \lambda_k^{-\rho}}$.

6.4 Cross City Elasticity (Expression 17)

$$\frac{\partial \ln \pi_c}{\partial \ln T_{c'k}} \approx \frac{\partial \ln [\sum_k T_{ck}^{\frac{1}{1-\rho}} \lambda_k^{-\rho}]}{\partial \ln T_{c'k}} - \frac{\partial \ln [\sum_k \lambda_k^{1-\rho}]}{\partial \ln T_{c'k}}$$

Consider the derivative of λ_k with respect to $T_{c'k}$:

$$\frac{\partial \lambda_k}{\partial T_{c'k}} = \left(\frac{1}{1-\rho} \right) \left(\frac{1}{T_{c'k}} \right) [T_{c'k} (Z_{c'}^{-\theta})]^{\frac{1}{1-\rho}}$$

We now decompose log-derivatives into level derivatives:

$$\frac{\partial \ln \pi_c}{\partial \ln T_{c'k}} \approx T_{ck}^{\frac{1}{1-\rho}} \left(\frac{\partial \lambda_k^{-\rho}}{\partial T_{c'k}} \right) \left(\frac{T_{c'k}}{\sum_k T_{ck}^{\frac{1}{1-\rho}} \lambda_k^{-\rho}} \right) - \left(\frac{\partial \lambda_k^{1-\rho}}{\partial T_{c'k}} \right) \left(\frac{T_{c'k}}{\sum_k \lambda_k^{1-\rho}} \right)$$

Now consider the first term:

$$\begin{aligned}
T_{ck}^{\frac{1}{1-\rho}} \left(\frac{\partial \lambda_k^{-\rho}}{\partial T_{c'k}} \right) \left(\frac{T_{c'k}}{\sum_k T_{ck}^{\frac{1}{1-\rho}} \lambda_k^{-\rho}} \right) &= T_{ck}^{\frac{1}{1-\rho}} (-\rho) (\lambda_k^{-\rho-1}) \left(\frac{1}{1-\rho} \right) \left(\frac{1}{T_{c'k}} \right) [T_{c'k} (Z_{c'}^{-\theta})]^{\frac{1}{1-\rho}} \left(\frac{T_{c'k}}{\sum_k T_{ck}^{\frac{1}{1-\rho}} \lambda_k^{-\rho}} \right) \\
&= - \left(\frac{\rho}{1-\rho} \right) \left(\frac{[T_{c'k} (Z_{c'}^{-\theta})]^{\frac{1}{1-\rho}}}{\lambda_k} \right) \left(\frac{T_{ck}^{\frac{1}{1-\rho}} \lambda_k^{-\rho}}{\sum_k T_{ck}^{\frac{1}{1-\rho}} \lambda_k^{-\rho}} \right) \\
&= - \left(\frac{\rho}{1-\rho} \right) \left(\frac{[T_{c'k} (Z_{c'}^{-\theta})]^{\frac{1}{1-\rho}}}{\lambda_k} \right) \phi_{ck}
\end{aligned}$$

The second term can be derived in the following way:

$$\begin{aligned}
- \left(\frac{\partial \lambda_k^{1-\rho}}{\partial T_{c'k}} \right) \left(\frac{T_{c'k}}{\sum_k \lambda_k^{1-\rho}} \right) &= -(1-\rho) (\lambda_k^{-\rho}) \left(\frac{1}{1-\rho} \right) \left(\frac{1}{T_{c'k}} \right) [T_{c'k} (Z_{c'}^{-\theta})]^{\frac{1}{1-\rho}} \left(\frac{T_{c'k}}{\sum_k \lambda_k^{1-\rho}} \right) \\
&= -(\lambda_k^{-\rho}) [T_{c'k} (Z_{c'}^{-\theta})]^{\frac{1}{1-\rho}} \left(\frac{1}{\sum_k \lambda_k^{1-\rho}} \right)
\end{aligned}$$

Putting these together, we can derive the following expression for the cross-city elasticity:

$$\begin{aligned}
\frac{\partial \ln \pi_c}{\partial \ln T_{c'k}} &\approx -(Z_{c'}^{-\theta})^{\frac{1}{1-\rho}} \left(\frac{T_{c'k}^{\frac{1}{1-\rho}}}{\lambda_k} \right) \left[\frac{\lambda_k^{1-\rho}}{\sum_k \lambda_k^{1-\rho}} + \frac{\rho}{1-\rho} \phi_{ck} \right] \\
&= -\pi_{c'} \phi_{c'k} \left[1 + \left(\frac{\sum_k \lambda_k^{1-\rho}}{\lambda_k^{1-\rho}} \right) \left(\frac{\rho}{1-\rho} \right) \phi_{ck} \right]
\end{aligned}$$

$$\frac{\partial \ln \pi_c}{\partial \ln T_{c'k}} \approx -\pi_{c'} \phi_{c'k} \left[1 + \left(\frac{\rho}{1-\rho} \right) \left(\frac{\phi_{ck}}{\omega_k} \right) \right]$$

Where $\omega_k = \frac{\lambda_k^{1-\rho}}{\sum_k \lambda_k^{1-\rho}}$.