The Choice of Technology in Economic Development

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Abstract

The impact of capital accumulation on job creation is an important and interesting issue in economic development. This model provides a general-equilibrium framework for studying technology choice with unemployment in a developing economy based on microfoundations. Unemployment in the urban sector results from the existence of efficiency wages. Manufacturing firms engage in oligopolistic competition and choose technologies to maximize profits. A more advanced technology uses more capital and less labor. In the steady state, an increase in the amount of capital induces firms to choose more advanced technologies and the wage rate increases. While a higher capital stock always induces firms to choose more advanced technologies, urban unemployment rate may decrease, and agricultural sector employment may increase.

Keywords: Economic development, technology choice, unemployment, increasing returns, rural-urban migration

JEL Classification Numbers: O14, J64, E24, L13

1. Introduction

Capital accumulation was emphasized in the Lewis model in economic development after World War II. The Lewis model has been criticized because capital accumulation may not lead to the reduction of unemployment when firms adopt more advanced technologies which use less labor in producing each unit of output (Todaro and Smith, 2012, p. 118). Impact of capital accumulation on technology choice and unemployment is an important and interesting issue. However, there is limited formal research on this issue.

In this paper, we provide a general-equilibrium framework for studying technology choice with unemployment in a developing economy based on microfoundations. One choice to be made is how to incorporate unemployment into the model. Search models and efficiency wage models are two popular approaches on unemployment based on microfoundations. While both approaches are popular and elegant, the efficiency wage approach chosen in this model is especially relevant for economic development because higher wage can increase the level of nutrition and thus productivities of workers in developing countries with limited income. Shapiro and Stiglitz (1984, p. 413) state that efficiency wage models are especially relevant for "lower-paid, lower-skilled, blue-collar occupations" and many jobs in developing countries belong to those categories. Bardhan (1993) states that the efficiency wage theory originated from studies addressing issues in economic development. For empirical research, Kumbhakar (1996) finds evidence that wages paid by farmers in rural India are efficiency wages. In their study on incentive-wage effects for workers in China, Fleisher and Wang (2001) find strong evidence that higher wages enhance productivity, and they also find evidence that firms paying higher efficiency wages have less shirking among their workers.

A second choice to be made is the type of market structure when technology choice is incorporated into the model. In a stimulating paper, Murphy et al. (1989) have modelled industrialization as the adoption of increasing returns technologies. Consistent with their approach, we capture technology choice as the choice among increasing returns technologies. With the existence of increasing returns, the type of market structure could be monopolistic competition or oligopoly. In this model, we assume that firms engage in oligopolistic competition to address a firm's technology choice. Under monopolistic competition and constant elasticity of demand, a firm's output does not depend on population size. Under oligopolistic competition and constant elasticity of demand, a firm's output changes with population size. To address a firm's technology choice which depends on its output level, oligopolistic competition will fit the question to be addressed better.

With increasing returns in production, management, and distribution, oligopoly became a dominant type of market structure for developed countries such as German and the United States from the Second Industrial Revolution (Chandler, 1990). In their microeconomics textbook, Pindyck and Rubinfeld (2005, p. 441) state that "oligopoly is a prevalent form of market structure. Examples of oligopolistic industries include automobiles, steel, aluminum, petrochemicals, electrical equipment, and computers." With barriers such as cumbersome licensing process and complex financing arrangements, underdeveloped financial and capital markets, and restrictive trade regimes, the number of firms serving an industry in developing countries could be limited. Thus, oligopoly is also an important type of market structure for developing countries.

In this model, there are two sectors of production: agriculture and manufacture. Land and labor are used to produce the agricultural good. There is no unemployment in the agricultural sector. An individual moving from the agricultural sector in the rural area to the manufacturing sector in the urban area will be unemployed first (Chin, 1998). Unemployment in the manufacturing sector is the result of the existence of efficiency wages (Shapiro and Stiglitz, 1984).[1] With the existence of fixed costs, the manufacturing sector has increasing returns in production. The existence of increasing returns leads to the specification that manufacturing firms engage in oligopolistic competition. Manufacturing firms choose technologies optimally to maximize profits. A more advanced technology uses more capital as fixed costs and lower amount of labor as marginal cost of production.

The specification on the choice of technology here is consistent with microeconomics textbook presentations on short-run and long-run cost curves. Fixed costs can be mapped into the number of machines. In the short run, the number of machines is fixed. In the long run, a firm can choose the number of machines. With a higher number of machines, variable costs in terms of labor costs will decrease. That is, there is a tradeoff between fixed and marginal costs of production.

The incorporation of technology choice in this model of economic development allows us to address the critique on the Lewis model directly. With a two-sector general equilibrium model featuring oligopolistic competition, the model is surprisingly tractable. We show that an increase in the capital endowment increases the wage rate and manufacturing firms will adopt more advanced technologies. In general, whether a higher capital stock will reduce unemployment in an economy or not is ambiguous. With special functional forms of technologies, we show that an increase in the amount of capital reduces the urban unemployment rate. However, this reduction is achieved through increasing employment in the agricultural sector. That is, capital accumulation does not lead to workers relocated from rural area to urban area. Thus, while capital accumulation is still important in leading firms to choose more advanced technologies(as demonstrated in the successful stories of East Asian tigers with fast capital accumulation after World War II), governments in developing economies may need to find alternative ways to facilitate relocation of workers from rural to urban area.

This paper is related to three lines of literature. First, it is related to the literature on rural-urban migration, pioneered by Harris and Todaro (1970) who study a model of homogenous workers in a closed economy and unemployment results from minimum wages. In their model, production in the manufacturing sector has constant returns to scale. The wage rate in the urban area is determined exogenously by institutional factors and is higher than the market-clearing wage

[1] Alternatively, unemployment in urban area could be modeled as employment in an informal sector. For simplicity, this alternative is not pursued in this model.

rate. Thus, unemployment in the urban area results. If workers base their decisions to migrate on expected wages, workers in the rural area will move to the urban area even though there is unemployment in the urban area if the expected wage rate in the urban area is not lower than the level of income in the rural area. They show that a subsidy to job creation in the urban sector can make unemployment worse. Bencivenga and Smith (1997) have studied a model of rural-urban migration with heterogenous workers. Chin (1998) has examined social welfare implications of different government policies for a small open economy with dual labor markets with prices determined by international markets. There are some significant differences between those models and this one. First, those models do not incorporate a manufacturing firm's choice of technology. Second, with constant returns, manufacturing firms engage in perfect competition in those models. With increasing returns, firms engage in oligopolistic competition in this model.

Second, this paper is related to models of unemployment based on efficiency wages (Shapiro and Stiglitz, 1984). Because workers could not be monitored perfectly, unemployment is needed to discipline workers from shirking in equilibrium. While Shapiro and Stiglitz (1984) focus on the steady state of the economy without capital accumulation, Kimball (1994) has explored the out-of-steady-state dynamics, and Brecher, Chen, and Choudhri (2010) have further incorporated capital accumulation in their dynamic model addressing impact of different policies. The focuses in their models are significantly different from that in this model. In their models, firms engage in perfect competition and technology choice and rural-urban migration are not addressed. Wen and Zhou (2020) have studied a model of economic integration based on efficiency wages. There are some important differences between this paper and Wen and Zhou (2020). First, in that model, labor market in the agricultural sector is treated in the same way as labor markets in the manufacturing sector. In this model, there is no unemployment in the agricultural sector. Second, in Wen and Zhou (2020), labor is the only factor of production in the agricultural sector. In this model, in additional to labor, land is also a factor of production in the agricultural sector.

Third, this paper is related to the literature on technology choice in economic development. Developing countries may have factor endowments different from those in developed countries and capital-intensive technologies may not be appropriate for developing countries. With job creation in mind, the choice of appropriate technologies has been discussed extensively in economic development (Stewart, 1977). Zhou (2013, 2015) has studied technology choice in formal models of rural-urban migration. Zhou (2013) has studied the choice of increasing returns technologies in a model with urbanization. One substantial difference between this model and Zhou (2013) is that the wage rate is exogenously given in Zhou (2013) while it is endogenously determined in this model. Zhou (2015) has examined a model of technology choice in a one-sector model and rural-urban migration is not addressed in that model.

The plan of the paper is as follows. Section 2 specifies the model and establishes equilibrium conditions for the steady state. Section 3 establishes the existence of a unique steady state and addresses how endogenous variables in the steady state such as the level of technology for a manufacturing firm and the urban unemployment rate change with key parameters such as the level of capital stock and the level of labor market efficiency. Section 4 discusses some potential generalizations of the model and concludes.

2. The model

In this section, we specify the model and derive the equilibrium conditions. First, we study a representative consumer's utility maximization. Second, we address a representative manufacturing firm's profit maximization through choices of output and technology. Third, we establish market-clearing conditions such as the clearance of markets for goods and factors of production.

Time is continuous. To avoid clutter, variables are not indexed by time when there is no confusion from doing this. The size of the population is L and it does not change over time. Individuals live forever. There is an agricultural good and its price is p_a. Land and labor are used in producing the agricultural good, and there is no unemployment in the agricultural sector. There is a manufactured good and its price is p. Capital and labor are used in producing the manufactured good. The total amount of capital in this economy is K, which is exogenously given. The interest rate is r. Since a worker in the manufacturing sector could not be monitored perfectly, unemployment in the manufacturing sector exists to deter a worker for shirking. The wage rate in the manufacturing sector is w, and the unemployment rate in the manufacturing sector is u. Land and capital are owned equally by all individuals.[2]

2.1. Utility maximization

[2] With homothetic preferences assumed in this paper, the distribution of ownership of land and capital will not affect aggregate demand of final goods.

An individual's consumption of the agricultural good is c_a and her consumption of the manufactured good is c. Each individual is endowed with one unit of labor in each period. The cost of effort for a worker without shirking in a period is z. The subjective discount rate of an individual is ρ. For $\alpha \in (0,1)$, an individual's utility function is specified as

$$\int_0^\infty U_t e^{-\rho t} dt,$$

$$U_t = c_a^\alpha c^{1-\alpha} - \mu z. \tag{1}$$

In the above specification, $\mu \in \{0, 1\}$. If a worker shirks, then $\mu = 0$; if a worker does not shirk, then $\mu = 1$. Since the per period utility function in equation (1) is the Cobb-Douglass type, utility maximization requires that a consumer spend α percent of income on the agricultural good and $1 - \alpha$ percent of income on the manufactured good. This specification of the utility function also leads to the result that the absolute value of a consumer's elasticity of demand for the manufactured good is one.

An individual's expenditure is I, which is spent on the agricultural good and the manufactured good: $p_a c_a + pc = I$. For an individual, regardless of living in a rural area or in a city, the per capita income from ownership of capital and land is η. There is no unemployment compensation. If an individual is employed, $I = w + \eta$; if an individual is unemployed, $I = \eta$. The price index is denoted by $P \equiv \frac{p_a^\alpha p^{1-\alpha}}{\alpha^\alpha (1-\alpha)^{1-\alpha}}$. From the specification of the utility function in (1), the indirect utility function can be written as

$$V(I, p_a, p, z) = \frac{I}{P} - \mu z = \frac{\alpha^\alpha (1-\alpha)^{1-\alpha}}{p_a^\alpha p^{1-\alpha}} I - \mu z. \tag{2}$$

If a worker shirks, the probability that shirking is detected is q. A shirker is immediately fired. In addition to being fired because of shirking, the exogenous job separation rate faced by a worker in the manufacturing sector is b. The expected lifetime utility of an employed shirker is V_E^S, that of an employed non-shirker is V_E^N, and that of an unemployed individual is V_u. Like Shapiro and Stiglitz (1984), the asset equation for a shirker is

$$\rho V_E^S = U(w + \eta) + (b + q)(V_u - V_E^S). \tag{3}$$

Equation (3) states that for a shirker, the discount rate times asset value equals flow benefit $U(w + \eta)$ plus a possibility of $b + q$ of suffering from a capital loss of $V_u - V_E^S$.

For a non-shirker, the exogenous job separation rate at each moment is b. The asset equation for a non-shirker is

$$\rho V_E^N = U(w+\eta) - z + b(V_u - V_E^N). \tag{4}$$

Equation (4) states that for a non-shirker, the discount rate times asset value equals flow benefit $U(w+\eta) - z$ plus a possibility of b of suffering from a capital loss of $V_u - V_E^N$.

The tradeoff faced by a worker considering whether to shirk is that shirking saves effort cost z, but increases the possibility of being fired. A worker will not shirk if the expected lifetime utility from not shirking is not lower than that from shirking. From equations (3) and (4), for a worker not to shirk, the following condition needs to be satisfied:

$$U(w+\eta) \geq \rho V_u + \frac{(\rho+b+q)z}{q}. \tag{5}$$

The instant rate for an unemployed individual to find employment is a, which is endogenously determined in this model. The asset equation for an unemployed individual is

$$\rho V_u = U(\eta) + a[\max(V_E^S, V_E^N) - V_u]. \tag{6}$$

Equation (6) shows that for an unemployed individual, the discount rate times asset value equals flow benefit of $U(\eta)$ plus the possibility a of experiencing a capital gain of $\max(V_E^S, V_E^N) - V_u$.

In equilibrium, $\max(V_E^S, V_E^N) = V_E^N$. From equations (4) and (6), we have

$$\rho V_u = \frac{a[U(w+\eta)-z]+(\rho+b)U(\eta)}{a+b+\rho}. \tag{7}$$

In a period, the job creation rate is au and the job destruction rate is $b(1-u)$. In a steady state, unemployment rate does not change. Thus, $au = b(1-u)$. Rearrangement of this equation yields

$$a = b\frac{1-u}{u}. \tag{8}$$

In equilibrium, like Brecher, Chen, and Choudhri (2010, p. 1394), the no-shirking condition (5) holds with equality. From equations (5), (7), and (8), the no-shirking condition can be expressed as

$$\frac{\alpha^\alpha(1-\alpha)^{1-\alpha}}{p_a^\alpha p^{1-\alpha}} w - z - \frac{z}{q}\left(\frac{b}{u} + \rho\right) = 0. \tag{9}$$

2.2. Profit maximization

The agricultural sector has constant returns to scale. The amount of exogenously given land is $T > 0$. The number of individuals employed in the agricultural sector is L_a. For the constant $\theta \in (0,1)$, the level of output in the agricultural sector is $L_a^\theta T^{1-\theta}$. Firms in the agricultural sector engage in perfect competition.

For the manufacturing sector, in each period, there are m identical firms producing the manufactured good, and $m > 0$. Firms producing the manufactured good engage in Cournot competition. To produce the manufactured good, there is a continuum of technologies indexed by $n \in R_+^1$ with different levels of fixed and marginal costs (Zhou, 2004, 2009, 2013, 2021).[3] A more advanced technology is associated with a higher value of n. For technology n, the level of fixed cost in terms of capital needed is $f(n)$ and the level of marginal cost in terms of labor used is $\beta(n)$. Both fixed cost and marginal cost are assumed to be twice continuously differentiable. To capture capital-labor substitution in production,[4] we assume that a more advanced technology has a higher fixed cost but a lower marginal cost of production: $f'(n) > 0$ and $\beta'(n) < 0$.[5] A firm's cost for each unit of capital is r. A manufacturing firm's output is x and its profit is $px - f(n)r - \beta(n)xw$. Since there is an agricultural sector with constant returns demanding labor, a manufacturing firm takes the wage rate as given. In a Cournot-Nash equilibrium, a manufacturing firm takes the interest rate and other manufacturing firms' technologies and outputs as given and chooses its technology and output to maximize its profit.

The first order condition for a manufacturing firm's optimal choice of technology is

$$-f'(n)r - \beta'(n)xw = 0. \tag{10}$$

The first order condition for a manufacturing firm's optimal choice of output is $p + x\frac{\partial p}{\partial x} - \beta(n)w = 0$. Plugging the result that the absolute value of the elasticity of demand for the manufactured good is one into this condition yields

$$p\left(1 - \frac{1}{m}\right) = \beta w. \tag{11}$$

For convenience, the number of firms producing the manufactured good is a real number, rather than restricted to be an integer. With fixed costs as entry barriers, the number of firms producing the manufactured good is determined by the zero-profit condition.[6] Zero-profit for a manufacturing firm requires

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[3] Zhou (2009) studies the choice of technology during the process of industrialization in a dynamic general equilibrium model. One significant difference between this paper and Zhou (2009) is that unemployment is not addressed in that paper.
[4] Prendergast (1990) conducts empirical research on the choices of technologies in three manufacturing sectors. His study supports the assumption that marginal cost of labor decreases when the amount of capital used increases.
[5] For the second order condition for a firm's optimal choice of technology to be satisfied, we also assume that $f''(n) \geq 0$ and $\beta''(n) \geq 0$. That is, fixed costs increase at a nondecreasing rate and marginal cost decreases at a nonincreasing rate with the level of technology.
[6] See Liu and Wang (2010) for an example of models featuring Cournot competition with free entry.

$$px - fr - \beta xw = 0. \quad (12)$$

2.3. Market-clearing conditions

For the market for capital, each of the m firms demands f units of capital as fixed costs in producing the manufactured good. Thus, total demand for capital is mf. Total supply of capital is K. The clearance of the market for capital requires

$$mf = K. \quad (13)$$

For the labor market, one manufacturing firm employs βx workers and the total number of workers employed in producing the manufactured good is $m\beta x$. Taking into account of the existence of unemployment, the number of workers in the manufacturing sector is $\frac{m\beta x}{1-u}$, and the number of workers in the agricultural sector is L_a. Total labor supply is L. Equilibrium in the labor market requires

$$\frac{m\beta x}{1-u} + L_a = L. \quad (14)$$

Each individual spends α percent of income on the agricultural good and the total value of the supply of the agricultural good is $p_a L_a^{\theta} T^{1-\theta}$. Each individual spends $1-\alpha$ percent of income on the manufactured good and the total value of the supply of the manufactured good is pmx. Goods market equilibrium requires

$$\frac{\alpha}{1-\alpha} = \frac{p_a L_a^{\theta} T^{1-\theta}}{pmx}. \quad (15)$$

Because an individual could not search for a job in the urban area directly from the rural area, a rural worker in the agricultural sector comes to the manufacturing sector in the urban area first as an unemployed (Chin, 1998). For an individual, the expected lifetime utility of being unemployed is V_u. For an individual in the rural area, the labor return in a period is $p_a \theta \left(\frac{T}{L_a}\right)^{1-\theta}$ and total discounted return is $\frac{p_a \theta}{\rho}\left(\frac{T}{L_a}\right)^{1-\theta} + \frac{\eta}{\rho}$. Remembering in equation (2), an individual's indirect utility is the quotient of income divided by the price index. By using (2), the expected lifetime utility for an individual in the rural area is $\left(\frac{p_a \theta}{\rho}\left(\frac{T}{L_a}\right)^{1-\theta} + \frac{\eta}{\rho}\right)/P$. In equilibrium, the expected lifetime utility of being unemployed in the manufacturing sector and that from working in the rural area should be equal:

$$V_u = \frac{\frac{p_a\theta}{\rho}\left(\frac{T}{L_a}\right)^{1-\theta} + \frac{\eta}{\rho}}{P}. \tag{16}$$

In equilibrium, the non-shirking condition holds with equality:

$$V_E^N = V_E^S. \tag{17}$$

From equations (3) and (4), it can be shown that $V_E^N - V_u = \frac{z}{q}$. Combining this with equations (6) and (16) yields

$$p_a\theta\left(\frac{T}{L_a}\right)^{1-\theta} = \frac{zb(1-u)}{uq}\frac{p_a^\alpha p^{1-\alpha}}{\alpha^\alpha(1-\alpha)^{1-\alpha}}. \tag{18}$$

In equilibrium, the total amount of revenue received by all individuals as owners of capital and land ηL should be equal to the sum of capital income rK and land revenue $(1-\theta)p_a L_a^\theta T^{1-\theta}$:

$$\eta L = rK + (1-\theta)p_a L_a^\theta T^{1-\theta}. \tag{19}$$

For the rest of the paper, the manufactured good is used as the numeraire: $p \equiv 1$.[7] In a steady state, variables do not change over time. In a steady state, equations (9)-(15), (18), and (19) form a system of nine equations defining nine variables L_a, w, u, η, p_a, r, m, x, and n as functions of exogenous parameters.

3. The steady state

From equations (11) and (13), the wage rate can be expressed as

$$w = \frac{1}{\beta}\left(1 - \frac{f}{K}\right). \tag{20}$$

Plugging the value of x from equation (10) into equation (12), the equilibrium level of technology is defined implicitly by

$$-\beta f' - (K-f)\beta' = 0. \tag{21}$$

The system of equations defining the steady state can be block determined. From equation (21), the level of technology is a function of the amount of capital only: $n = n(K)$. From equations (20) and (21), the wage rate can be expressed solely as a function of the amount of capital: $w = w(K)$. In addition, from equation (11), the number of firms producing the manufactured good is solely determined by the amount of capital. From equation (21), $\frac{dn}{dK} = -\frac{\beta'}{\beta f'' + (K-f)\beta''} > 0$. That

[7] The choice of numeraire does not affect real variables, such as the unemployment rate. When the manufactured good is chosen as the numeraire, the wage rate should be interpreted as the ratio of the nominal wage rate to the price of the manufactured good. The manufactured good rather than the agricultural good is chosen as the numeraire here to highlight increasing returns in the manufacturing sector.

is, the equilibrium level of technology increases with the amount of capital: $n'(K) > 0$. Applying envelope theorem on equation (20) yields $\frac{dw}{dK} = \frac{f}{\beta K^2} > 0$. That is, the equilibrium wage rate increases with the amount of capital: $w'(K) > 0$.

Surprisingly, in this model the level of technology and the equilibrium wage rate are not affected by population size. With the existence of increasing returns in the manufacturing sector, we may have expected that the equilibrium wage rate will increase with population size. This does not happen because equations (20) and (21) together define the wage rate and the equilibrium level of technology independent of other variables. It is capital alone determining the level of technology and the wage rate. An increase in land endowment changes neither the wage rate nor the equilibrium level of technology.

To understand this result that the equilibrium level of technology is a function of capital only, we can revisit equation (10). This equation is the first order condition for a manufacturing firm's optimal choice of technology. From this equation, a firm's technology choice might be affected by the interest rate, the level of output, and the wage rate. While a higher interest rate may induce a firm to choose a less advanced technology, a higher output level will induce a firm to choose a more advanced technology. From equation (12), a firm's output increases with the interest rate. Thus, with the effects from output and interest rate cancelling out each other, the only variable affecting a firm's technology choice is the wage rate, which is endogenously determined. From equations (11) and (13), the wage rate is solely determined by the amount of capital and the level of technology. Overall, the wage rate and the level of technology are determined solely by the amount of capital.

The system of nine equations defining the steady state can be reduced to the following system of three equations defining three variables u, p_a, and L_a as functions of exogenous parameters:[8]

$$\Gamma_1 \equiv \frac{\alpha^{\alpha}(1-\alpha)^{1-\alpha}}{(p_a)^{\alpha}} w(K) - z - \frac{z}{q}\left(\frac{b}{u} + \rho\right) = 0, \tag{22a}$$

$$\Gamma_2 \equiv \alpha^{\alpha}(1-\alpha)^{1-\alpha}\theta\left(\frac{T}{L_a}\right)^{1-\theta} p_a^{1-\alpha} - \frac{zb(1-u)}{uq} = 0, \tag{22b}$$

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[8] The derivation of equations (22a) -(22c) is as follows. First, equation (22a) comes from equation (9) by showing that the wage rate depends solely on the amount of capital. Second, equation (22b) is the same as equation (18). Third, plugging the value of m from equation (11) and the value of x from equation (12) into equation (15), the value of r can be expressed as a function of other variables. Plugging this value of r, the value of m from equation (11), and the value of x from equation (12) into equation (14) yields equation (22c).

$$\Gamma_3 \equiv (1-\alpha)\beta(K)p_a L_a^{\theta} T^{1-\theta} - \alpha(1-u)(L-L_a) = 0. \tag{22c}$$

Partial differentiation of equations (22a) -(22c) with respect to p_a, u, L_a, ρ, K, q, z, and L yields

$$\begin{pmatrix} \frac{\partial\Gamma_1}{\partial p_a} & \frac{\partial\Gamma_1}{\partial u} & 0 \\ \frac{\partial\Gamma_2}{\partial p_a} & \frac{\partial\Gamma_2}{\partial u} & \frac{\partial\Gamma_2}{\partial L_a} \\ \frac{\partial\Gamma_3}{\partial p_a} & \frac{\partial\Gamma_3}{\partial u} & \frac{\partial\Gamma_3}{\partial L_a} \end{pmatrix} \begin{pmatrix} dp_a \\ du \\ dL_a \end{pmatrix} = -\begin{pmatrix} \frac{\partial\Gamma_1}{\partial\rho} \\ 0 \\ 0 \end{pmatrix} d\rho - \begin{pmatrix} \frac{\partial\Gamma_1}{\partial K} \\ 0 \\ \frac{\partial\Gamma_3}{\partial K} \end{pmatrix} dK$$

$$-\begin{pmatrix} \frac{\partial\Gamma_1}{\partial q} \\ \frac{\partial\Gamma_2}{\partial q} \\ 0 \end{pmatrix} dq - \begin{pmatrix} \frac{\partial\Gamma_1}{\partial z} \\ \frac{\partial\Gamma_2}{\partial z} \\ 0 \end{pmatrix} dz - \begin{pmatrix} 0 \\ 0 \\ \frac{\partial\Gamma_3}{\partial L} \end{pmatrix} dL - \begin{pmatrix} 0 \\ \frac{\partial\Gamma_2}{\partial T} \\ \frac{\partial\Gamma_3}{\partial T} \end{pmatrix} dT. \tag{23}$$

Let Δ denote the determinant of the coefficient matrix of endogenous variables of (23):

$$\Delta \equiv \frac{\partial\Gamma_1}{\partial p_a}\frac{\partial\Gamma_2}{\partial u}\frac{\partial\Gamma_3}{\partial L_a} + \frac{\partial\Gamma_1}{\partial u}\frac{\partial\Gamma_2}{\partial L_a}\frac{\partial\Gamma_3}{\partial p_a} - \frac{\partial\Gamma_1}{\partial p_a}\frac{\partial\Gamma_2}{\partial L_a}\frac{\partial\Gamma_3}{\partial u} - \frac{\partial\Gamma_1}{\partial u}\frac{\partial\Gamma_2}{\partial p_a}\frac{\partial\Gamma_3}{\partial L_a}.$$

With $\frac{\partial\Gamma_1}{\partial p_a} < 0$, $\frac{\partial\Gamma_1}{\partial u} > 0$, $\frac{\partial\Gamma_2}{\partial p_a} > 0$, $\frac{\partial\Gamma_2}{\partial u} > 0$, $\frac{\partial\Gamma_2}{\partial L_a} < 0$, $\frac{\partial\Gamma_3}{\partial p_a} > 0$, $\frac{\partial\Gamma_3}{\partial u} > 0$, and $\frac{\partial\Gamma_3}{\partial L_a} > 0$, it is clear that $\Delta < 0$. With Δ nonsingular, a unique steady state exists. According to the correspondence principle (Samuelson, 1983, chap. 9), stability requires that $\Delta < 0$. Thus, the steady state is stable.

Developing countries have significantly different saving rates, which can be related to time preferences of individuals. A country with more patient citizens can have higher saving rates. The following proposition studies the impact of a change in the time preference.

Proposition 1: An increase in the discount rate increases the unemployment rate. The number of workers employed in the agricultural sector increases and the price of the agricultural good decreases.

Proof: Partial differentiation of (22b) and (22c) yields

$$\frac{\partial\Gamma_2}{\partial u}\frac{\partial\Gamma_3}{\partial p_a} - \frac{\partial\Gamma_2}{\partial p_a}\frac{\partial\Gamma_3}{\partial u} > 0.$$

Applying Cramer's rule on (23) yields

$$\frac{du}{d\rho} = \frac{\partial\Gamma_1}{\partial\rho}\left(\frac{\partial\Gamma_2}{\partial p_a}\frac{\partial\Gamma_3}{\partial L_a} - \frac{\partial\Gamma_2}{\partial L_a}\frac{\partial\Gamma_3}{\partial p_a}\right)/\Delta > 0,$$

$$\frac{dp_a}{d\rho} = \frac{\partial\Gamma_1}{\partial\rho}\left(\frac{\partial\Gamma_2}{\partial L_a}\frac{\partial\Gamma_3}{\partial u} - \frac{\partial\Gamma_2}{\partial u}\frac{\partial\Gamma_3}{\partial L_a}\right)/\Delta < 0,$$

$$\frac{dL_a}{d\rho} = \frac{\partial\Gamma_1}{\partial\rho}\left(\frac{\partial\Gamma_2}{\partial u}\frac{\partial\Gamma_3}{\partial p_a} - \frac{\partial\Gamma_2}{\partial p_a}\frac{\partial\Gamma_3}{\partial u}\right)/\Delta > 0. \blacksquare$$

The intuition behind Proposition 1 is as follows. From the non-shirking condition (9), a higher unemployment rate is needed to provide incentives for a worker not to shirk when the discount rate increases. When fewer workers are attracted into the manufacturing sector, agricultural output increases and the price of the agricultural good decreases.

In the Lewis model, it is assumed that profits in the manufacturing sector will be used for capital accumulation. Capital accumulation leads to job creation, and surplus labor from the agricultural sector will be gradually absorbed into the manufacturing sector. The following proposition studies the impact of a change in capital endowment.

Proposition 2: An increase in capital endowment leads to an increase in the price of the agricultural good and has an ambiguous effect on the number of individuals employed in the agricultural sector and the unemployment rate. A sufficient condition for urban unemployment rate to decrease and employment in the agricultural sector to increase is

$$\alpha w \frac{d\beta}{dK} + \beta \frac{dw}{dK} > 0. \tag{24}$$

Proof: Applying Cramer's rule on (23) yields

$$\frac{dp_a}{dK} = \left(\frac{\partial \Gamma_1}{\partial K}\frac{\partial \Gamma_2}{\partial L_a}\frac{\partial \Gamma_3}{\partial u} - \frac{\partial \Gamma_1}{\partial K}\frac{\partial \Gamma_2}{\partial u}\frac{\partial \Gamma_3}{\partial L_a} - \frac{\partial \Gamma_1}{\partial u}\frac{\partial \Gamma_2}{\partial L_a}\frac{\partial \Gamma_3}{\partial K}\right)/\Delta > 0,$$

$$\frac{du}{dK} = \left(\frac{\partial \Gamma_1}{\partial p_a}\frac{\partial \Gamma_2}{\partial L_a}\frac{\partial \Gamma_3}{\partial K} - \frac{\partial \Gamma_1}{\partial K}\frac{\partial \Gamma_2}{\partial L_a}\frac{\partial \Gamma_3}{\partial p_a} + \frac{\partial \Gamma_1}{\partial K}\frac{\partial \Gamma_2}{\partial p_a}\frac{\partial \Gamma_3}{\partial L_a}\right)/\Delta, \tag{25}$$

$$\frac{dL_a}{dK} = \left(\frac{\partial \Gamma_1}{\partial K}\frac{\partial \Gamma_2}{\partial u}\frac{\partial \Gamma_3}{\partial p_a} - \frac{\partial \Gamma_1}{\partial p_a}\frac{\partial \Gamma_2}{\partial u}\frac{\partial \Gamma_3}{\partial K} + \frac{\partial \Gamma_1}{\partial u}\frac{\partial \Gamma_2}{\partial p_a}\frac{\partial \Gamma_3}{\partial K} - \frac{\partial \Gamma_1}{\partial K}\frac{\partial \Gamma_2}{\partial p_a}\frac{\partial \Gamma_3}{\partial u}\right)/\Delta. \tag{26}$$

In general, since the signs of the right-hand side of (25) and (26) are ambiguous, the signs of $\frac{du}{dK}$ and $\frac{dL_a}{dK}$ are ambiguous. Partial differentiation of equations (22a) and (22c) yields the result that the sign of $\frac{\partial \Gamma_1}{\partial p_a}\frac{\partial \Gamma_3}{\partial K} - \frac{\partial \Gamma_1}{\partial K}\frac{\partial \Gamma_3}{\partial p_a}$ is the same as the sign of $-\alpha w \frac{d\beta}{dK} - \frac{dw}{dK}\beta$. If (24) is valid, then $\frac{\partial \Gamma_1}{\partial p_a}\frac{\partial \Gamma_3}{\partial K} - \frac{\partial \Gamma_1}{\partial K}\frac{\partial \Gamma_3}{\partial p_a} > 0$, which is a sufficient condition for $\frac{\partial \Gamma_1}{\partial p_a}\frac{\partial \Gamma_2}{\partial L_a}\frac{\partial \Gamma_3}{\partial K} - \frac{\partial \Gamma_1}{\partial K}\frac{\partial \Gamma_2}{\partial L_a}\frac{\partial \Gamma_3}{\partial p_a} + \frac{\partial \Gamma_1}{\partial K}\frac{\partial \Gamma_2}{\partial p_a}\frac{\partial \Gamma_3}{\partial L_a} > 0$ because $\frac{\partial \Gamma_1}{\partial K}\frac{\partial \Gamma_2}{\partial p_a}\frac{\partial \Gamma_3}{\partial L_a}$ is always positive. If (24) is valid, this is also sufficient for $\frac{\partial \Gamma_1}{\partial K}\frac{\partial \Gamma_2}{\partial u}\frac{\partial \Gamma_3}{\partial p_a} - \frac{\partial \Gamma_1}{\partial p_a}\frac{\partial \Gamma_2}{\partial u}\frac{\partial \Gamma_3}{\partial K} + \frac{\partial \Gamma_1}{\partial u}\frac{\partial \Gamma_2}{\partial p_a}\frac{\partial \Gamma_3}{\partial K} - \frac{\partial \Gamma_1}{\partial K}\frac{\partial \Gamma_2}{\partial p_a}\frac{\partial \Gamma_3}{\partial u} < 0$ because $\frac{\partial \Gamma_1}{\partial u}\frac{\partial \Gamma_2}{\partial p_a}\frac{\partial \Gamma_3}{\partial K} - \frac{\partial \Gamma_1}{\partial K}\frac{\partial \Gamma_2}{\partial p_a}\frac{\partial \Gamma_3}{\partial u}$ is always negative. From (25) and (26), when (24) is valid, we have $\frac{du}{dK} < 0$ and $\frac{dL_a}{dK} > 0$. ■

To understand Proposition 2, first consider the case without technology choice. In this case, fixed and marginal costs are given, and $\frac{d\beta}{dK} = 0$. When the amount of capital increases, manufacturing output increases. Agricultural output and the price of the agricultural good also increase. While the unemployment rate in the urban sector is lower, labor does not move into cities because the higher price of the agricultural good makes employment in the agricultural sector also more attractive. With the choice of technology, condition (24) makes sure that the above effect still dominates.

With the choice of technology, if fixed and marginal costs are specified, condition (24) can be checked. One example that (24) is satisfied is the following. Suppose we specify fixed and marginal costs as $f(n) = \gamma n^b$ and $\beta(n) = \tau n^{-h}$, where γ, τ, h, and b are positive constants. In this case, solving equations (20) and (21) yields $n = \left[\frac{hK}{\gamma(h+b)}\right]^{\frac{1}{b}}$ and $w = \frac{b}{\tau(h+b)}\left[\frac{hK}{\gamma(h+b)}\right]^{\frac{h}{b}}$. Partial differentiation of equations (22a) and (22c) yields the result that the sign of $\frac{\partial \Gamma_1}{\partial p_a}\frac{\partial \Gamma_3}{\partial K} - \frac{\partial \Gamma_1}{\partial K}\frac{\partial \Gamma_3}{\partial p_a}$ is the same as the sign of $-\alpha w \frac{d\beta}{dK} - \frac{dw}{dK}\beta = -\frac{(1-\alpha)h}{(h+b)K} < 0$. In this case, we have $\frac{du}{dK} < 0$ and $\frac{dL_a}{dK} > 0$. That is, with special fixed and marginal costs, urban equilibrium unemployment rate can decrease with capital endowment. However, this is achieved by having more individuals employed in the agricultural sector.

In the Lewis model, capital accumulation is essential for economic development and high saving rates are emphasized. The Lewis model has been criticized on the ground that capital accumulation may not lead to job creation when firms adopt more advanced technologies substituting capital for labor.[9] Our model provides a framework for addressing technology choice with unemployment in a developing economy based on microfoundations. Proposition 2 shows that the criticism on the Lewis model is valid under some circumstances. When condition (24) is satisfied, a higher capital stock actually induces workers to relocate from urban area to rural area!

The impact of an increase in the endowment of capital on the unemployment rate is not addressed explicitly in Shapiro and Stiglitz (1984). However, if an increase in the amount of capital increases a worker's marginal product, then an increase in the endowment of capital will always decrease the unemployment rate in their model. With the incorporation of technology choice in

[9] Capital accumulation is not the same as technical progress. As illustrated in the Solow model, without technical progress, capital accumulation will not generate sustained growth.

this model, there is one additional effect reducing the demand for labor because firms choose more advanced technologies. The overall effect of an increase in capital stock on unemployment is thus ambiguous in this model.

For empirical research on the adoption of more advanced technologies on employment, Autor and Salomons (2018) show that while automations reduce labor demand directly, labor demand can increase through indirect effects (own-industry output effects; cross-industry input–output effects; between-industry shifts; and final demand effects). In general, the impact of technological innovations on aggregate labor demand is ambiguous.

The probability that shirking is detected is related to the level of efficiency in the labor market. A higher probability of detection may be associated with a more efficient labor market. This probability could be affected by a country's labor market institutions. The following proposition studies the implication of a change in the probability that shirking is detected on endogenous variables.[10]

Proposition 3: An increase in the probability that shirking is detected causes urban unemployment rate to decrease and the price of the agricultural good to increase. The impact on the number of workers employed in the agricultural sector is ambiguous.[11]

Proof: Applying Cramer's rule on (23) yields

$$\frac{du}{dq} = \left(\frac{\partial\Gamma_1}{\partial q}\frac{\partial\Gamma_2}{\partial p_a}\frac{\partial\Gamma_3}{\partial L_a} - \frac{\partial\Gamma_1}{\partial q}\frac{\partial\Gamma_2}{\partial L_a}\frac{\partial\Gamma_3}{\partial p_a} - \frac{\partial\Gamma_1}{\partial p_a}\frac{\partial\Gamma_2}{\partial q}\frac{\partial\Gamma_3}{\partial L_a}\right)/\Delta < 0,$$

$$\frac{dp_a}{dq} = \left(\frac{\partial\Gamma_1}{\partial q}\frac{\partial\Gamma_2}{\partial L_a}\frac{\partial\Gamma_3}{\partial u} + \frac{\partial\Gamma_1}{\partial u}\frac{\partial\Gamma_2}{\partial q}\frac{\partial\Gamma_3}{\partial L_a} - \frac{\partial\Gamma_1}{\partial q}\frac{\partial\Gamma_2}{\partial u}\frac{\partial\Gamma_3}{\partial L_a}\right)/\Delta,$$

$$\frac{dL_a}{dq} = \left(\frac{\partial\Gamma_1}{\partial q}\frac{\partial\Gamma_2}{\partial u}\frac{\partial\Gamma_3}{\partial p_a} + \frac{\partial\Gamma_1}{\partial p_a}\frac{\partial\Gamma_2}{\partial q}\frac{\partial\Gamma_3}{\partial u} - \frac{\partial\Gamma_1}{\partial q}\frac{\partial\Gamma_2}{\partial p_a}\frac{\partial\Gamma_3}{\partial u} - \frac{\partial\Gamma_1}{\partial u}\frac{\partial\Gamma_2}{\partial q}\frac{\partial\Gamma_3}{\partial p_a}\right)/\Delta.$$

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[10] Like the proof of Proposition 3, it can be shown that an increase in the cost of exerting effort leads to a higher urban unemployment rate. The number of workers employed in the agricultural sector increases and the impact on the price of the agricultural good is ambiguous. To understand this, when the cost of exerting effort increases, from equation (9), a higher unemployment rate is needed to deter a worker from shirking. When more workers are absorbed into the agricultural sector, the level of output in the agricultural sector increases. This tends to reduce the price of the agricultural good. However, with a lower employment in the manufacturing sector, manufactured output tends to decrease, and the price of the manufactured good tends to increase. Since the price of the manufactured good is normalized to one, the price of the agricultural good is the relative price of the agricultural good to that of the manufactured good. The two effects have opposite implications on the price of the agricultural good. Without adding additional structure, the impact of an increase in the cost of exerting effort on the price of the agricultural good is ambiguous.

[11] When the probability that shirking is detected increases, the equilibrium wage rate and technology do not change. This is consistent with the result that both of them are solely determined by capital endowment.

Since $\frac{\partial\Gamma_1}{\partial u}\frac{\partial\Gamma_2}{\partial q}-\frac{\partial\Gamma_1}{\partial q}\frac{\partial\Gamma_2}{\partial u}=-\frac{be^2}{u^2q^3}(b+\rho)<0$, $\frac{\partial\Gamma_1}{\partial q}\frac{\partial\Gamma_2}{\partial L_a}\frac{\partial\Gamma_3}{\partial u}+\frac{\partial\Gamma_1}{\partial u}\frac{\partial\Gamma_2}{\partial q}\frac{\partial\Gamma_3}{\partial L_a}-\frac{\partial\Gamma_1}{\partial q}\frac{\partial\Gamma_2}{\partial u}\frac{\partial\Gamma_3}{\partial L_a}<0$, thus $\frac{dp_a}{dq}>0$. Since the sign of $\frac{\partial\Gamma_1}{\partial q}\frac{\partial\Gamma_2}{\partial u}\frac{\partial\Gamma_3}{\partial p_a}+\frac{\partial\Gamma_1}{\partial p_a}\frac{\partial\Gamma_2}{\partial q}\frac{\partial\Gamma_3}{\partial u}-\frac{\partial\Gamma_1}{\partial q}\frac{\partial\Gamma_2}{\partial p_a}\frac{\partial\Gamma_3}{\partial u}-\frac{\partial\Gamma_1}{\partial u}\frac{\partial\Gamma_2}{\partial q}\frac{\partial\Gamma_3}{\partial p_a}$ is ambiguous, the sign of $\frac{dL_a}{dq}$ is ambiguous. ■

To understand Proposition 3, when the probability that shirking is detected increases, a lower unemployment rate is needed to provide incentives for a worker not to shirk. A lower unemployment rate in the manufacturing sector tends to make working in the manufacturing sector more attractive. As a response, the price of the agricultural good increases to retain workers in the agricultural sector. A lower unemployment rate makes the manufacturing sector more attractive and a higher price of the agricultural good makes the agricultural sector more attractive. Overall, the impact of an increase in the probability that shirking is detected on the number of workers employed in the agricultural sector is ambiguous.

Developing countries are experiencing demographic transformations. With lower death rates resulting from better health conditions and the availability of medicines and high birth rates, many developing countries have high population growth rates. The following proposition studies the impact of a change in population size.

Proposition 4: An increase in population size leads to more workers employed in the agricultural sector. Both the price of the agricultural good and the equilibrium unemployment rate increase.

Proof: Applying Cramer's rule on (23) yields

$$\frac{dp_a}{dL}=-\frac{\partial\Gamma_1}{\partial u}\frac{\partial\Gamma_2}{\partial L_a}\frac{\partial\Gamma_3}{\partial L}/\Delta>0,$$

$$\frac{dL_a}{dL}=\frac{\partial\Gamma_3}{\partial L}\left(\frac{\partial\Gamma_1}{\partial u}\frac{\partial\Gamma_2}{\partial p_a}-\frac{\partial\Gamma_1}{\partial p_a}\frac{\partial\Gamma_2}{\partial u}\right)/\Delta>0,$$

$$\frac{du}{dL}=\frac{\partial\Gamma_1}{\partial p_a}\frac{\partial\Gamma_2}{\partial L_a}\frac{\partial\Gamma_3}{\partial L}/\Delta>0. \blacksquare$$

Proposition 4 shows that some of the increased population will be absorbed into the agricultural sector. Since the amount of land in the agricultural sector is given, a higher number of workers in this sector will reduce marginal product of a worker in the agricultural sector. With a higher average cost of production, the price of the agricultural good increases.

Land is a kind of resource endowment. As shown in the literature on Dutch diseases, an increase in resource endowment may not be beneficial to a country. The following proposition studies the impact of an increase in land endowment on the unemployment rate and other variables.

Proposition 5: A higher land endowment leads to a lower urban unemployment rate and the price of the agricultural good decreases. Impact on the number of individuals employed in the agricultural sector is ambiguous.

Proof: Applying Cramer's rule on (23) yields

$$\frac{dp_a}{dT} = \frac{\partial \Gamma_1}{\partial u}\left(\frac{\partial \Gamma_2}{\partial T}\frac{\partial \Gamma_3}{\partial L_a} - \frac{\partial \Gamma_2}{\partial L_a}\frac{\partial \Gamma_3}{\partial T}\right)/\Delta < 0,$$

$$\frac{du}{dT} = \frac{\partial \Gamma_1}{\partial p_a}\left(\frac{\partial \Gamma_2}{\partial L_a}\frac{\partial \Gamma_3}{\partial T} - \frac{\partial \Gamma_2}{\partial T}\frac{\partial \Gamma_3}{\partial L_a}\right)/\Delta < 0,$$

$$\frac{dL_a}{dT} = \left(\frac{\partial \Gamma_1}{\partial p_a}\frac{\partial \Gamma_2}{\partial T}\frac{\partial \Gamma_3}{\partial u} + \frac{\partial \Gamma_1}{\partial u}\frac{\partial \Gamma_2}{\partial p_a}\frac{\partial \Gamma_3}{\partial T} - \frac{\partial \Gamma_1}{\partial p_a}\frac{\partial \Gamma_2}{\partial u}\frac{\partial \Gamma_3}{\partial T} - \frac{\partial \Gamma_1}{\partial u}\frac{\partial \Gamma_2}{\partial T}\frac{\partial \Gamma_3}{\partial p_a}\right)/\Delta.$$

Since the sign of $\frac{\partial \Gamma_1}{\partial p_a}\frac{\partial \Gamma_2}{\partial T}\frac{\partial \Gamma_3}{\partial u} + \frac{\partial \Gamma_1}{\partial u}\frac{\partial \Gamma_2}{\partial p_a}\frac{\partial \Gamma_3}{\partial T} - \frac{\partial \Gamma_1}{\partial p_a}\frac{\partial \Gamma_2}{\partial u}\frac{\partial \Gamma_3}{\partial T} - \frac{\partial \Gamma_1}{\partial u}\frac{\partial \Gamma_2}{\partial T}\frac{\partial \Gamma_3}{\partial p_a}$ is ambiguous, the sign of $\frac{dL_a}{dT}$ is ambiguous. ■

To understand Proposition 5, when land endowment increases, other things equal, output in the agricultural sector increases and the price of the agricultural good decreases. When the price of the agricultural good decreases, through the non-shirking condition, urban unemployment rate decreases. While an increase in the amount of land tends to increase the value marginal product of an agricultural worker, a decrease in the price of the agricultural good tends to reduce this value marginal product. Overall, the impact of an increase in land endowment on the number of individuals in the agricultural sector is ambiguous.

A country has a comparative advantage in producing the manufactured good if the relative price of the manufactured good to that of the agricultural good is lower. In this model, since the price of the manufactured good is normalized to one, the relative price of the manufactured good to that of the agricultural good is the inverse of the price of the agricultural good. Thus, a country with a higher price of the agricultural good has a comparative advantage in producing the manufactured good. From Proposition 1, a country with more patient citizens has a comparative advantage in producing the manufactured good. From Proposition 2, a country with a higher capital endowment has a comparative advantage in producing the manufactured good. From Proposition 3, a country with a more efficient labor market has a comparative advantage in producing the manufactured good. From Proposition 4, other things equal, a country with a larger population has a comparative advantage in producing the manufactured good. From Proposition 5, an economy with a lower endowment of natural resources has a comparative advantage in producing the manufactured good. This is consistent with the observation that countries like Japan and Singapore with limited natural resources export manufactured goods.

4. Conclusion

While more advanced technologies mean higher labor productivities, a developing country considering technology adoption is also concerned with the existence of unemployment. Since more advanced technologies are usually capital-intensive rather than labor-intensive, will the adoption of more advanced technologies increase unemployment? Will capital accumulation lead to job creation in economic development if firms choose technologies substituting labor for capital? In this paper, we have provided a general-equilibrium framework (in which manufacturing firms engage in Cournot competition) for studying the interaction between technology choice and unemployment in a developing economy based on microfoundations. We have established the following analytical results for the steady state. An increase in capital endowment increases the equilibrium wage rate and induces manufacturing firms to adopt more advanced technologies. Capital accumulation can lead to a lower urban unemployment rate even though firms choose more advanced technologies.

There are some potential interesting generalizations and extensions of the model. First, government policies such as a subsidy to technology adoption, output subsidy, and wage subsidy or taxes can be introduced into the model. Second, in this model, the amount of capital is exogenously given. The model can be generalized to the case that the accumulation of capital is studied explicitly. If the amount of capital stock is endogenously determined, a higher interest rate could lead to a higher capital stock and thus a government subsidy to capital usage could lead firms to adopt more advanced technologies. Third, we have studied a closed economy. The model could be used to address issues from the opening of international trade. When a country opens trade with another country with different factor endowments and labor market conditions, how will this affect a country's unemployment rate and technology choice will be an interesting avenue for future research.

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