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Zhou, Haiwen

20 October 2017

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Haiwen Zhou

Abstract

This paper studies a general equilibrium model of rural-urban migration in which manufacturing firms engage in oligopolistic competition and choose increasing returns technologies to maximize profits. Urban residents incur commuting costs to work in the Central Business District. Surprisingly a change in the size of the population or an increase in the exogenously given wage rate will not affect a manufacturing firm's choice of technology. This helps to explain why firms in developing countries may not adopt labor intensive technologies even under abundant labor supply. An increase in the number of manufacturing firms increases both the employment rate and the level of employment in the manufacturing sector. However, manufacturing firms choose less advanced technologies. Capital accumulation leads manufacturing firms to choose more advanced technologies, but may not increase employment in the manufacturing sector.

Keywords: Economic development, the choice of technology, rural-urban migration, increasing returns, urbanization

JEL Classification Numbers: O14, O18, R14

1. Introduction

Economic development is associated with structural changes as labor force relocates from the agricultural sector to the manufacturing sector (Lewis, 1954). With the existence of high levels of fixed costs of production, modern technologies displays significant degrees of increasing returns (Chandler, 1990). Even though advanced technologies have high levels of labor productivity, those technologies with high levels of fixed costs associated with capital equipments may not be the best technologies for a developing country with limited supplies of capital and the choice of appropriate technologies is a long-lasting interesting question in economic development (Sen, 1960, Stewart, 1977). While the classic models of rural-urban migration such as Lewis (1954), Ranis and Fei (1961), and Harris and Todaro (1970) have received a lot of deserved attention, surprisingly, the choice of increasing returns technologies in a general equilibrium model of rural-urban migration has not been addressed formally in the literature.

This paper contributes to the literature by incorporating the choice of increasing returns technologies into a general equilibrium model of rural-urban migration and by modeling the urban spatial structure. In this model, individuals derive utility from the consumption of an agricultural good, a manufactured good, and residential land. The production of the manufactured good is concentrated at the Central Business District (CBD). Following Harris and Todaro (1970), we assume that the wage rate in the manufacturing sector is exogenously given.[1] With the rigid manufacturing wage rate higher than the market clearing wage rate, workers in the manufacturing sector are subject to unemployment/underemployment.

Rural-urban migration is a very significant issue in the process of economic development. Most of the megacities in the world currently are located in developing countries (Todaro and Smith, 2012, chap. 7). Rural-urban migration has led to the existence of a large informal sector in the cities of many developing countries (Rauch, 1993). In this model, individuals consider moving into the manufacturing sector by comparing the wage rate in the agricultural sector and the expected wage rate in the manufacturing sector.

A manufacturing firm's fixed costs consist of capital only and its marginal costs consist of labor only. The existence of fixed costs of production leads to increasing returns in the manufacturing sector. With increasing returns, the type of market structure in the manufacturing sector is oligopoly. Manufacturing firms choose their levels of output and technologies to maximize profits.

A more advanced technology is specified as a technology with a higher fixed but a lower marginal cost of production. When a manufacturing firm chooses its technology, it faces the following tradeoff. The marginal benefit of adopting a more advanced technology is that marginal cost of production decreases. The higher the level of output, the higher is the saving on total marginal cost. The marginal cost of adopting a more advanced technology is that the fixed costs composed of capital are higher. A manufacturing firm's optimal choice of technology leads to the equalization of the marginal benefit and marginal cost of adopting a more advanced technology.

With the conditions for the optimal choices of output and technologies established, we then impose various market clearing conditions, including markets for the agricultural good, the manufactured good, labor, and capital. Also, since individuals have equal ownership of land, capital and possible profit, we also impose the condition that the sum of revenue distributed to individuals is equal to the sum of returns to land, capital, and firms.

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[1] The wage rate is rigid could be a result of government regulations or the existence of unions. Alternatively, the wage rate can be viewed as given in a Lewis type model when a large amount of surplus labor exists. The wage rate will increase when surplus labor decreases. Empirical research on the wage rate during China's economic development is provided by Zhang, Yang, and Wang (2011). They show that China's wage rate was stagnant before 2000 and China reached the Lewis turning point in about 2000 and the wage rate began to rise since then.

We show that when the number of manufacturing firms is exogenously given, an increase in the number of manufacturing firms causes both the employment rate and the level of employment in the manufacturing sector to increase. However, manufacturing firms choose less advanced technologies when the number of firms increases. This result that a decrease in the number of firms induces each firm to adopt more advanced technologies is consistent with the usage of industrial policies in countries such as South Korea to restrict the number of firms in strategic industries (Wade, 1990, Amsden, 2001).

Surprisingly a change in the manufacturing wage rate does not affect the level of manufacturing technology even though this kind of change affects the costs of labor for a manufacturing firm. The reason is as follows. In this general equilibrium model, the equilibrium level of technology may be affected by multiple equilibrium conditions. In addition to the condition for the optimal choice of technology, another condition affecting the equilibrium level of technology is that the quantity supplied and quantity demanded of capital should be equal. First, when the number of manufacturing firms is exogenously given, if the manufacturing wage rate increases, the return to capital will increase correspondingly according to a firm's condition for the optimal choice of technology. Since the impact of a higher wage rate is cancelled out by the impact of a higher cost of capital, the level of technology in the manufacturing sector does not change with the manufacturing wage rate. In this case, the level of technology is determined by the condition for the clearance of the market for capital. Second, when the number of manufacturing firms is endogenously determined by the zero profit condition, the price and the level of output of a manufacturing firm will change correspondingly if the manufacturing wage rate increases. These changes will cancel out the impact of a change in the manufacturing wage rate. As a result, a firm's equilibrium choice of technology determined by the condition for the optimal choice of technology and the condition for the clearance of the market for capital is not affected by the level of the manufacturing wage rate.

In this model, an increase in the size of the population will not affect the level of technology in the manufacturing sector. The reason is that the size of the population enters neither the condition for a manufacturing firm's optimal choice of technology nor the condition for the clearance of the market for capital. The size of the population may affect the level of manufacturing technology indirectly through the wage rate. However, as we have discussed, a change in the manufacturing wage rate does not affect a manufacturing firm's choice of technology. Thus an increase in the size of the population will not affect the equilibrium level of technology in this general equilibrium model. This result that the size of the population may not affect the level of technology helps to explain why firms in developing countries may not adopt labor intensive technologies even under abundant labor supply. In the literature, White (1978) and Pack (1982) have discussed factors preventing firms from choosing appropriate technologies, such as training and information costs. Here we show that firms actually may not adopt labor intensive technologies even without training and information costs.

We show that capital accumulation may not increase the level of employment in the manufacturing sector. The reason behind this is that an increase in the amount of capital leads manufacturing firms to choose more advanced technologies. Because the marginal cost of labor for each unit of output for a more advanced technology decreases, total employment in the manufacturing sector may not increase with capital accumulation. In Lewis (1954), capital accumulation is equivalent to job creation. The Lewis model has been criticized because capital accumulation leads to the adoption of more labor saving technologies while employment in the manufacturing sector may not increase (Todaro and Smith, 2012, p. 118). Here we provide a formal presentation that when manufacturing firms choose among increasing returns technologies, the level of employment in the manufacturing sector may not increase with the endowment of capital.

This paper is related to three lines of literature. First, this paper is related to the literature on rural-urban migration in the process of economic development, such as Harris and Tadaro (1970), Zhang (2002), and Yuki (2007). However, the choice of technologies in the manufacturing sector is not studied in the above models.

Second, this paper is related to the literature studying urban spatial structure, as surveyed in Anas et al. (1998). More specifically, Wheaton (1974) and Takuma and Sasaki (2000) have conducted comparative statics on urban spatial structure. However, rural-urban migration and the choice of technologies in the manufacturing sector are not addressed in this line of literature.

Third, this paper is mainly related to the literature on the choice of technologies in economic development. Sen (1960) has studied the choice of technologies when increasing returns are absent. In his survey, White (1978) has argued that the adoption of appropriate technologies in developing countries is possible and that the scales of production of firms affect their choice of technologies. In a stimulating paper, Murphy et al. (1989) have modeled industrialization as the adoption of increasing returns technologies when an economy may employ either constant or increasing returns technologies to produce a manufactured good.[2] While Murphy et al. (1989) have focused on a closed economy, Trindade (2005) also considers the impact of international trade on the adoption of increasing returns technologies. Different from the literature on the choice of technology in the 1960s and 1970s which mainly focused on the possibilities of more job creation by adopting more labor intensive technologies, the possibility of the existence of multiple equilibria is the main concern in Murphy et al. (1989) and Trindade (2005). Rural-urban migration and the urban spatial structure are not addressed in the above models.

The plan of the paper is as follows. Section 2 specifies the model. Section 3 studies the equilibrium in which the number of manufacturing firms is exogenously given. Section 4 revisits the equilibrium in which the number of manufacturing firms is endogenously determined by the zero-profit condition. Section 5 discusses some possible generalizations and extensions of the model and concludes.

2. Specification of the model

In this economy, there are three factors of production: labor, capital, and land. The size of the population is L and each individual is endowed with one unit of labor. The endowment of capital is K. The total amount of land in this economy is T. All individuals are assumed to have the same preferences. An individual derives utility from the consumption of three types of goods: an agricultural good, a manufactured good, and residential land. First, the agricultural good is produced by labor and land with a technology exhibiting constant returns. The number of individuals working in the agricultural sector is L_a. Second, the manufactured good is produced by labor and capital. The number of individuals working in the manufacturing sector is L_m. Third, land may be used for residence directly.

We assume that the production of the agricultural good does not need to be concentrated. Agriculture is located in rural areas. Rural land is used both for residential purposes and for the production of the agricultural good. Regardless of the usage, land in the agricultural sector has the same level of rent. The manufacturing sector is located in the urban area. Urban land is used for

[2] There are several significant differences between this model and Murphy et al. (1989). First, capital is not a factor of production in their model. Second, in their model, manufacturing firms engage in monopolistic competition. In this model, manufacturing firms engage in oligopolistic competition. Third, rural-urban migration and urban spatial structure are not addressed in their model.

residential purposes only. Depending on the distance from the CBD, land at different locations in the urban sector may have different levels of rents. The spatial structure of this economy is specified as a linear city type as shown in Figure 1.

Figure 1

	b		CBD		b	
Rural area	↓	Urban	↓	Urban	↓	Rural area

In Figure 1, the total length of the line is T and the center of this line is the CBD. Similar to the urban economics literature, we assume that the production of the manufacturing good needs to be concentrated in the CBD.[3] Workers employed in the manufacturing sector live on the two sides of the CBD and workers employed in the agricultural sector live in the rural areas which are located relatively far away from the CBD. The points b (determined endogenously in equilibrium) are the division points of the rural areas and the urban sector. The higher the number of workers employed in the manufacturing sector, the higher the demand for residential land in the urban sector, and the larger the distance between the CBD and the two points b. Workers employed in the manufacturing sector need to commute to the CBD to work. Commuting takes time only, and no pecuniary cost is involved. Except for commuting costs, there is no transportation cost for the agricultural good and the manufactured good. Workers employed in the manufacturing sector choose where to live. Rents in the urban sector are bid up in such a way that utilities at different locations will be the same: a location closer to the CBD has a lower commuting cost but a higher level of rent.

Let c_a denote a representative consumer's consumption of the agricultural good, c_m denote her consumption of the manufactured good, and q denote her consumption of residential land. For $\theta \in (0,1)$, this representative consumer's utility function is specified as

$$U(c_a, c_m, q) = c_a{}^{\theta} c_m{}^{1-\theta} q . \tag{1}$$

[3] One justification of this assumption that manufacturing firms need to be concentrated in the CBD is that concentration of manufacturing firms helps exploiting increasing returns in the provision of public utilities such as electricity.

Residents have an equal share of land, capital, and firms. A consumer's total income I is the sum of the wage income and ownership from land, capital, and firms. The exogenously given wage rate at the CBD is $\overline{w}$. If there are no commuting costs, an individual is able to supply one unit of labor. The per unit commuting cost in terms of the amount of labor used is τ. For a worker employed in the manufacturing sector with a distance s from the CBD, the amount of time spent on commuting is τs. This person is able to supply $1-\tau s$ units of labor to a manufacturing firm. The employment rate in the urban sector is e. Rather than interpreting e as the percentage of workers employed in the manufacturing sector, in this model it is interpreted as the percentage of time that an individual in the manufacturing sector is employed.[4] Since the probability of being employed is e, the expected wage income of an individual employed in the manufacturing sector is $(1-\tau s)e\overline{w}$.

The per capita income from ownership of land, capital, and firms is η. An individual commuting a distance of s with income from ownership of land, capital, and firms of η has a total income of $(1-\tau\ s)e\overline{w}+\eta$:

$$I=(1-\tau\ s)e\overline{w}+\eta\ . \tag{2}$$

The price of the agricultural goods is p_a and the price of the manufactured good is p_m. Similar to Takuma and Sasaki (2000), a consumer's consumption of residential land is exogenously fixed at $\overline{q}$. Since all individuals have the same level of utility in equilibrium, without loss of generality, we focus on the study of an individual located at one of the two points b. Let the rent at the border of the rural area and the urban sector be $r(b)$. This consumer's total spending on the three types of goods is $p_a c_a + p_m c_m + r(b)\overline{q}$. This consumer's budget constraint states that

$$p_a c_a + p_m c_m + r(b)\overline{q} = I\ . \tag{3}$$

A consumer chooses the quantities of consumption of the agricultural good and the manufactured good to maximize utility (1), subject to her budget constraint (3). For an individual living closer to the CBD, the increased wage income is exactly offset by the higher level of rent. As a result, individuals reach the same level of utility in equilibrium. For a consumer located at

[4] One advantage of this interpretation is that every individual in the manufacturing sector has a positive income and thus positive consumption.

one of the borders of the rural areas and the urban sector, this consumer's utility maximization leads to the following levels of demand for the agricultural good and the manufactured good:

$$c_a = \frac{\theta\left(I - r(b)\overline{q}\right)}{p_a}, \tag{4}$$

$$c_m = \frac{(1-\theta)\left(I - r(b)\overline{q}\right)}{p_m}. \tag{5}$$

For the production of the manufactured good, both capital and labor are needed: capital is the fixed cost and labor is the marginal cost of production. The existence of fixed costs of production leads to increasing returns in the manufacturing sector. Similar to Zhou (2004, 2007, 2009), to produce the manufactured good, we assume that there is a continuum of increasing returns technologies indexed by a positive number n.[5] A higher value of n indicates a more advanced technology. The fixed cost associated with technology n in terms of the amount of capital used is $f(n)$ and the marginal cost in terms of the amount of labor used is $\beta(n)$. To capture the substitution between fixed and marginal costs of production, we assume that the fixed cost increases while the marginal cost decreases with the level of technology: $f'(n) > 0$ and $\beta'(n) < 0$.[6] We also assume that $f''(n) \geq 0$ and $\beta''(n) \geq 0$. That is, when a more advanced technology is chosen, the fixed cost increases at a nondecreasing rate and the marginal cost decreases at a nonincreasing rate.

The number of identical firms producing the manufactured good is m. Firms producing the manufactured good are assumed to engage in Cournot competition. They choose their levels of output and technologies to maximize profits. The per unit cost of capital is R. For a manufacturing firm with output level x, the revenue is $p_m x$ and the costs of capital are $f R$ and the costs of labor are $\beta x \overline{w}$. Thus its profit is $p_m x - f R - \beta x \overline{w}$. A manufacturing firm's optimal

[5] Zhou (2009) provides a more detailed illustration of the adoption of increasing returns technologies in the process of economic development for firms engaging in oligopolistic competition.

[6] The adoption of containers in the transportation sector illustrates the substitution between fixed and marginal costs of production in the choice of technologies. Before the adoption of containers in the 1950s, the loading and unloading of cargos were handled by longshoremen and were labor intensive. With high wage rates, the marginal cost was high. The adoption of containers led to a sharp rise of fixed costs because specially designed cranes, containerships and container ports had to be built. However, the marginal cost of loading and unloading decreased sharply (Levinson, 2006). For some other examples of the substitution between fixed and marginal costs, see Prendergast (1990) who discusses technology choices in three industries: nuts and bolts, iron founding, and machine tools.

choice of output requires that $p_m + x\frac{\partial p_m}{\partial x} - \beta \bar{w} = 0$. With the specification of the utility function in equation (1), the absolute value of a consumer's elasticity of demand for the manufactured good is one. Plugging this result into the condition for a manufacturing firm's optimal choice of output leads to

$$p_m\left(1 - \frac{1}{m}\right) = \beta \bar{w}. \tag{6}$$

A manufacturing firm's optimal choice of technology leads to[7]

$$- f'(n)R - \beta'(n)x\bar{w} = 0. \tag{7}$$

From equation (7), a manufacturing firm's choice of technology n could be affected by the endogenous variables R and x, and the exogenous parameter $\bar{w}$. As will be shown later on, since the endogenous variables R and x could be affected by the exogenous parameter $\bar{w}$, in equilibrium, a firm's choice of technology may not be affected by the manufacturing wage rate $\bar{w}$.

For the labor market in the manufacturing sector, an individual living in the CBD does not incur any commuting cost. There are $L_m/2$ individuals employed on each side of the CBD. Since each of the $L_m/2$ individuals need $\bar{q}$ units of land for residence, an individual living in the border of the rural sector and the urban sector needs to travel a distance of $\bar{q}L_m/2$ and has commuting costs of $\tau\bar{q}L_m/2$. Thus the average amount of commuting time for a urban resident is $\tau\bar{q}L_m/4$ and the total commuting time of the L_m individuals in the urban sector is $\tau\bar{q}L_m^2/4$. Deducting the level of commuting time, the total amount of labor available from the L_m individuals employed in the manufacturing sector is $L_m - \frac{\tau}{4}\bar{q}L_m^2$. Since the employment rate in the manufacturing sector is e, the actual provision of labor in the manufacturing sector is $e\left(L_m - \frac{\tau}{4}\bar{q}L_m^2\right)$. Each of the m manufacturing firms demands βx units of labor and the total demand for labor in the

[7] A second order condition corresponding to (7) is $-f''R - \beta''x\bar{w} < 0$. With the assumptions on fixed and marginal costs of production, this second order condition is always satisfied and is later on used for comparative statics.

manufacturing sector is $m\beta x$. Equilibrium of the labor market in the manufacturing sector requires that

$$m\beta x = e\left(L_m - \frac{\tau}{4}\bar{q}L_m^{\ 2}\right). \tag{8}$$

For the labor market for this economy as a whole, demand for labor is the sum of demand from the manufacturing sector and the agricultural sector. Employment in the manufacturing sector is L_m and employment in the agricultural sector is L_a. Thus total demand for labor in this economy is $L_a + L_m$. Total supply of labor is L. The clearance of the labor market for this economy requires that

$$L_a + L_m = L. \tag{9}$$

For the market for capital, each of the m manufacturing firms demands f units of capital and the total demand for capital is mf. Total supply of capital is K. The clearance of the market for capital requires that

$$mf = K. \tag{10}$$

For the market for the agricultural good, from equation (4), each of the L consumers demands $\theta\left(I - r(b)\bar{q}\right)/p_a$ units of the agricultural good and the total demand for the agricultural good is $L\theta\left(I - r(b)\bar{q}\right)/p_a$. Since each of the L individuals needs $\bar{q}$ units of land for residence, the total amount of land used for residence is $\bar{q}L$. Thus the remaining amount of land available for the production of the agricultural good is $T - \bar{q}L$. For $\gamma \in (0,1)$, the level of output of the agricultural good is specified as $L_a^{\ 1-\gamma}(T - \bar{q}L)^{\gamma}$. That is, total supply of the agricultural good is $L_a^{\ 1-\gamma}(T - \bar{q}L)^{\gamma}$. The clearance of the market for the agricultural good requires that

$$\frac{L\theta\left(I - r(b)\bar{q}\right)}{p_a} = L_a^{\ 1-\gamma}(T - \bar{q}L)^{\gamma}. \tag{11}$$

For the market for the manufactured good, from equation (5), each of the L consumers demands $(1-\theta)\left(I - r(b)\bar{q}\right)/p_m$ units of the manufactured good and total demand for the manufactured good is $L(1-\theta)\left(I - r(b)\bar{q}\right)/p_m$. Each of the m manufacturing firms supplies x units of the manufactured good and total supply of the manufactured good is mx. The clearance of the market for the manufactured good requires that

$$\frac{L(1-\theta)\left(I-r(b)\bar{q}\right)}{p_m} = m\,x\,. \tag{12}$$

The amount of rents for a location in the urban sector with a distance of s from the CBD is determined by the condition that individuals living at different locations of the urban sector have the same level of utility. Deducting the amount of income spent on paying rents, an individual living at any location has the same amount of income $(1-\tau s)e\bar{w}+\eta-r(s)\bar{q}$, which is spent on the agricultural good and the manufactured good. That is, $(1-\tau s)e\bar{w}+\eta-r(s)\bar{q}=p_a c_a + p_m c_m$. Rearrangement of this equation leads to

$$r(s)=[(1-\tau s)e\bar{w}+\eta-p_a c_a - p_m c_m]/\bar{q}\,. \tag{13}$$

For land on the borders of the rural sector and the urban sector (points b), it may be used either for residential purposes or for the production of the agricultural good. If it is used for residential purposes, the return is $r(b)$. If it is used for the production of the agricultural good, the return is the marginal value product of land $\gamma\, p_a L_a^{\;1-\gamma}(T-\bar{q}L)^{\gamma-1}$. In equilibrium, the returns to land on points b used for either residential or agricultural purposes should be equal:

$$r(b)=\gamma\, p_a L_a^{\;1-\gamma}(T-\bar{q}L)^{\gamma-1}\,. \tag{14}$$

Urbanization rates in developing countries are higher than those in developed countries when they were at similar levels of income (Todaro and Smith, 2012, chap. 7). In this model, a worker may be employed either in the agricultural sector or move to the manufacturing sector. Individuals consider whether to move into the manufacturing sector or not by comparing the wage rate in the agricultural sector and the expected wage rate in the manufacturing sector. A worker employed in the agricultural sector lives close to his work place and does not incur any commuting costs. This worker is paid by the marginal value product of labor in the agricultural sector, which is $(1-\gamma)p_a L_a^{\;-\gamma}(T-\bar{q}L)^{\gamma}$. A worker's expected return in the manufacturing sector is $\left(1-\frac{\tau}{2}\bar{q}\;L_m\right)e\bar{w}$. For a worker to be indifferent between employed in the agricultural sector and employed in the manufacturing sector, the return in the two sectors should be equal:

$$(1-\gamma)p_a L_a^{\;-\gamma}(T-\bar{q}L)^{\gamma} = \left(1-\frac{\tau}{2}\bar{q}\;L_m\right)e\bar{w}\,. \tag{15}$$

To complete the model, we need to determine the profit of a manufacturing firm. Depending on whether the entry into the manufacturing sector is blocked or free, a manufacturing firm's profit may be positive or zero. In the following, we study the two scenarios in turn.

3. The equilibrium with an exogenous number of firms in the manufacturing sector

Before the 1980s, many developing countries adopted the import substitution strategy to develop their manufacturing sector. To support domestic firms, tariffs and quotas were frequently used to limit international competition. Countries such as South Korea used licenses to limit the number of firms in strategic industries (Cimoli et al., 2009). Patents could also make entry of new domestic firms in the manufacturing sector unlikely. In this section, we study the equilibrium in which the number of manufacturing firms is exogenously given. With blocked entry, the profit of a manufacturing firm will be nonnegative.

Each unit of land in this economy earns a level of rent not lower than that of the agricultural sector, which is equal to $r(b)$. Land in the urban sector earns extra rents. The total amount of extra rents in the urban sector is equal to the total commuting costs of urban residents $\tau e \overline{w}\,\overline{q} L_m^{\,2}/4$. Thus the total amount of rents in the economy is $T r(b) + \frac{\tau}{4} e \overline{w}\,\overline{q} L_m^{\,2}$. This amount of total rents $T r(b) + \frac{\tau}{4} e \overline{w}\,\overline{q} L_m^{\,2}$, profits from the manufacturing sector $n\pi$, and the total return to capital RK are shared equally by all L individuals. Remember that $\pi = p_m x - f R - \beta x \overline{w}$. Thus the total amount of revenue from ownership of land, capital, and firms is $T r(b) + \frac{\tau}{4} e \overline{w}\overline{q}\, L_m^{\,2} + m(p_m x - f R - \beta x \overline{w}) + RK$. Each of the L individuals receives η and the total amount of revenue from ownership of land, capital, and firms is ηL. In equilibrium, we have

$$T r(b) + \frac{\tau}{4} e \overline{w}\,\overline{q}\, L_m^{\,2} + m(p_m x - f R - \beta x \overline{w}) + RK = \eta L . \quad (16)$$

Plugging the value of $r(b)$ from equation (14) into equation (16) leads to

$$T\left(\gamma\, p_a L_a^{\,1-\gamma} (T - \overline{q}L)^{\gamma-1}\right) + \frac{\tau}{4} e \overline{w}\,\overline{q}\, L_m^{\,2} + m(p_m x - f R - \beta x \overline{w}) + RK = \eta L . \quad (17)$$

When the number of manufacturing firms is exogenously given, equations (2), (6)-(12), (14)-(15), and (17) form a system of eleven equations defining a system of eleven variables p_a,

p_m, R, x, n, L_a, L_m, I, η, r, and e as functions of exogenous parameters. An equilibrium when the number of firms is exogenously given is a tuple (p_a, p_m, R, x, n, L_a, L_m, I, η, r, e) satisfying equations (2), (6)-(12), (14), (15), and (17).[8] For the rest of the paper, we use the price of the agricultural good as the numeraire: $p_a \equiv 1$.

To conduct comparative statics, we need to reduce the system of eleven equations to a smaller and thus manageable number of equations. Simplification of the above system of eleven equations leads to the following system of three equations defining three endogenous variables L_m, e, and n as functions of exogenous parameters:[9]

$$\Omega_1 \equiv \left(1-\frac{\tau}{2}\bar{q}\,L_m\right)e\,\bar{w}-(1-\gamma)\frac{(T-\bar{q}\,L)^{\gamma}}{(L-L_m)^{\gamma}}=0\,, \tag{18a}$$

$$\Omega_2 \equiv \left(1-\frac{1}{m}\right)(1-\theta)(L-L_m)^{1-\gamma}\left(T-\bar{q}\,L\right)^{\gamma}-\theta\,e\,\bar{w}\left(L_m-\frac{\tau}{4}\bar{q}\,L_m{}^2\right)=0\,, \tag{18b}$$

$$\Omega_3 \equiv m\,f-K=0\,. \tag{18c}$$

Partial differentiation of the system of equations Ω_1, Ω_2, and Ω_3 with respect to e, L_a, n, $\bar{w}$, L, T, m, K, and τ leads to

$$\begin{pmatrix} \frac{\partial\Omega_1}{\partial e} & \frac{\partial\Omega_1}{\partial L_m} & 0 \\ \frac{\partial\Omega_2}{\partial e} & \frac{\partial\Omega_2}{\partial L_m} & 0 \\ 0 & 0 & \frac{\partial\Omega_3}{\partial n} \end{pmatrix}\begin{pmatrix} de \\ dL_m \\ dn \end{pmatrix} = -\begin{pmatrix} \frac{\partial\Omega_1}{\partial \bar{w}} \\ \frac{\partial\Omega_2}{\partial \bar{w}} \\ 0 \end{pmatrix} d\bar{w} - \begin{pmatrix} \frac{\partial\Omega_1}{\partial L} \\ \frac{\partial\Omega_2}{\partial L} \\ 0 \end{pmatrix} dL$$

[8] For this system of equations (2), (6)-(12), (14), (15), and (17) defining the equilibrium in which the number of manufacturing firms is exogenously given, if equations (2), (6)-(12), (14), and (15) are satisfied, it can be checked that equation (17) is always satisfied. That is, one equation is redundant. With Walras's law in mind, this redundancy is not surprising.

[9] Equations (18a)-(18c) are derived as follows. First, equation (18a) is derived by plugging the value of L_a from equation (9) into equation (15). Second, dividing equation (11) by equation (12), plugging the value of p from equation (6) and the value of x from equation (8), and plugging the value of L_a from equation (9) into the resulting equation lead to equation (18b). Third, equation (18c) is the same as equation (10).

$$-\begin{pmatrix} \frac{\partial \Omega_1}{\partial T} \\ \frac{\partial \Omega_2}{\partial T} \\ 0 \end{pmatrix} dT - \begin{pmatrix} 0 \\ \frac{\partial \Omega_2}{\partial m} \\ \frac{\partial \Omega_3}{\partial m} \end{pmatrix} dm - \begin{pmatrix} 0 \\ 0 \\ \frac{\partial \Omega_3}{\partial K} \end{pmatrix} dK - \begin{pmatrix} \frac{\partial \Omega_1}{\partial \tau} \\ \frac{\partial \Omega_2}{\partial \tau} \\ 0 \end{pmatrix} d\tau . \qquad (19)$$

Let Δ denote the determinant of the coefficient matrix of (19): $\Delta = \frac{\partial \Omega_3}{\partial n}\left(\frac{\partial \Omega_1}{\partial e}\frac{\partial \Omega_2}{\partial L_m} - \frac{\partial \Omega_1}{\partial L_m}\frac{\partial \Omega_2}{\partial e}\right)$. Partial differentiation of equations (18a)-(18c) leads to $\frac{\partial \Omega_1}{\partial e} > 0$, $\frac{\partial \Omega_1}{\partial L_m} < 0$, $\frac{\partial \Omega_2}{\partial L_m} < 0$, $\frac{\partial \Omega_2}{\partial e} < 0$, and $\frac{\partial \Omega_3}{\partial n} > 0$. As a result, $\Delta < 0$. With Δ nonsingular, there exists a unique equilibrium for the system (19).

When the manufacturing wage rate increases, labor costs for a manufacturing firm increase. Will this lead a manufacturing firm to choose a more advanced technology to decrease the usage of labor? When the manufacturing wage rate increases, will more workers enter into the manufacturing sector? The following proposition studying the impact of a change in the manufacturing wage rate will answer those questions.

Proposition 1: An increase in the manufacturing wage rate decreases the employment rate in the manufacturing sector, and does not change the level of employment and the level of technology in the manufacturing sector.[10]

Proof: An application of Cramer's rule on the system (19) leads to $\frac{de}{d\underline{\underline{w}}} = \frac{\partial \Omega_3}{\partial n}\left(\frac{\partial \Omega_1}{\partial L_m}\frac{\partial \Omega_2}{\partial \underline{\underline{w}}} - \frac{\partial \Omega_1}{\partial \underline{\underline{w}}}\frac{\partial \Omega_2}{\partial L_m}\right)/\Delta < 0$, $\frac{dL_m}{d\underline{\underline{w}}} = \frac{\partial \Omega_3}{\partial n}\left(\frac{\partial \Omega_1}{\partial \underline{\underline{w}}}\frac{\partial \Omega_2}{\partial e} - \frac{\partial \Omega_1}{\partial e}\frac{\partial \Omega_2}{\partial \underline{\underline{w}}}\right)/\Delta$, and $\frac{dn}{d\underline{\underline{w}}} = 0$.

Partial differentiation of equations (18a) and (18b) leads to $\frac{\partial \Omega_1}{\partial \underline{\underline{w}}}\frac{\partial \Omega_2}{\partial e} - \frac{\partial \Omega_1}{\partial e}\frac{\partial \Omega_2}{\partial \underline{\underline{w}}} = 0$. As a result, $\frac{dL_m}{d\underline{\underline{w}}} = 0$.

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[10] Similar to the proof of Proposition 1, it can be shown that when the number of manufacturing firms is exogenously given, an increase in the percentage of income spent on the manufactured good increases the level of employment in the manufacturing sector, while leaves the employment rate and the level of technology of a manufacturing firm unchanged. Later on, similar to the proof of Proposition 7, it can be shown that when the number of manufacturing firms is endogenously determined, an increase in the percentage of income spent on the manufactured good leads to effects similar to the situation when the number of manufacturing firms is exogenously given.

To understand Proposition 1, when the manufacturing wage rate increases, the expected wage rate does not change because the employment rate decreases correspondingly. As a result, the level of employment in the manufacturing sector does not change. As discussed in the Introduction, when the manufacturing wage rate increases, the cost of capital R increases correspondingly so that the condition for a manufacturing firm's optimal choice of technology (equation (7)) is always satisfied. That is, when x and $\overline{w}$ change, R will change correspondingly so that equation (7) remains valid. Since the impact of an increase in the wage rate is cancelled out by the impact of an increase in the cost of capital, the level of technology in the manufacturing sector does not change with the manufacturing wage rate. Instead, the level of technology is determined by the condition for the clearance of the market for capital (equation (10)).

An increase in the size of the population increases the supply of workers. Will this decrease the cost of labor and lead manufacturing firms to choose less advanced technologies using more labor? Will this decrease the employment rate in the manufacturing sector? The following proposition studying the impact of a change in the size of the population does not give an unambiguous answer on the level of employment in the manufacturing sector.

Proposition 2: When the size of the population increases, the level of technology of a manufacturing firm does not change, and the impact on the level of employment and employment rate in the manufacturing sector is ambiguous.

Proof: An application of Cramer's rule on (19) leads to $\frac{de}{dL} = \frac{\partial\Omega_3}{\partial n}\left(\frac{\partial\Omega_1}{\partial L_m}\frac{\partial\Omega_2}{\partial L} - \frac{\partial\Omega_1}{\partial L}\frac{\partial\Omega_2}{\partial L_m}\right)/\Delta$, $\frac{dL_m}{dL} = \frac{\partial\Omega_3}{\partial n}\left(\frac{\partial\Omega_1}{\partial L}\frac{\partial\Omega_2}{\partial e} - \frac{\partial\Omega_1}{\partial e}\frac{\partial\Omega_2}{\partial L}\right)/\Delta > 0$, and $\frac{dn}{dL} = 0$. Partial differentiation of equations (18a) and (18b) leads to $\partial\Omega_1 / \partial L_m < 0$, , $\partial\Omega_1 / \partial L > 0$, and $\partial\Omega_2 / \partial L_m < 0$. Because the sign of $\partial\Omega_2 / \partial L$ is ambiguous, the signs of de / dL and dL_m / dL are ambiguous.

When the size of the population increases, there are two effects on the employment rate in the manufacturing sector working in opposite directions. First, since each individual needs a given amount of land for residence, an increase in the size of the population decreases the amount of land available for the production of the agricultural good. Thus the value marginal product of an individual employed in the agricultural sector decreases. Through the labor market equilibrium condition, this effect decreases the employment rate in the manufacturing sector. Second, an increase in the size of the population increases the demand for the manufactured good. This latter effect increases the employment rate in the manufacturing sector. Without adding more structure to the model, it is not clear which effect dominates and thus the impact of an increase in the size of the population is ambiguous.

Land is used for both residential purposes and for the production of the agricultural good. How will an increase in the amount of land affect the levels of employment and technology in the manufacturing sector?

Proposition 3: An increase in the amount of land increases the employment rate, and does not change the level of employment in the manufacturing sector and the level of technology of a manufacturing firm.

Proof: An application of Cramer's rule on the system (19) leads to $\frac{de}{dT} = \frac{\partial \Omega_3}{\partial n}\left(\frac{\partial \Omega_1}{\partial L_m}\frac{\partial \Omega_2}{\partial T} - \frac{\partial \Omega_1}{\partial T}\frac{\partial \Omega_2}{\partial L_m}\right)/\Delta > 0$, $\frac{dL_m}{dT} = \frac{\partial \Omega_3}{\partial n}\left(\frac{\partial \Omega_1}{\partial T}\frac{\partial \Omega_2}{\partial e} - \frac{\partial \Omega_1}{\partial e}\frac{\partial \Omega_2}{\partial T}\right)/\Delta$, and $\frac{dn}{dT} = 0$. Partial differentiation of equations (18a) and (18b) leads to $\frac{\partial \Omega_1}{\partial T}\frac{\partial \Omega_2}{\partial e} - \frac{\partial \Omega_1}{\partial e}\frac{\partial \Omega_2}{\partial T} = 0$. As a result, $\frac{dL_m}{dT} = 0$.

To understand Proposition 3, when the amount of land increases, there are two effects on the level of employment in the manufacturing sector. First, since the marginal productivity of an individual employed in the agricultural sector increases and employment in the agricultural sector becomes more lucrative, the level of employment in the manufacturing sector will decrease. Second, an increase in the amount of land will increase the level of output of the agricultural good. With the homothetic preference specified in equation (1), product market equilibrium requires that the ratio between the total value of the agricultural good and the total value of the manufactured good be fixed. To maintain equilibrium in the product market, the level of employment in the manufacturing sector will increase. The two effects work in opposite directions and cancel out each other. As a result, the number of individuals employed in the agricultural sector does not change with the endowment of land. An increase in the endowment of land increases the marginal productivity of an individual employed in the agricultural sector. Since the price of the agricultural good is normalized to one, the return to labor in the agricultural sector increases. To maintain equilibrium in the labor market, the employment rate in the manufacturing sector increases. Similar to the discussion of Proposition 1, the return to capital adjusts in such a way that the level of technology in the manufacturing sector does not change with the amount of land.

For a country's development, the process of industrialization is also the process of urbanization. On the one hand, a country's level of industrialization has an important impact on this country's level of urbanization. On the other hand, urbanization is not totally determined by the level of industrialization of a country. For example, it is argued that in Mexico the process of urbanization moved ahead of the process of industrialization (Gilbert and Gugler, 1992). However, in the case of China, it is frequently argued that the process of urbanization has been lagging behind the level of industrialization (Deng et al., 2008). In this model, a change in the level of commuting costs affects the urban spatial structure. Will a change in commuting costs also affect the process of industrialization as measured by the level of employment in the manufacturing sector? The following proposition studies how a change in commuting costs affects the levels of technology and employment of the manufacturing sector.

Proposition 4: An increase in the level of commuting costs increases the employment rate and does not change the level of technology in the manufacturing sector. The impact on the level of employment in the manufacturing sector is ambiguous.

Proof: An application of Cramer's rule on (19) leads to

$$\frac{de}{d\tau} = \frac{\partial\Omega_3}{\partial n}\left(\frac{\partial\Omega_1}{\partial L_m}\frac{\partial\Omega_2}{\partial\tau} - \frac{\partial\Omega_1}{\partial\tau}\frac{\partial\Omega_2}{\partial L_m}\right)/\Delta > 0 \ , \quad \frac{dL_m}{d\tau} = \frac{\partial\Omega_3}{\partial n}\left(\frac{\partial\Omega_1}{\partial\tau}\frac{\partial\Omega_2}{\partial e} - \frac{\partial\Omega_1}{\partial e}\frac{\partial\Omega_2}{\partial\tau}\right)/\Delta \ , \quad \frac{dn}{d\tau} = 0 \ .$$

Since the sign of $\frac{\partial\Omega_1}{\partial\tau}\frac{\partial\Omega_2}{\partial e} - \frac{\partial\Omega_1}{\partial e}\frac{\partial\Omega_2}{\partial\tau}$ is undetermined, the sign of $dL_m / d\tau$ is undetermined.

To understand Proposition 4, when the level of commuting costs increases, there are two effects on the level of employment in the manufacturing sector working in opposite directions. First, since commuting costs are time costs, an increase in commuting costs decreases the supply of labor in the manufacturing sector. To maintain labor market equilibrium in the manufacturing sector, the level of employment in the manufacturing sector should increase. Second, an increase in commuting costs decreases the return to an individual employed in the manufacturing sector. As a result, individuals will move out of the manufacturing sector and the level of employment in the manufacturing sector will decrease. Since it is not clear which effect will dominate, the impact of an increase in commuting costs on the level of employment in the manufacturing sector is ambiguous.

Unemployment is a chronic problem for developing countries. Why did not firms in developing countries create enough jobs? While both advanced technologies and higher employment in the manufacturing sector could be desirable for a developing country, the following proposition studying the impact of a change in the degree of competition on the level of employment and technology in the manufacturing sector shows that opposite implications on the level of technology and the level of employment can happen when the number of firms in the manufacturing sector increases.

Proposition 5: When the number of manufacturing firms increases, the employment rate in the manufacturing sector increases, the level of employment in the manufacturing sector increases, and a manufacturing firm chooses a less advanced technology.

Proof: Partial differentiation of equations (18a)-(18c) yields $\partial\Omega_1 / \partial L_m < 0$, $\partial\Omega_1 / \partial e > 0$, $\partial\Omega_2 / \partial m > 0$, $\partial\Omega_2 / \partial e < 0$, $\partial\Omega_2 / \partial L_m < 0$, $\partial\Omega_3 / \partial m > 0$, and $\partial\Omega_3 / \partial n > 0$. An application of Cramer's rule on (19) leads to $\frac{de}{dm} = \frac{\partial\Omega_1}{\partial L_m}\frac{\partial\Omega_2}{\partial m}\frac{\partial\Omega_3}{\partial n} / \Delta > 0$, $\frac{dL_m}{dm} = -\frac{\partial\Omega_1}{\partial e}\frac{\partial\Omega_2}{\partial m}\frac{\partial\Omega_3}{\partial n} / \Delta > 0$, and

$$\frac{dn}{dm} = \frac{\partial\Omega_3}{\partial m}\left(\frac{\partial\Omega_1}{\partial L_m}\frac{\partial\Omega_2}{\partial e} - \frac{\partial\Omega_1}{\partial e}\frac{\partial\Omega_2}{\partial L_m}\right) / \Delta < 0.$$

From Proposition 5, job creation and exploiting increasing returns in production may be conflicting goals in the process of economic development. To understand Proposition 5, when the number of manufacturing firms increases, the price charged by a manufacturing firm as a markup over its marginal cost of production decreases. This will reduce the total value of the manufactured good. To maintain equilibrium in the product market, the level of employment in the manufacturing sector increases. With a smaller number of individuals working in the agricultural sector, marginal productivity of an agricultural work increases. To ensure that an individual is still indifferent between working in the agricultural sector and the manufacturing sector, the employment rate in the manufacturing sector increases. When the number of manufacturing firm increases, each firm receives a smaller amount of capital. As a result, each firm chooses a less advanced technology.

In the model of Lewis (1954), capital accumulation leads to the expansion of production and an increase in the level of employment in the manufacturing sector. The following proposition shows that capital accumulation may not necessarily lead to an increase in the level of employment in the manufacturing sector.

Proposition 6: An increase in the amount of capital does not change the employment rate and the level of employment in the manufactured sector. An increase in the amount of capital leads a manufacturing firm to choose a more advanced technology.

Proof: An application of Cramer's rule on (19) leads to $\frac{de}{dK} = 0$, $\frac{dL_m}{dK} = 0$, and

$$\frac{dn}{dK} = \frac{\partial \Omega_3}{\partial K}\left(\frac{\partial \Omega_1}{\partial L_m}\frac{\partial \Omega_2}{\partial e} - \frac{\partial \Omega_1}{\partial e}\frac{\partial \Omega_2}{\partial L_m}\right) / \Delta > 0 .$$

To understand Proposition 6, since the number of manufacturing firms is exogenously given, an increase in the amount of capital means that each manufacturing firm receives a higher amount of capital and thus the equilibrium level of technology increases. From equation (8), the level of employment in the manufacturing sector is affected by the number of manufacturing firms, marginal cost in terms of labor units, and output. When the amount of capital in this economy increases, a manufacturing firm chooses a more advanced technology and marginal cost in terms of labor units decreases. However, because the increase in output exactly cancels out the impact of the decrease in the marginal cost, the level of employment in the manufacturing sector does not change.

4. The equilibrium with an endogenous number of firms in the manufacturing sector

Some countries such as Chile did not restrict the number of firms and relied on market force to determine the number of firms in an industry (Amsden, 2001, p. 211). In the long run, patents may expire and new firms may enter an industry. In this section, we study the equilibrium in which the number of manufacturing firms is endogenously determined by the zero profit condition.[11]

With free entry and exit in the manufacturing sector, a manufacturing firm earns a profit of zero:[12]

$$p_m x - f\,R - \beta\, x\, \overline{w} = 0\,. \tag{20}$$

With profits from the manufacturing sector equal to zero, the total revenue of the government is the sum of the total amount of rents $T\,r(b) + \frac{\tau}{4} e\,\overline{w}\,\overline{q}\,L_m{}^2$ and total return to capital $R\,K$. Each of the L individuals receives a revenue from ownership of land, capital, and firms of η and the total amount of revenue received by all individuals from ownership of land, capital, and firms is $\eta\,L$. In equilibrium, we have

$$T\,r(b) + \frac{\tau}{4} e\,\overline{w}\,\overline{q}\,L_m{}^2 + R\,K = \eta\,L\,. \tag{21}$$

Plugging the value of $r(b)$ from equation (14) into equation (21) leads to

$$T\left(\gamma\, p_a L_a{}^{1-\gamma}\,(T - \overline{q}L)^{\gamma-1}\right) + \frac{\tau}{4} e\,\overline{w}\,\overline{q}\,L_m{}^2 + R\,K = \eta\,L\,. \tag{22}$$

When the number of manufacturing firms is endogenously determined by the zero profit condition, equations (2), (6)-(12), (14), and (15) are still valid. Equations (2), (6)-(12), (14)-(15), (20), and (22) form a system of twelve equations defining a system of twelve variables p_a, p_m, R, x, m, L_a, L_m, I, n, η, r, and e as functions of exogenous parameters. An equilibrium in which the number of manufacturing firms is endogenously determined is a tuple (p_a, p_m, R, x, m, L_a, L_m, I, n, η, r, e) satisfying equations (2), (6)-(12), (14)-(15), (20), and (22).[13]

[11] See Chao and Yu (1997), Lahiri and Ono (2004), Zhang (2007), and Chen and Shieh (2011) for examples of oligopolistic competition with free entry.

[12] To facilitate presentation, the number of manufacturing firms is specified as a real number, rather than restricted to be an integer number.

[13] For this system of equations (2), (6)-(12), (14)-(15), (20), and (22) defining the equilibrium in which the number of manufacturing firms is endogenously determined, if equations (2), (6)-(12), (14)-(15), and (20) are satisfied, it can be checked that equation (22) is always satisfied. That is, one equation is redundant. With Walras's law in mind, this redundancy is not surprising.

To conduct comparative statics, simplification of this system of twelve equations (2), (6)-(12), (15), (20), and (22) leads to the following system of three equations defining three endogenous variables e, L_m, and n as functions of exogenous parameters:[14]

$$\Gamma_1 \equiv \left(1-\frac{\tau}{2}\bar{q}L_m\right)e\bar{w}-(1-\gamma)\frac{(T-\bar{q}L)^{\gamma}}{(L-L_m)^{\gamma}}=0, \tag{23a}$$

$$\Gamma_2 \equiv \left(1-\frac{f}{K}\right)(1-\theta)(L-L_m)^{1-\gamma}\left(T-\bar{q}L\right)^{\gamma}-\theta e\bar{w}\left(L_m-\frac{\tau}{4}\bar{q}L_m^{\ 2}\right)=0, \tag{23b}$$

$$\Gamma_3 \equiv f'\beta+\beta'(K-f)=0. \tag{23c}$$

Partial differentiation of the system of equations Γ_1-Γ_3 with respect to e, L_m, n, $\bar{w}$, L, θ, T, K, and τ leads to

$$\begin{pmatrix} \frac{\partial\Gamma_1}{\partial e} & \frac{\partial\Gamma_1}{\partial L_m} & 0 \\ \frac{\partial\Gamma_2}{\partial e} & \frac{\partial\Gamma_2}{\partial L_m} & \frac{\partial\Gamma_2}{\partial n} \\ 0 & 0 & \frac{\partial\Gamma_3}{\partial n} \end{pmatrix}\begin{pmatrix} de \\ dL_m \\ dn \end{pmatrix} = -\begin{pmatrix} \frac{\partial\Gamma_1}{\partial\bar{w}} \\ \frac{\partial\Gamma_2}{\partial\bar{w}} \\ 0 \end{pmatrix}d\bar{w}-\begin{pmatrix} \frac{\partial\Gamma_1}{\partial L} \\ \frac{\partial\Gamma_2}{\partial L} \\ 0 \end{pmatrix}dL$$

$$-\begin{pmatrix} 0 \\ \frac{\partial\Gamma_2}{\partial\theta} \\ 0 \end{pmatrix}d\theta-\begin{pmatrix} \frac{\partial\Gamma_1}{\partial T} \\ \frac{\partial\Gamma_2}{\partial T} \\ 0 \end{pmatrix}dT-\begin{pmatrix} 0 \\ \frac{\partial\Gamma_2}{\partial K} \\ \frac{\partial\Gamma_3}{\partial K} \end{pmatrix}dK-\begin{pmatrix} \frac{\partial\Gamma_1}{\partial\tau} \\ \frac{\partial\Gamma_2}{\partial\tau} \\ 0 \end{pmatrix}d\tau. \tag{24}$$

Let Δ_Γ denote the determinant of the coefficient matrix of (24): $\Delta_\Gamma=\frac{\partial\Gamma_3}{\partial n}\left(\frac{\partial\Gamma_1}{\partial e}\frac{\partial\Gamma_2}{\partial L_m}-\frac{\partial\Gamma_1}{\partial L_m}\frac{\partial\Gamma_2}{\partial e}\right)$. Partial differentiation of equations (23a)-(23c) leads to $\frac{\partial\Gamma_1}{\partial e}>0$, $\frac{\partial\Gamma_1}{\partial L_m}<0$, $\frac{\partial\Gamma_2}{\partial L_m}<0$, and $\frac{\partial\Gamma_2}{\partial e}<0$. Partial differentiation of equations (23c) leads to

[14] Equations (23a)-(23c) are derived as follows. First, equation (23a) is the same as equation (18a). Second, equation (23b) is derived by plugging the value of m from equation (10) into equation (18b). Third, from equation (20), the level of output of a manufacturing firm can be expressed as $x=fR/(p_m-\beta\bar{w})$. Plugging this value of x into equation (7) leads to $f'(p_m-\beta\bar{w})+\beta'\bar{w}f=0$. Plugging the value of p_m from equation (6) and the value of m from equation (10) into the above equation leads to equation (23c).

$\frac{\partial \Gamma_3}{\partial n} = f''\beta + \beta''(K - f) > 0$. As a result, $\Delta_\Gamma < 0$. With Δ_Γ nonsingular, there exists a unique equilibrium for the system (24).

The following proposition revisits the impact of a change in the endowment of capital on a manufacturing firm's choice of technology when the number of manufacturing firms is endogenously determined.

Proposition 7: When the number of manufacturing firms is endogenously determined by the zero-profit condition, an increase in the amount of capital leads a manufacturing firm to choose a more advanced technology.

Proof: An application of Cramer's rule on (24) leads to

$$\frac{dn}{dK} = \frac{\partial \Gamma_3}{\partial K}\left(\frac{\partial \Gamma_1}{\partial L_m}\frac{\partial \Gamma_2}{\partial e} - \frac{\partial \Gamma_1}{\partial e}\frac{\partial \Gamma_2}{\partial L_m}\right) / \Delta_\Gamma > 0 .$$

When the number of manufacturing firms is endogenously determined, the impact of an increase in the amount of capital on the employment rate and the level of employment in the manufacturing sector is ambiguous. The reason is as follows. When the amount of capital increases, there are two effects on the level of employment in the manufacturing sector. First, to produce a given level of output, because a manufacturing firm chooses a more advanced technology and the unit labor requirement for each unit of output decreases, the demand for labor in the manufacturing sector decreases. Second, an increase in the amount of capital is an increase in a factor of production and this will lead to an increase in the level of output because capital is fully employed. To produce a higher level of output, the demand for labor in the manufacturing sector increases. Because the two effects work in opposite directions and it is not clear which effect dominates, the impact of an increase in the amount of capital on the level of employment in the manufacturing sector is ambiguous.

Similar to the proof of Proposition 7, applications of Cramer's rule on the system (24) reveal that the impact of an increase in the manufacturing wage rate, an increase in the size of the population, an increase in the amount of land, and an increase in commuting costs when the number of manufacturing firms is endogenously determined are similar to the results when the number of firms in the manufacturing sector is exogenously given. Thus, Propositions 1, 2, 3, and 4 are robust regardless of whether the number of firms in the manufacturing sector is exogenously given or endogenously determined by the zero-profit condition.

When the number of manufacturing firms is endogenously determined, the reason that an increase in the manufacturing wage rate does not change the level of technology is as follows. From equation (20), a manufacturing firm's level of output is $x = f R/(p_m - \beta\overline{w})$. Plugging this level of output into the condition for a firm's optimal choice of technology (equation (7)) leads to $f' R(p_m - \beta\overline{w}) + \beta' R\overline{w} f = 0$. As a result, R cancels out and the equation reduces to $f'(p_m - \beta\overline{w}) + \beta'\overline{w} f = 0$. From equation (6), $p_m = \beta\overline{w}\dfrac{m}{m-1}$. From equation (10), $m = K / f$. Plugging the values of p_m and m into $f'(p_m - \beta\overline{w}) + \beta'\overline{w} f = 0$ leads to $f'\beta\overline{w}\left(\dfrac{1}{1 - f/K}\right) + \beta'\overline{w} f = 0$. Simplification of this equation leads to equation (23c) determining the level of technology in which the level of the exogenously given wage rate is now absent because a change in the price of the manufactured good cancels out a change in the manufacturing wage rate. That is, as discussed in the Introduction, when the manufacturing wage rate increases, the price of the manufactured good as a markup over the marginal cost increases. The level of output of a manufacturing firm is affected by the price of the manufactured good. Since the output change of a manufacturing firm incorporates the impact of a change in the price of the manufactured good, these changes will cancel out the impact of a change in the manufacturing wage rate. Thus, a manufacturing firm's choice of technology in equilibrium is not affected by the level of the manufacturing wage rate.

5. Conclusion

In this paper, we have studied a general equilibrium model of rural-urban migration in which manufacturing firms engage in oligopolistic competition and choose increasing returns technologies to maximize profits. Workers need to incur commuting costs to work in the CBD. We have established the following results. First, an increase in the number of manufacturing firms causes both the employment rate and the level of employment in the manufacturing sector to increase. However, manufacturing firms choose less advanced technologies. Second, an increase in the manufacturing wage rate decreases the employment rate in the manufacturing sector, and affects neither the level of employment nor the level of technology in the manufacturing sector. Third, an increase in the size of the population increases the level of employment in the manufacturing sector, and does not change the level of technology of a manufacturing firm. The impact of a change in the size of the population on the employment rate in the manufacturing sector is ambiguous. Fourth, an increase in the amount of land increases the employment rate, and affects neither the level of employment nor the level of technology in the manufacturing sector. Finally, an increase in commuting costs increases the employment rate, and does not change the level of technology in the manufacturing sector.

We have made various assumptions to simplify the analysis. There are some interesting generalizations and extensions of the model. First, in this model with a homothetic preference of consumers, a consumer spends a fixed percentage of income on each type of goods. The incorporation of a non-homothetic preference will lead to more complicated interactions between the agricultural sector and the manufacturing sector. Second, in this model, labor mobility from the rural sector to the urban sector is assumed to be free. In China, labor mobility between rural areas and cities is frequently restricted. Policy analysis such as policies limiting labor mobility between rural areas and cities should be an interesting avenue for future research.

Acknowledgements:

I thank Zhiqi Chen for his very insightful comments. I am solely responsible for all the remaining errors.

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