Outsourcing, Inequality, and Cities

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Abstract

Communication technology breakthroughs have made it possible to separate the proximity of certain production tasks. For instance, lawyers and secretaries used to have to work in the same building, but now secretaries can type a lawyer's dictation miles away from where the lawyer works. In other words, the secretarial job can now be "outsourced."

The previous literature on outsourcing has been concerned with its role in an international context. It has examined changes in the location of jobs. From a domestic perspective, outsourcing can have an additional affect: it can change where people live. Given lawyers and secretaries no longer need to work in the same building, they no longer need to live in the same city either.

This paper exams how the new technologies affect where people work and where they live, on both the empirical and theoretical fronts. Its empirical contribution is to show two facts: (i) "back office" activity like low skill secretarial work is increasingly concentrated in small cities, while "front office" activity like high skill managerial work is increasingly specialized in large cities; (ii) workers without college degrees are migrating to small cities, whereas workers with degrees are moving to large cities. The theoretical contribution of this paper is to explore how the new technologies lead to the observed increasing geographic segregation of workers by skills in a system of cities model. An important question addressed by the theory is how the advent of the new technologies affects city characteristics and the welfare of skilled and unskilled individuals.

JEL: F0; R12; R13; R23

Key words: Outsourcing; segregation; inequality

1 Introduction

Communication technology breakthroughs[1] in the 1990s, including the advent of the internet, have made it possible to separate the proximity of certain production tasks. For instance, lawyers and secretaries used to have to work in the same building, but now secretaries can type a lawyer's dictation miles away from where the lawyer works[2]. In other words, the secretarial job can now be "outsourced."

The emerging literature on outsourcing has been concerned with its role in an international context. It has examined changes in the location of jobs. From a domestic perspective, outsourcing can have an additional effect: it can change where people live. Given that lawyers and secretaries no longer need to work in the same building, they no longer need to live in the same city either.

This paper examines how the new technologies affect where people *work* and where they *live*, on both the empirical and theoretical fronts. Its empirical contribution is to show that "back office" activity like unskilled secretarial work is increasingly concentrated in small cities, while "front office" activity like skilled managerial work is increasingly specialized in large cities. Also, it presents evidence that unskilled workers are migrating to small cities, whereas their skilled counterparts are moving to large cities. These empirical patterns indicate increasing geographic segregation of workers by skills.

The theoretical contribution of this paper is to explore how the new technologies lead to the observed increasing geographic segregation of workers by skills in a Henderson's (1974) system of cities model. An important question addressed by the theory is how the advent of the new technologies affects city characteristics and the welfare of skilled and unskilled individuals.

[1] The first all digital telephony country was born in the early 90s. From the mid 90s to the late 90s, the world started to get online and E-mail became a major communication tool. In 1998, the first deployment of IP telephony was announced. This technology is used by Dell Inc. for calls made to its India service center, and by Ford Co. for communication between its US plants. Because of these new technologies, communication costs fell dramatically as was widely documented in the press, e.g. *The Economist*,

[2] An example is http://www.legaltypist.com/

In the model economy, the centripetal force that agglomerates cities is a static production externality, e.g. knowledge spillover by Lucas (1988), that exists locally. However, agglomeration yields congestion which is a centrifugal force. The balance of the two powers determines the size of cities.

There are two main ingredients besides the standard system of cities framework in the model developed here. First, it has heterogeneous agents of two skill types - skilled workers who bring externality and unskilled workers who do not. For instance, the information exchange between stockbrokers seems to increase the total factor productivity in Wall Street, whereas bookkeepers may not have sufficient knowledge to comprehend market information and share analysis with colleagues.

Second, a frictional cost is incurred if unskilled individuals work separately from their skilled counterparts. Because the empirical part of this study focuses on the 1990s when communication friction declined dramatically, the model assumes the cost is due to communication. Certainly, one may assume the cost is due to transportation if the concern is the 1980s. Previously, the friction was high, and having unskilled and skilled employees working and living together in cities was the viable way to organize production. Nowadays, the low friction makes it possible to move unskilled personnel out of cities and have them working separately from skilled workers, which is desirable because unskilled workers increase congestion but do not aid externality.

The model implicitly assumes only face to face communication can facilitate production externality so that the advent of communication technology will not dissolve the fundamental need of cities. This paper does not intend to justify this assumption, but recent research, e.g. Brown and Liedholm (2002), does argue that for sophisticated ideas, face to face communication is more effective than long distance communication.

The model presents striking results that are in contrast with commentators' conjectures on how new technology and unskilled job outsourcing would affect the economy. First, new technology that eliminates communication friction will enlarge cities, transform them to places for elites, and make them more productive. The technology does not, as presumed, eradicate the need for big cities as production centers. Second, outsourcing is beneficial to unskilled workers, but it can make skilled workers worse off. This finding is contrary to the supposition that outsourcing helps skilled workers at the cost of unskilled laborers. Moreover, instead of worsening welfare inequality, the change reduces it along with higher aggregate welfare.

As mentioned earlier, the current literature on outsourcing is in international context. Like my paper, Kremer and Maskin (2003) and Antras, Garicano and Rossi-Hansberg (2004) show that new technology results in outsourcing of unskilled jobs and study the impact on welfare. The main differences are: (i) I consider domestic outsourcing in which people can also relocate, whereas they concern jobs to India in which people cannot move; (ii) I prove that domestic outsourcing is beneficial to unskilled domestic workers, while they show that international outsourcing can hurt these people.

On domestic outsourcing, the literature is just new, and a systematic analysis is waiting for development, as pointed out by Antras and Helpman (2004). Abraham and Taylor (1996) document a fast growing trend of domestic outsourcing. From the theoretic perspective, there is Duranton and Puga (forthcoming) which is closest to mine. They show that: (i) When communication friction is high, firms have managerial and production functions integrated in the same places and cities are specialized by industry; (ii) When the friction is low, firms have the two functions separated in different places and cities are specialized by function. In the second case, readers can notice domestic outsourcing at the plant level. The main differences between their paper and mine are: (i) I focus on welfare analysis by having heterogeneous workers, while they do not touch the issue but consider industrial structural change in cities by assuming homogeneous workers. (ii) In terms of empirical contribution, I study the new wave of white-color job outsourcing and present geographic segregation between skilled and unskilled workers, while they study geographic specialization of manufacturing industries and the functions of cities. (iii) From modeling aspect, the emergence of cities in my model is due to a Marshallian production externality, whereas it is due to product variety in their work.

This paper is also different from Kremer and Maskin (1996). In particular, my model consider geographic segregation between skilled and unskilled workers, while their work concerns cross sector segregation between the two types of workers and does not have spatial element.

The remainder of this paper is organized as follows. Section 2 presents evidences on increasing geographic segregation between skilled and unskilled workers. Section 3 sets up the model. Section 4 characterizes solutions and analyzes how new technology affects segregation, city characteristics, and workers' welfare. Section 5 concludes and discusses the boundary of the theory.

2 The Facts

Organized in two parts, this section presents evidences that indicate increasing geographic segregation between skilled and unskilled workers. In the first part, I consider changes in *the locations of jobs*. The findings are: (i) Outsourcing of unskilled secretarial kinds of supportive jobs is prevalent and is fast growing; (ii) These outsourced jobs are increasingly and disproportionally allocated in small cities; (iii) While these jobs are increasingly concentrated in small cities, the geographic concentration of their main users does not change; (iv) These main users are skilled industries; (v) Even within these main users, unskilled supportive jobs are increasingly concentrated in small cities, whereas skilled managerial jobs are increasingly specialized in large cities. In the second part, I examine changes in *the locations of people* and find that: Through cross city migration, workers without a bachelor degree are moving from large cities to small cities whereas workers with degrees are moving in the opposite direction. The sources of evidences are County Business Pattern, Public Used Micro Samples, and Input-Output Accounts. In the appendix, details on the use of the data are provided.

2.1 Unskilled and Skilled Jobs Are Geographically Separated

Here, I focus on the industry of Business Support Services (NAICS 5614) and those industries who are main users of the support services. By definition, Business Support Services perform outsourced ongoing supportive routines, such as document preparation, telemarketing, and customer services. The industry is unskilled because in 2000 only 17% of its employees had a bachelor degree or more while 26% of American workers had that qualification. Due to the new outsourcing wave of white-color unskilled jobs (part of these jobs go to India as well known), this industry is emerging and is fast growing. Before 1997, it was unremarked and did not have its own classification, but in 2002, it had 0.7 million employees, a figure 1.3 times as large as the industry of Air Transportation. Between 1998 and 2002, it grew twice as fast as the US employment growth (See Table 1).

Table 2 reports the employment of Business Support Services in 1998 and 2002 by four city size classes. The grouping criteria are: (i) Large cities are metropolitan areas with more than two million people; (ii) Upper medium cities are metropolitan areas having a population between one and two millions; (iii) Lower medium cities are metropolitan areas with a population between a quarter and one million; (iv) Small cities include rural areas and metropolitan areas with less than a quarter million people. The table shows disproportional growth of the industry across places. During the four year period, the industry employment increased by more than 20% in lower medium cities and in small cities, while it had virtually no growth in upper medium and in large cities.

Table 3 presents the evolution of geographic concentration of Business Support Services from 1998 to 2002. For each city size class (location) I calculate and report the industry location quotient (LQ), which is the ratio of the location's share of the industry employment to its share of aggregate employment. A value above one means that the location is relatively specialized in the industry; whereas a value below one shows that the location is relatively less concentrated in the industry. If every location has a value of one, it implies that the industrial activities are evenly distributed across places. The table shows consistent increase of the industry LQ in lower medium and small cities and consistent decline in large and upper medium cities over time. In the four year period, the LQ increased by around 14% and 18% in lower medium cities and in small cities, whereas it decreased by about 8% and 5% in large cities and in upper medium cities. These changes indicate that geographic concentration of Business Support Services is moving from large cities to small cities.

To understand whether or not this new wave of unskilled job outsourcing results in geographic separation between unskilled and skilled workers, it is important to know the characteristics and geographic concentrations of those industries who are main users of Business Support Services. Table 4 presents the usage of the services by industry in 1997. In the table, industries are classified by 2 digit NAICS codes except three smaller industries including legal services (5411) are reported separately, because they are the extremely intensive user in the 2 digit classification they belong. The first nine industries used up 75% of total intermediate supplied by Business Support Services but weighted only 38% of the US GDP. Moreover, the nine industries all used the services intensively as indicated in column 7. Therefore, I consider these industries as the main users of the services and sometimes call them, as a whole, the downstream sector.

Table 5 presents LQ of the main users of Business Support Services by city size class between 1998 and 2002. The direction of changes was ambiguous for the first three classes. In small cities, industries such as legal services (5411), information (51), and financial services (52) had decreasing LQ. For all the main users as a whole, changes of LQ were tiny. Therefore, the geographic concentration of the downstream sector might not change during the period.

We have seen the geographic separation between Business Support Services and the downstream sector. If this separation can constitute geographic segregation between skilled and unskilled workers, then the main users of the services have to be skilled industries in general. Table 6 summarizes skill composition by industry in 2000. Except wholesale trade and retail trade, all the main users had a much larger share of workers having a bachelor degree or more comparing to the US average 26%. This skilled share was 59% in legal services and 58% in scientific services, and the share was more than 40% in four other main users. As a whole, the downstream sector had a skilled share of 33%, 7% higher than the US average. Therefore, the main users are skilled industries in general.

Given that the downstream sector has created the new wave of outsourcing, it is interesting to see if those white-color unskilled jobs remaining in the sector are also being sent to small cities and being segregated from skilled jobs. If the answer is positive, then an important evidence of increasing geographic segregation between skilled and unskilled workers is found, because the downstream sector consistently weighted more than 47% of US employment between 1998 and 2002.

To investigate, I consider managers and office and administrative supportive workers. In the downstream sector, managers are skilled jobs because 57% of them had a bachelor degree or more in 2000. On the other hand, supportive workers, including secretaries, customer service representatives, typists, etc, are unskilled positions because only 15% of them had degrees in that year. Another important reason to study supportive workers is that they are with the highest risk to be outsourced from the downstream sector. In 2000, 48% of employees in Business Support Services were this type of workers.

In Table 7, I calculate and report the occupation LQ. For example, the manager LQ is the ratio of the location's share of managers in the downstream sector to its share of total employment in that sector. The table presents occupation LQ in 1990 and in 2000 by city size class. From the highest to the smallest class, the manager LQ changed by about 4%, 6%, -5%, and -11% whereas the LQ of secretaries changed by around -7%, -1%, 3%, and 11% during the decade. This indicates that the geographic concentration of skilled managerial activities was shifting from small cities to large cities, while the concentration of unskilled supportive activities was shifting in the opposite direction.

Table 8 presents a clear pattern of increasing geographic segregation between skilled and unskilled workers during the period between 1990 and 2000. In 1990, one might meet 69 managers and 163 supportive workers by greeting one thousand employees in the downstream sector in small cities. Ten years after, the person greeted another one thousand employees in the sector in small cities, and she would find that she met 6 less managers and 27 more supportive workers comparing to 1990. By doing the same experiment, one would find that in 2000, she would meet 7 more managers and 3 less supportive workers in large cities comparing to the result in 1990. As showed in the table, the downstream sector's managerial jobs moved to larger cities whereas supportive jobs in the sector moved to smaller cities during the decade. Given that the downstream sector had about half of US employment in 2000, this is an important evidence of increasing geographic segregation between skilled and unskilled workers.

2.2 Unskilled and Skilled People Are Geographically Separated

Here, I focus on changes in the locations of people. More precisely, it is on how people migrate across cities. Because domestic outsourcing not only affects where jobs are located but also has an impact on where people live, if the displacement of unskilled jobs for some industries is strong enough in large cities, then we may also observe that large cities are losing unskilled workers through cross city migration, even though job mobility across occupations and industries (e.g. a secretary can be a taxi driver) may counteract the significance.

Using migration data in PUMS 2000, the evidence presented here is that unskilled workers are migrating from large cities to small cities, whereas their skilled counterparts are migrating in the opposite direction. By skill type (having a B.A. or not), I calculate each metropolitan area's in-migration and out-migration flows, between 1995 and 2000, for workers not in the armed forces. Out-migration is subtracted out from in-migration, to get the net-migration flow of the 5 year period. Then, I derive the net-migration rate which is the net-migration flow as a percentage of the approximated 1995 skill specific non-armed labor force.

By skill type, I regress, for each metropolitan areas, the net migration rate against the log city size and have the result in figure 1 and figure 2. Figure 1 presents a negative relationship between the log city size and the net migration rate of workers without college degrees. It indicates that small cities were gaining unskilled workers through cross city migration while large cities were losing them, during the five years. Figure 2 shows a positive relationship between the log city size and the net migration rate of workers with degrees. It indicates that large cities were gaining skilled workers through cross city migration whereas small cities were losing them. The coefficients and standard errors of the regressions are reported in the figures. The results are significant at 5% level and indicate increasing geographic segregation between skilled and unskilled workers.

3 The Model and Definitions

In the economy, competitive firms can produce tradable numeraire at a location with the technology

$$Y = AF(H, M)$$

where H is total ideas and M is total intermediate goods both used in producing total output Y at the location. A is a static production externality arising from the agglomeration of ideas at the location. Assumed

$$A = H^{\gamma}$$

For simplicity, the internal technology of firms, $F(.,.)$, is assumed Cobb-Douglas:

$$F(H, M) = H^{\alpha} M^{1-\alpha}$$

although the theory will work for CES functional forms with positive elasticity of substitution.

Ideas are made internally in firms, but intermediate goods are a composite of perfectly substitutable support

$$M = L + \tau L_r$$

where L is total in-house support at the location and L_r is total outsourcing support done by remote subcontractors. Remote support is subject to an iceberg cost. Only τ portion of the remote support can survive after transmission. Therefore $\tau \in [0, 1]$ is the technology level with which we are concerned. When $\tau = 0$, outsourcing support is not possible. When $\tau = 1$, support can be done anywhere without a friction.

The economy has a unit measure of workers of two skill types. Let ϕ be the fraction of population that is skilled. Each skilled worker generates one unit of idea, and every unskilled worker provides one unit of support. They choose where to live and where to work, and have linear preference over numeraire consumption. Each individual must pay rent for one unit of residential land and must commute between home and workplace. The commuting cost is c units of numeraire per unit of land round trip.

The economy has infinite supply of land on a real line, and has a continuum of competitive land developers who organize cities on the line with zero sunk cost. A developer can collect rent from its residents and may offer them transfer. Cities have a monocentric structure, with a center point called Central Business District (CBD) as the production center and workers' homes lined up equally on both sides of the CBD.

Cities create congestion from commutes, although they facilitate production spillover. Consider a city with size N population. Workers living z units away from the CBD must pay cz commuting cost, and the city edges are $\frac{N}{2}$ units away from the CBD. Therefore, the city's total commuting cost is

$$\text{Total commuting cost} = 2\int_0^{\frac{N}{2}} cz dz = \frac{cN^2}{4}$$

This congestion cost increases exponentially with the city size.

Rural areas are the land outside cities. They are inexhaustible and are of measure zero size. Thus, workers residing there pay zero rent and have jobs right next to home, and the production spillover will be zero in rural areas.

I now proceed with definitions. For simplicity, I consider symmetric cities, following the common practice in the literature. An *allocation* is a vector of five variables: (i) H is the representative city's total (used for citywide level from now) skilled population; (ii) L is the city's total unskilled population; (iii) L_r is the total number of outside unskilled workers delivering remote support into the city; (iv) N is the city size; (v) μ is the measure of cities. The first three variables are the *production factors* used in the city.

Definition 1 *An optimal allocation is* (H, L, L_r, N, μ) *that maximizes the economy's aggregate welfare, which is aggregate output net of aggregate congestion cost, subject to feasibility constraints.*

Definition 2 *A competitive equilibrium is an allocation* (H, L, L_r, N, μ)*, a price vector* (w_h, w_l, w_{lr})*, and a transfer* κ *such that: (i) Workers maximize preference by choosing where to work and where to live; (ii) Competitive firms maximize profit by choosing where to produce and how much to employ; (iii) Competitive city developers maximize profit; (iv) Market clearing conditions hold.*

The feasibility constraints and market clearing conditions can be written as

$$\begin{aligned} H + L &= N \\ H\mu &= \phi \\ L\mu + L_r\mu &= 1 - \phi \end{aligned} \tag{1}$$

which require: (i) A city's population is the sum of total skilled and total unskilled workers living in the representative city; (ii) The economy's measure of skilled workers equals the representative city's total skilled workers times the measure of cities; (iii) The economy's measure of unskilled workers equals the measure of cities times the sum of the representative city's total unskilled workers and the total rural unskilled workers delivering remote support into the city.

The above conditions acknowledge two facts: (i) All unskilled workers providing remote support live in rural areas; (ii) All skilled workers live in cities. The former is the result of avoiding unnecessary congestion and rent, and the later is because skilled jobs are only available in cities.

The last definition is about segregation:

Definition 3 *The economy is completely integrated if unskilled personnel all live together with skilled workers in cities. In such case, $L_r = 0$. The economy is completely segregated if unskilled personnel all live in rural areas while skilled workers all live in cities. In this case, $L = 0$. The economy is partially segregated if there are unskilled individuals in cities as well as in rural areas.*

Finally, I make four assumptions: (i) $\gamma \in (0, 1)$; (ii) $\phi \geq \frac{2\gamma-(1-\alpha)}{2\gamma}$; (iii) $2\gamma > 1 - \alpha$; (iv) $\frac{\alpha-\gamma}{1-\gamma} > \phi$. The first assumption guarantees city size will not grow explosively, the second one assures the existence of the symmetric equilibrium, the third one is for regularity, and the last one simply makes skilled workers obtain higher welfare than unskilled personnel.

4 Solutions and Analysis

This section analyzes how better technology affects segregation, city characteristics, and workers' welfare. I divide the section into three parts. In the first part, I characterize the optimal allocation and the equilibrium at two limiting levels of technology, $\tau = 1$ and $\tau = 0$. A direct comparison between solutions of the two cases illustrates key implications of the model easily. In the second part, I discuss the solution of the general case, $\tau \in (0, 1)$. In the last part, I formally state, prove, and discuss the model's implications which apply generally.

4.1 Two Limiting Cases:

4.1.1 $\tau = 1$

Optimal Allocation When $\tau = 1$, all unskilled personnel should live and work in rural areas, because rural unskilled workers do not create congestion but do have the same marginal productivity as urban unskilled workers given this frictionless technology. The economy should have complete segregation and $L_1 = 0$, where the subscript indicates the solution at $\tau = 1$. The planner's welfare optimization can be written as an unconstrained problem in which the planer simply chooses city size (H in this case) to maximize aggregate output minus aggregate congestion cost:

$$\underset{H}{MAX} \left\{ \phi H^{\gamma} \left(\frac{1-\phi}{\phi} \right)^{1-\alpha} - \phi \frac{c}{4} H \right\}$$

A larger agglomeration (H) on one hand raises aggregate output, but on the other hand increases aggregate congestion due to the longer average commuting distance $\frac{H}{4}$ of bigger cities. Since $\gamma < 1$, there exists a unique optimal size of spillover which occurs when agglomeration benefit weighs urban congestion at the margin.

The first order condition implies

$$H_1 = \left(\frac{4\gamma}{c} \right)^{\frac{1}{1-\gamma}} \left(\frac{1-\phi}{\phi} \right)^{\frac{1-\alpha}{1-\gamma}} \tag{2}$$

The optimal allocation is characterized by H_1, $L_1 = 0$, and (1).

Not surprisingly, optimal size of agglomeration increases with γ but decreases with c. When γ is large, marginal effect of the agglomeration on total factor productivity decays slowly. Large agglomeration is desired. On the contrary, when c is high, commuting cost increases drastically in distance and urban congestion outweighs agglomeration benefit easily. Small agglomeration is preferred.

Competitive Equilibrium In the equilibrium, urban cost of living, the sum of rent and commuting cost, is homogeneous everywhere within cities because citizens must be indifferent between where to live. In a size N city,

$$\text{Urban cost of living } = \frac{cN}{2}$$

since workers living at the city edges pay zero rent and $\frac{cN}{2}$ commuting cost. Given the homogeneous urban cost of living, workers must pay cx extra rent by living x units closer to the CBD. Therefore, the total rent of the city is

$$\text{Total rent} = 2\int_0^{\frac{N}{2}} c\left(\frac{N}{2} - z\right) dz = \frac{cN^2}{4}$$

When $\tau = 1$, rural unskilled workers earn the same income as urban unskilled workers, because remote support and in-house support are perfectly substitutable. Moreover, rural unskilled workers need not pay urban cost of living. Therefore, all unskilled individuals prefer living in rural areas, and $L_1 = 0$.

The representative city developer maximizes profit, which is the city's total rent less total transfer payment. Its decision is subject to the "no incentive to leave" constraints. That is the developer must guarantee utility and wage levels such that production factors and firms have no incentive to relocate. To attract skilled workers, the production factor that brings externality, the developer offers them a transfer κ. In addition to the city size and the transfer, the total amount of each production factor used in the city is also picked, in order to affect guaranteed levels. However, the levels are equalized over the economy and must be taken as given due to competition among developers.

Given that $L_1 = 0$ in the equilibrium, the developer's problem is reduced to

$$\begin{aligned} \underset{\{H,L_r,\kappa\}}{MAX} \quad & \left\{ \frac{cH^2}{4} - \kappa H \right\} \\ s.t. \quad & V_h = p_h + \kappa - \frac{cH}{2} \\ & V_l = p_{lr} \\ & w_h = \alpha H^{\gamma+\alpha-1} L_r^{1-\alpha} \\ & w_{lr} = (1-\alpha) H^{\gamma+\alpha} L_r^{-\alpha} \end{aligned}$$

where the first two constraints are the indirect utilities of skilled and rural unskilled workers and the last two constraints are equilibrium wage functions derived from firms' profit maximization. The indirect utility and the equilibrium wage function of urban unskilled workers are omitted here because $L_1 = 0$.

The first order conditions imply the transfer as a function of production factors. Substituting out L_r using $L_1 = 0$ and (1), it is

$$\kappa = \gamma H^{\gamma} \left(\frac{1-\phi}{\phi} \right)^{1-\alpha} \tag{3}$$

In the equilibrium, the developer must earn zero profit due to free entry. This condition together with (3) implies (2). (1), (2) and $L_1 = 0$ then characterize the equilibrium allocation, which in turn solves the equilibrium wages and transfer.

4.1.2 $\tau = 0$

When $\tau = 0$, outsourcing support to remote subcontractors is not possible. Therefore, all unskilled workers must live in cities and $L_{r0} = 0$. Given this fact, solving the optimal allocation and the equilibrium is analogous to the $\tau = 1$ case. The solutions can be determined after deriving

$$H_0 = \phi^{\frac{2}{1-\gamma}} \left(\frac{4\gamma}{c} \right)^{\frac{1}{1-\gamma}} \left(\frac{1-\phi}{\phi} \right)^{\frac{1-\alpha}{1-\gamma}} \tag{4}$$

4.1.3 Comparison

A direct comparison between equilibrium outcomes at the above two limiting cases easily illustrates implications on how better technology affects segregation, city characteristics, and welfare. From $\tau = 0$ to $\tau = 1$, the economy is subject to the following changes. First, unskilled workers leave cities and the economy changes from complete integration ($L_r = 0$) to complete segregation ($L = 0$). Second, city size increases, because given that $\phi \in (0, 1)$,

$$N_1 = H_1 > \phi^{\frac{1+\gamma}{1-\gamma}} H_1 = \frac{1}{\phi} H_0 = N_0$$

Consequently, cities' average rent $\frac{cN}{4}$ increases. Third, unskilled workers' welfare W_l becomes higher, because given that $H_1 > H_0$,

$$W_{l1} = H_1^{\gamma} (1 - \alpha) \left(\frac{1 - \phi}{\phi} \right)^{-\alpha} > H_0^{\gamma} (1 - \alpha) \left(\frac{1 - \phi}{\phi} \right)^{-\alpha} - \frac{c}{2} N_0 = W_{l0}$$

unskilled workers benefit from more productive cities and earn higher income than before. Moreover, they save urban cost of living. Fourth, skilled workers' welfare W_h may decrease, because on one hand, they obtain higher income.

$$H_1^{\gamma} (\alpha + \gamma) \left(\frac{1 - \phi}{\phi} \right)^{1-\alpha} > H_0^{\gamma} (\alpha + \gamma) \left(\frac{1 - \phi}{\phi} \right)^{1-\alpha}$$

On the other hand, they pay more urban cost of living.

$$\frac{c}{2} N_1 > \frac{c}{2} N_0$$

In a numerical example that $\alpha = 0.66$, $\phi = 0.5$, and $\gamma = 0.2$, skilled workers get worse of from $\tau = 0$ to $\tau = 1$.

4.2 The General Case

One might like to solve the equilibrium at $\tau \in (0,1)$. Solving this general case is an analogy of solving limiting cases, noticing that: (i) The representative city developer is now subject to three constraints of indirect utilities, three constraints of equilibrium wages, and non-negative constraints of L and L_r; (ii) When both non-negative constraints are not binding, unskilled workers must be indifferent between living in cities and living in rural areas. Solving the equilibrium, one can see that: (i) The economy is of partial segregation when τ is in a range of medium values,

$$(\underline{\tau}, \bar{\tau}) = \left(\frac{(1-\alpha) - 2\gamma(1-\phi)}{(1-\alpha)}, \frac{(1-\alpha)}{(1-\alpha) + 2\gamma\left(\frac{1-\phi}{\phi}\right)} \right)$$

(ii) It is of complete integration, when $\tau \leq \underline{\tau}$. (iii) It is of complete segregation, when $\tau \geq \bar{\tau}$.

4.3 Analysis

Here I formally analyze how an increase of technology τ affects segregation, city characteristics, and workers' welfare. The following propositions *focus on the case that* $\tau \in [\underline{\tau}, \bar{\tau})$, because if and only if τ is in this range, an increase of τ can alter segregation and city characteristics. The analysis on the two other cases that $\tau \in [0, \underline{\tau})$ and $\tau \in [\bar{\tau}, 1]$ are fairly easy and are excluded from the propositions. Briefly speaking, when $\tau \in [0, \underline{\tau})$, a marginal increase of τ has no effect. When $\tau \in [\bar{\tau}, 1]$, a marginal increase of τ increases aggregate welfare and benefits both types of workers without changing the equilibrium allocation.

Proposition 4 *Increasing τ increases geographic segregation between skilled and unskilled workers.*

Proof. For ease of exposition, define $\rho = \frac{L}{H}$ be the ratio of cities' unskilled to skilled workers. When $\tau \in [\underline{\tau}, \bar{\tau})$, it is necessary that unskilled workers are indifferent between living in rural areas and living in cities. The wage premium of urban unskilled workers is to compensate urban cost of living. That is

$$(1-\tau)(1-\alpha) H^{\gamma} \left(\rho + \tau \left(\frac{1-\phi}{\phi} - \rho\right)\right)^{-\alpha} = \frac{c(1+\rho)}{2} H$$

in which N, L, and L_r are substituted out by ρ and H. From the above equation, it is seen that holding ρ and H fixed, a marginal increase of τ reduces the wage premium of urban unskilled workers so that the premium is not enough to compensate urban cost of living. The left hand side expression becomes smaller than the right hand side expression. In other words, cities are too expensive to live for the unskilled workers. This inequality motivates urban unskilled workers relocating to rural areas. Given that $\frac{\partial H}{\partial \tau} > 0$, which will be proved true, restoring the equality requires $\frac{\partial \rho}{\partial \tau} < 0$, which implies less urban unskilled workers in the equilibrium. That is higher segregation. ■

Proposition 5 *The First Welfare Theorem holds.*

Proof. The gap between social and private marginal productivity of skilled workers is

$$\frac{\partial}{\partial H} H^{\gamma+\alpha} M^{1-\alpha} - \frac{\partial}{\partial H} A H^{\alpha} M^{1-\alpha} = \gamma H^{\gamma} \left(\frac{M}{H}\right)^{1-\alpha}$$

which is exactly the transfer κ offered by city developers. The First Welfare Theorem holds because city developers internalize the production externality. ■

Proposition 6 *Increasing τ increases production spillover H^{γ}, city size N and average rent $\frac{cN}{4}$.*

Proof. The proof is fairly simple and intuitive given that the First Welfare Theorem holds. When $\tau \in [\underline{\tau}, \bar{\tau})$, a marginal increase of τ results in unskilled workers leaving cities. If a skilled worker is added into the city when a unskilled worker leaves, the city size does not change, and consequently the total congestion is invariant. Nevertheless, the density of skilled workers increases in the city. The higher density enhances agglomeration benefit and makes it outweigh total congestion at the original city size. Therefore, city size should increase by attracting even more skilled workers. As a result, the average rent increases. ■

Proposition 7 *Increasing τ raises aggregate welfare and aggregate output.*

Proof. Only aggregate output

$$\tilde{Y} = \phi H^{\gamma} \left(\frac{M}{H}\right)^{1-\alpha} \tag{5}$$

needs to be considered, since congestion always takes away γ portion of the output as a standard feature of system of cities. The value of (5) depends on (i) H^{γ} the size of production spillover and (ii) M/H the total employment of intermediate goods relative to ideas in cities. In the appendix, I show that a higher τ, though does decrease M/H, increases $\tilde{Y}$, because its positive effect on the production spillover always dominates. This suffices to the proof. ■

Proposition 8 *Increasing τ reduces welfare inequality between skilled and unskilled workers.*

Proof. We have the following facts. First, given unit elasticity of substitution, skilled and unskilled workers earn constant shares of aggregate output. The shares are α for skilled workers and $1-\alpha$ for unskilled workers in this model. Second, given the structure of system of linear cities, the aggregate urban cost of living is $2\gamma\tilde{Y}$. Half of the cost is aggregate congestion, and the other half is aggregate rent which eventually becomes a part of skilled workers' income through city developers' transfer payment. Third, every urban worker pays the same urban cost of living regardless of types. When τ is such that a θ measure of unskilled workers living in rural areas, the economy has $1-\theta$ urban workers and ϕ of them is skilled. Therefore, $\phi/(1-\theta)$ portion of the aggregate urban cost of living is paid by skilled workers, and the other $(1-\phi-\theta)/(1-\theta)$ portion is paid by unskilled workers. Thus, the welfare of a skilled worker is

$$W_h = \left[\alpha + \gamma - \left(\frac{\phi}{1-\theta}\right) 2\gamma\right] \frac{\tilde{Y}}{\phi} \tag{6}$$

and for an unskilled worker, it is

$$W_l = \left[(1-\alpha) - \left(\frac{1-\phi-\theta}{1-\theta}\right) 2\gamma\right] \frac{\tilde{Y}}{1-\phi} \tag{7}$$

Given that $\frac{\partial\theta}{\partial\tau} > 0$ by proposition 4, clearly $\frac{\partial(W_h/W_l)}{\partial\tau} < 0$ as $\tau \in [\underline{\tau}, \bar{\tau})$. ■

Proposition 9 *Increasing τ raises unskilled workers' welfare.*

Proof. Given that $\frac{\partial\theta}{\partial\tau} > 0$ by proposition 4 and $\frac{\partial\tilde{Y}}{\partial\tau} > 0$ by proposition 7, clearly (7) is increasing in τ. ■

The above propositions make clear why unskilled workers can benefit from the geographic segregation between skilled and unskilled workers. The better technology expels unskilled workers, who do not aid production externality, from cities and brings in skilled workers who do contribute. This results in more efficient use of urban land space which makes viable larger cities and *higher* production spillover and raises unskilled workers' wages. Moreover, unskilled workers pay *smaller share* of aggregate urban cost of living as some of them relocate to rural areas. *In summary*, the better technology allows unskilled workers saving on rent and commuting cost while still benefiting from more productive cities.

Skilled workers may not benefit from the new technology and the spatial sorting. With the new technology, they have to pay an increasing share of the rising aggregate urban cost of living, although they do get higher income. The next proposition states this result.

Proposition 10 *Increasing τ decreases skilled workers' welfare.*

Proof. Because the expression inside the square bracket of (6) is decreasing in τ but $\frac{\partial\tilde{Y}}{\partial\tau} > 0$, it needs further calculation to determine the net effect of a higher τ on skilled workers' welfare. In the appendix, I show that the net effect is negative. ■

5 Concluding Remarks

This paper contributes to the research on domestic outsourcing, with evidence and theory. The empirical findings are that not only unskilled jobs but also unskilled workers are moving from large cities to small cities, whereas both skilled jobs and skilled workers are moving from small cities to large cities. The theory developed here shows how this increasing geographic segregation of workers by skill emerges. The advent of communication technology results in unskilled job outsourcing, and the released urban land space allows more skilled workers, who contribute production spillover, to come in. This spatial sorting in turn increases the density of urban skilled workers and enhances agglomeration benefit of cities. Therefore, cities enlarge and become places of elites.

To the extent of workers' welfare, the increasing geographic segregation in fact benefits unskilled workers. They earn higher wage since firms have higher total factor productivity, and they save urban cost of living by moving to rural areas. On the other hand, skilled workers are made worse off. Although their wage increases, the urban cost of living they have to pay increases even more.

The idea of this paper can be alternatively modeled in a core-periphery environment although this paper is in system of cities. Then, location changes of activities within a metropolitan area can be studied.

The welfare results rely on the assumption of mobility. If instead people are immobile across places, the results can be overturned. To see this, assume the economy is originally at a technology level such that there are unskilled workers in rural areas as well as in cities. Also, assume that relocation cost is so high that urban unskilled workers will not move given a technology progress. Then, city characteristics such as city size and size of production spillover will not change, but relative employment of intermediate goods to ideas becomes higher because rural unskilled workers can deliver more support. Consequently, urban unskilled workers are laid behind since they earn lower wages but pay the same urban cost of living as before. On the other hand, skilled workers are better off since their wages are higher but the urban cost of living is the same. As for rural unskilled workers, they are still better off because of increasing demand of unskilled jobs in rural areas. This environment in fact can fit into international outsourcing without much modification and has results consistent with trade literature.

The model of this paper is isolated from other possible sources of externality such as neighborhood effect. Since outsourcing results in segregation, one might wonder how neighborhood effect will influence if it is important. Rural unskilled workers might not learn from skilled workers. Rural children might have inferior education resources. If these are important, there may be more unskilled workers staying in cities and sacrificing current utility for better prospect of future. Moreover, segregation that deters social mobility may have long run impacts on skill composition and productivity of the economy. Further research effort is needed.

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Table 1: Size and growth of Business Support Services, 1998 - 2002

	Number of employees (Thousands)			
	All US	Business Support Services	Air Trans-portation	Motor Vehicle Manufacturing
Year \ NAICS		5614	481	3361
1998	108,118	642	560	235
2002	112,401	693	548	217
% growth	4.0%	7.9%	-2.1%	-7.9%

Table 2: Employment of Business Support Services by city sizes, 1998 - 2002

Business Support Services employment (Thousands)			
Size class\Year	1998	2002	% growth
2m+	322	325	0.93%
1m-2m	123	127	3.16%
0.25m-1m	108	131	21.58%
rural-0.25m	89	110	23.59%
US total employment (Thousands)			
Size class\Year	1998	2002	% growth
2m+	50,139	53,010	5.72%
1m-2m	16,190	16,969	4.82%
0.25m-1m	17,727	18,145	2.36%
rural-0.25m	24,062	24,279	0.90%

Table 3: Geographic concentration of Business Support Services, 1998 - 2002

	Business Support Services LQ					%change
Size class\Year	1998	1999	2000	2001	2002	98-02
2m+	1.08	1.05	1.02	1.02	0.99	-8.11%
1m-2m	1.28	1.25	1.25	1.18	1.21	-5.26%
0.25m-1m	1.02	1.08	1.11	1.14	1.17	14.41%
rural-0.25m	0.63	0.66	0.69	0.73	0.74	17.93%

Table 4: Usage of Business Support Services (BSS) by industry in 1997

NAICS	Industry	Column 1 BSS usage by industries in millions of dollars	Column 2 % Usage of BSS inter-mediates	Column 3 Cumlative % of BSS inter-mediates	Column 4 Value added by industries in millions of dollars	Column 5 % weight of value added in GDP	Column 6 Cumlative % of value added in GDP	Column 7 Intensity: column 2 divided by column 5
52	Finance and Insurance	5358	14.0	14	612350	7.3	7	1.9
42	Wholesale trade	4715	12.3	26	503890	6.0	13	2.0
62	Health Care and Social Assistance	4156	10.9	37	502908	6.0	19	1.8
44	Retail trade	3773	9.9	47	442995	5.3	25	1.9
334	Computer and Electronic Product Manufacturing	2397	6.3	53	156565	1.9	27	3.3
5411	legal services	2093	5.5	59	109805	1.3	28	4.2
51	Information	1970	5.2	64	351782	4.2	32	1.2
54A	Professional, Scientific, and Technical Services except 5411	1942	5.1	69	425981	5.1	37	1.0
813	Religious, Grantmaking, Civic, Professional and Similar	2082	5.5	75	57138	0.7	38	8.0
33A	Manufacturing 33 except 334	1242	3.3	78	495550	5.9	44	0.5
53	Real Estate and Rental and Leasing	1139	3.0	81	599139	7.2	51	0.4
61	Educational Services	936	2.5	83	59049	0.7	52	3.5
48	Transportation 8	783	2.1	85	198165	2.4	54	0.9
23	Construction	707	1.9	87	323862	3.9	58	0.5
32	Manufacturing 2	704	1.8	89	345308	4.1	62	0.4
71	Arts, Entertainment and Recreation	689	1.8	91	82714	1.0	63	1.8
81A	Other Services Except Public Administration and 813	477	1.2	92	194197	2.3	65	0.5
56	Administrative and Support and Waste Management…	651	1.7	94	245056	2.9	68	0.6
72	Accommodation and Food Services	518	1.4	95	220757	2.6	71	0.5
31	Manufacturing 1	481	1.3	96	200559	2.4	73	0.5
22	Utilities	403	1.1	97	154381	1.8	75	0.6
92	Local government	299	0.8	98	60351	0.7	76	1.1
49	Transportation 9	266	0.7	99	95071	1.1	77	0.6
93	Owner-occupied dwellings	203	0.5	99	516730	6.2	83	0.1
21	Mining	111	0.3	100	72171	0.9	84	0.3
91	Federal government	81	0.2	100	11732	0.1	84	1.5
11	Agriculture, Forestry, Fishing, and Hunting	3	0.0	100	9477	0.1	84	0.1
	Total intermediates of BSS	38179						
	GDP				8345646			

Table 5: Geographic concentrations of main users, 1998 and 2002

1998 LQ by size class by main industry using BSS										
Size Class \ industry	52	42	62	44	334	5411	813	51	54	All main users
2m+	1.15	1.14	0.93	0.88	1.31	1.23	0.95	1.23	1.33	1.04
1m - 2m	1.12	1.02	0.95	0.98	0.83	0.94	1.05	0.96	0.92	0.98
025m - 1m	0.92	0.90	1.07	1.08	0.79	0.88	1.09	0.85	0.80	0.98
rural - 0.25m	0.67	0.77	1.13	1.20	0.63	0.66	1.00	0.66	0.51	0.93
2002 LQ by size class by main industry using BSS										
Size Class \ industry	52	42	62	44	334	5411	813	51	54	All main users
2m+	1.14	1.15	0.92	0.90	1.29	1.25	0.95	1.24	1.31	1.05
1m - 2m	1.16	1.02	0.95	0.97	0.87	0.95	1.04	0.99	0.92	0.99
025m - 1m	0.92	0.90	1.08	1.08	0.78	0.89	1.11	0.84	0.81	0.99
rural - 0.25m	0.65	0.74	1.14	1.18	0.62	0.57	1.00	0.61	0.51	0.92
% change of the LQ between 1998 and 2002 by size class by main industry using BSS										
Size Class \ industry	52	42	62	44	334	5411	813	51	54	All main users
2m+	-0.6%	0.7%	-0.6%	1.9%	-1.0%	1.8%	-0.6%	0.2%	-1.6%	1.0%
1m - 2m	2.9%	-0.6%	0.2%	-1.7%	4.1%	0.6%	-0.5%	3.3%	0.6%	1.0%
025m - 1m	0.5%	0.3%	1.3%	0.7%	-1.4%	1.2%	1.9%	-1.0%	1.3%	1.0%
rural - 0.25m	-4.2%	-3.8%	0.8%	-1.7%	-1.6%	-12.5%	0.4%	-6.4%	1.2%	-1.1%

Table 6: Skill composition by industry, 2000

NAICS	Industry	% with BA	% without BA
52	Finance and Insurance	40	60
42	Wholesale trade	23	77
62	Health Care and Social Assistance	33	67
44	Retail trade	15	85
334	Computer and Electronic Product Manufacturing	45	55
5411	legal services	59	41
51	Information	40	60
54A	Professional, Scientific, and Technical Services except 5411	58	42
813	Religious, Grantmaking, Civic, Professional and Similar	47	53
	All Main Users	33	67
5414	Business Support Services	17	83
	All US industries	26	74

Table 7: Geographic concentrations of managers and supportive workers within the downstream sector, 1990 and 2000

Occupation: Managers			
	Occupation LQ of the downstream sector		
Size class	1990	2000	%change
2m+	1.07	1.00	-6.71%
1m-2m	1.02	1.02	-0.51%
0.25m-1m	1.00	1.02	2.52%
rural-0.25m	0.88	0.97	10.53%
Occupation: Office and Administrative Support			
	Occupation LQ of the downstream sector		
Size class	1900	2000	%change
2m+	1.12	1.17	4.35%
1m-2m	1.03	1.08	5.68%
0.25m-1m	0.97	0.92	-5.37%
rural-0.25m	0.82	0.73	-10.86%

Table 8: Number of occupation specific workers per 1000 downstream sector employees, 1990 and 2000

Number of mangers per 1000 downstream sector employees			
Size class\Year	1990	2000	Change
2m+	94	101	6.6
1m-2m	86	93	7.2
0.25m-1m	81	79	-2.4
rural-0.25m	69	63	-5.9
Number of supportive workers per 1000 downstream sector employees			
Size class\Year	1990	2000	Change
2m+	197	194	-2.9
1m-2m	189	198	9.5
0.25m-1m	184	199	15.2
rural-0.25m	163	190	27.2

Figure 1: Net migration rate (1995 - 2000) of unskilled workers by log city size

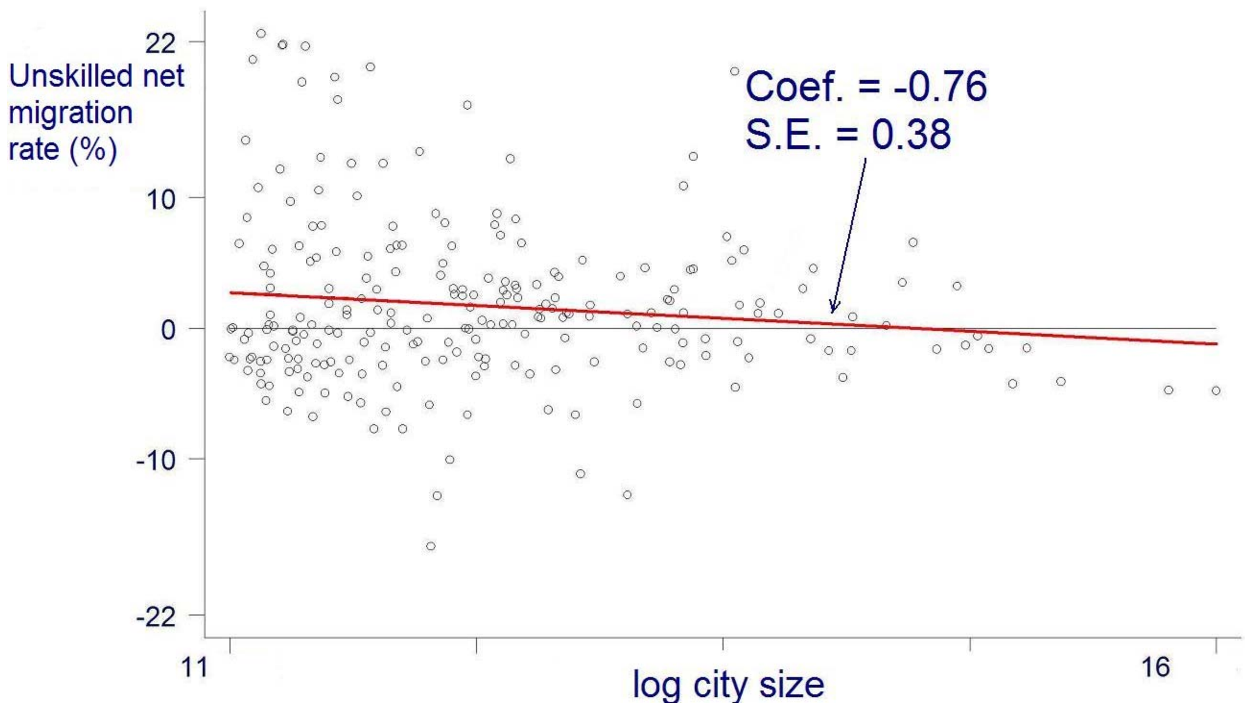
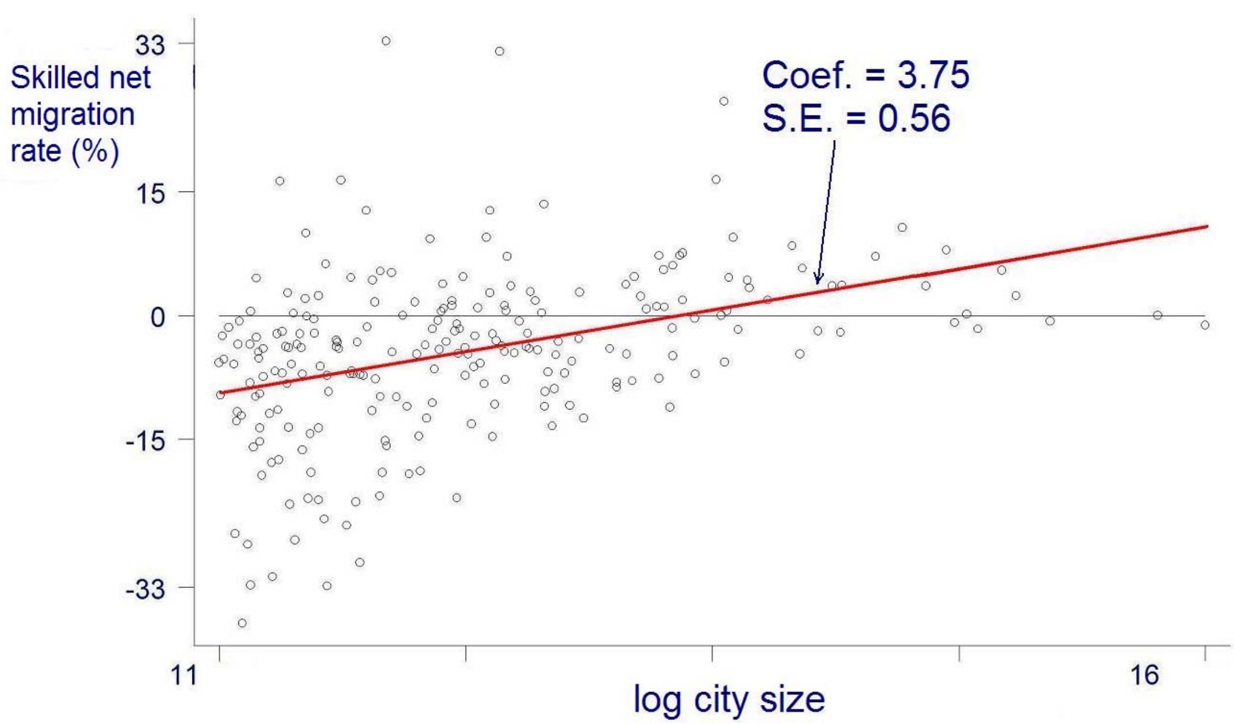


Figure 2: Net migration rate (1995 - 2000) of skilled workers by city size



6 Data Appendix

The sources of evidences of this paper are County Business Pattern (CBP) 1998 through 2002, Public Used Micro Samples (PUMS) 1990 and 2000, and Input-Output (I-O) Accounts 1997 Benchmark. The CBP data are used to produce Table 1, 2, 3, and 5. The PUMS data are used to produce Table 6, 7, and 8 and Figure 1 and 2. The Input-Output Accounts are used to produce Table 4.

The geographic units studied here are metropolitan areas and rural areas. For CBP data, metropolitan areas and rural areas are as defined in 1999 by the Office of Management and Budget (OMB). The concepts of metropolitan areas are NECMA for New England States and MSA/CMSA for other states. As producing Figure 1 and 2, I directly follow 2000 PUMS definition of metropolitan areas. As comparing 1990 and 2000 figures in Table 7 and 8, I actually use Integrated Public Used Micro Samples and metropolitan areas are in 1990 PUMS definition. Though here is lack of discipline, effectiveness of the evidences are not affected.

CBP data has a severe nondisclosure problem for determining the exact industrial employment at a location. Holmes and Stevens (2003) develop an estimation procedure. It is of particular value as estimating employment at a location having establishments in 1000-plus employee size classes. I follow their procedure to estimate county level employment and then aggregate data to the metropolitan level.

For PUMS data, I use uses 5% sample for 2000 and 1% metro sample for 1990 because of the interest in metropolitan data. The structure of the fundamental geographic unit (PUMA) in PUMS varied across years. For samples in 2000, the 5% is superior than 1%, because metropolitan information in geographic units with population less than 400,000 are not identifiable in the 1% sample. For 1990 samples, the 1% metro sample is superior than 5% state sample because 1% PUMAs follow metropolitan borders while 5% PUMAs do not.

7 Analytical Appendix

7.1 $\frac{\partial \tilde{Y}}{\partial \tau} > 0$

Here, I show that increasing τ has a positive net effect on aggregate output when $\tau \in [\underline{\tau}, \bar{\tau})$. This suffices to the proof of proposition 7. Substituting

$$H = \left(\frac{4\gamma}{c}\right)^{\frac{1}{1-\gamma}} (1+\rho(\tau))^{\frac{-2}{1-\gamma}} \left(\rho(\tau) + \tau\left(\frac{1-\phi}{\phi} - \rho(\tau)\right)\right)^{\frac{1-\alpha}{1-\gamma}} \tag{8}$$

for H in (5), we have

$$\begin{aligned} \widetilde{Y} &= \phi\left(\frac{4\gamma}{c}\right)^{\frac{\gamma}{1-\gamma}} \Theta(\tau)^{\frac{1}{1-\gamma}} \\ \Theta(\tau) &= (1+\rho(\tau))^{-2\gamma}\left(\rho(\tau) + \tau\left(\frac{1-\phi}{\phi} - \rho(\tau)\right)\right)^{1-\alpha} \end{aligned}$$

where

$$\rho(\tau) = \frac{(1-\alpha) - 2\gamma\frac{\tau}{(1-\tau)}\left(\frac{1-\phi}{\phi}\right)}{2\gamma - (1-\alpha)}$$

Taking derivative of Θ with respect to τ, one can see that $\Theta'(\tau) > 0$ for any $\tau \in [\underline{\tau}, \bar{\tau})$ if $\Theta'(\underline{\tau}) > 0$. Evaluating the derivative at $\underline{\tau}$, we have

$$\Theta'(\underline{\tau}) = \left[\left(\frac{1}{\phi}\right)^{2\gamma} - 1\right]\left[\frac{(1-\alpha)^2}{[2\gamma-(1-\alpha)](1-\phi)^{\alpha}\phi^{1-\alpha}}\right] > 0$$

Therefore,

$$\frac{\partial \widetilde{Y}}{\partial \tau} > 0, \ \forall \tau \in [\underline{\tau}, \bar{\tau})$$

7.2 $\frac{\partial(M/H)}{\partial\tau} < 0$

Applying (8) into the condition that urban wage premium of unskilled workers is to compensate urban cost of living

$$(1-\tau)(1-\alpha)H^{\gamma}\left(\frac{M}{H}\right)^{-\alpha} = \frac{c(1+\rho)H}{2}$$

we have

$$\frac{M}{H} = \frac{(1-\tau)(1+\rho(\tau))(1-\alpha)}{2\gamma}$$

which is decreasing in τ since $\rho'(\tau) < 0$.

7.3 $\frac{\partial W_h}{\partial\tau} < 0$

Here, I show that increasing τ has a negative net effect on the welfare of skilled workers when $\tau \in [\underline{\tau}, \bar{\tau})$. This suffices to the proof of proposition 10. A skilled worker's welfare is defined as

$$W_h = p_h + \kappa - \frac{cN}{2}$$

In the equilibrium, it is

$$W_h = \left(\frac{4\gamma}{c}\right)^{\frac{\gamma}{1-\gamma}}\left[\left(\rho(\tau) + \tau\left(\frac{1-\phi}{\phi} - \rho(\tau)\right)\right)^{\frac{1-\alpha}{1-\gamma}}\begin{pmatrix}(\alpha+\gamma)(1+\rho(\tau))^{\frac{-2\gamma}{1-\gamma}} \\ -2\gamma(1+\rho(\tau))^{\frac{-1-\gamma}{1-\gamma}}\end{pmatrix}\right]$$

Taking derivative with respect to τ, we have

$$\begin{aligned}
\frac{\partial W_h}{\partial\tau} &= \Psi(\tau)\left(\frac{4\gamma}{c}\right)^{\frac{\gamma}{1-\gamma}}\left(\frac{(2\gamma-(1-\alpha))^{\frac{2\gamma-(1-\alpha)}{1-\gamma}}(1-\alpha)^{\frac{1-\alpha}{1-\gamma}}}{(2\gamma)^{\frac{2\gamma}{1-\gamma}}(1-\gamma)\phi}\right)(1-\tau)^{\frac{\gamma-\alpha}{1-\gamma}}\left[\frac{\phi-\tau}{(1-\tau)\phi}\right]^{\frac{-\alpha-1}{1-\gamma}} \\
\Psi(\tau) &= \begin{bmatrix}(2\gamma-(1-\alpha))(1-\alpha) - \left(\frac{(1-\phi)(1+\gamma)(2\gamma-(1-\alpha))}{(1-\tau)}\right) \\ +\left(\frac{2\gamma(1-\phi)}{(1-\tau)} - (1-\alpha)\right)\left(\frac{\phi-\tau}{(1-\tau)\phi}\right)(\alpha+\gamma)\end{bmatrix}
\end{aligned}$$

$\frac{\partial W_h}{\partial \tau} < 0$ if and only if $\Psi(\tau) < 0$. To verify the sign of $\Psi(\tau)$, consider convex combinations of $\underline{\tau}$ and $\bar{\tau}$

$$\tau = (1-\lambda)\frac{(1-\alpha) - 2\gamma(1-\phi)}{(1-\alpha)} + \lambda \frac{(1-\alpha)}{(1-\alpha) + 2\gamma\left(\frac{1-\phi}{\phi}\right)}$$

for any $\lambda \in [0,1]$. After some mechanical algebraic operation, one can find that

$$\Psi(\tau) = -\left[\frac{(2\gamma - (1-\alpha))}{1 + \left(\frac{(2\gamma-(1-\alpha))(1-\phi)(1-\lambda)}{1-\alpha}\right)}\right]\left[\begin{array}{c} \frac{(1-\gamma)}{2\gamma}\left((1-\phi)2\gamma + (1-\alpha)\phi\right) \\ +(2\gamma-(1-\alpha))(1-\phi)\lambda \\ +(2\gamma-(1-\alpha))(\alpha+\gamma)(1-\alpha)\phi \\ +(2\gamma-(1-\alpha))(\alpha+\gamma)(1-\phi)(1-\lambda)2\gamma \\ +\frac{1}{2\gamma}\left(1-(2\gamma)^2\right)(\alpha+\gamma)(1-\alpha) \\ +\left(1-(2\gamma)^2\right)(1-\lambda)(\alpha+\gamma)\left(\frac{1-\phi}{\phi}\right) \end{array}\right] < 0$$

Therefore, for any $\tau \in [\underline{\tau},\bar{\tau})$, $\frac{\partial W_h}{\partial \tau} < 0$.