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Technology Adoption and Skill Premium in the Knowledge Economy*

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This paper introduces an indirect utility function with non-constant expenditure shares to analyze how technology adoption and skill premium are linked in the knowledge economy. The model shows that if and only if the technology is "general purpose technology" (GPT), technology adoption increases the skill premium in spite of the relative price decline of modern goods that are skill-intensive.

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I. Introduction

In the new or knowledge economy, the relative returns to skilled labor are increased with the acceleration in the rate of price decline in modern goods that are skilled-labor intensive.[1] This quite reverse result is also consistent with some stylized facts about the pervasive use of "general purpose technology" (GPT) such as information technology (IT) in the production of modern goods.[2] The GPT in

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[1] As in Gordon (2000), the New Economy defined as the post-1995 acceleration in the rate of price decline in computer hardware, software, and telephone services, the corollary of an acceleration of the exponential growth rate of computer power and the wildfire speed of development of the Internet. As in Powell and Snellman (2004), the knowledge economy is defined as production and services based on knowledge-intensive activities that contribute to an accelerated pace of technological and scientific advancement as well as equally rapid obsolescence.

[2] The GPT is a technology that initially has much scope for improvement and eventually comes to be widely used, to have many uses, and to have many Hicksian and technological complementarities

the form of, for example, a semiconductor, has been broadly used in a wide variety of other products as well as computing and communications equipment. This paper examines the effect of technology adoption on the skill premium in the knowledge economy.[3] The technology adoption increases the productivity of the modern sector, and induces the price decline of modern goods. This relative price decline of a modern good leads eventually to the increased modern sector share of total expenditure, and the wage premium of skilled labor, if and only if the new technology is GPT.[4] The price elasticity of demand for the better and cheaper modern good is so elastic that the usual substitution effect dominates the income effect.

The skill-biased technological change can help explain inequality between the rewards for skilled workers who effectively harness new information technologies and those of the unskilled workers (Acemoglu, 2002; Jacobs and Nahuis, 2002; OECD, 2007). Basically, when technology (or capital) and skills are complements, a decrease in the relative price of technology (or capital) increases the demand for skilled labor and wage inequality (Acemoglu, 1998; Dinopoulos *et al*., 2011; Goldin and Katz, 1998; Krusell et al., 2000; Maliar and Maliar, 2011; Wolff, 2002). However, we should look deeper than skill-biased technological change or technology (or capital) and skill complementarity if we are to fully understand widening wage dispersion. More specifically technology adoption in the modern sector can explain wage inequality in the knowledge economy, if and only if the new technology is GPT. As Hall and Khan (2003) point out, it is diffusion rather than invention that ultimately determines the pace of economic growth and the rate of change of productivity. Until many users adopt a new technology, it may contribute little to our well-being. On the other words, the ultimate effect of innovation depends on the demand-side even though technological change is made on the supply-side.

This paper examines the effects of adoption of new technology on the skill premium, paying particular attention to a North-North model of technology adoption.[5] Unlike most of the supply-side analysis, we put forth an argument that

(Helpman, ed., 1998, Ch. 2). GPTs are characterized by pervasiveness, inherent potential for technical improvements, and innovational complementarities, giving rise to increasing returns to scale (Bresnahan and Trajtenberg, 1995).

[3] For example, Autor, Katz and Kearney (2008) find the expansion of educational wage differentials by analyzing U.S. data from the Current Population Survey. In particular, from 1995 to 2005, the composition-adjusted mean real wages of college graduates increased by 12.5 log point, compared to those of high-school graduates, which increased by 5.8 log point.

[4] We can calculate the absolute value of the price elasticity of demand for the modern good such as computers, software, communications equipment, and information technology services from Jorgenson (2001) as follows: $\varepsilon_p = 2.75$ per year from 1990 to 1995, and $\varepsilon_p = 2.03$ per year from 1995 to 1999.

[5] In contrast to a North-South model of technology adoption in which the North introduces new

adoption rather than invention of new technology, if and only if the new technology is GPT, can mainly be a driving source of recent wage inequality. In support of this claim, we demonstrate that in addition to the standard theory of gains from technology adoption, both economies will experience further gains from the reallocation of workers across sectors within a national economy.[6]

This paper specifically introduces a simple two-sector general equilibrium model with an indirect utility form of non-constant expenditure shares to highlight a link between technology adoption and the skill premium in the knowledge economy. The arguments presented in this paper are based on the following assumptions. First, the consumer's preference takes an indirect utility form of non-constant expenditure shares. Second, the "general purpose" nature of technology is formulated in relation to price elasticity of demand for modern goods.[7] The generality of the technology is determined by the degree of price elasticity of demand for modern goods. Some evidence found in Jorgenson (2001) supports our assumption that the modern sector share of total expenditure is increasing with the relative price decline in modern goods because of the elastic (high) price elasticity of demand. Theoretically, when the relative price of modern goods decreases, a substitution effect shifts demand from the regular goods to the modern goods. In the standard Cobb-Douglas preferences, this effect is exactly off-set by an income effect. In our framework, however, the substitution effect outweighs the income effect if and only if technology is GPT. This paper adds major contributions to the existing theoretical literature on technology adoption. First, this paper explicitly introduces an indirect utility function with non-constant expenditure shares in the demand-side analysis. Second, the generality of the technology is formulated in relation to the price elasticity of demand for modern goods.

The paper proceeds as follows. Section II introduces an indirect utility form of non-constant expenditure shares, and analyzes a simple two-sector general equilibrium. Section III shows how technology adoption and the skill premium are linked in the new economy. Section IV provides some concluding remarks.

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goods that are then imported or imitated by the South (Grossman and Helpman, 1992), this paper develops a North-North model of technology adoption in which the North introduces new technology as intermediate inputs that are imported by the North. Since technology as intermediates is invented through costly R&D investment, technology adoption implies an implicit sharing of the technology that was created in other economies. This kind of trade in middle products provides a positive link between the number of specialized inputs and the productivity of the modern sector.

[6] Chun (2003) claims that "the diffusion of IT has contributed about 40% of the acceleration in the relative demand for educated workers (college graduates) from 1970 to 1996."

[7] As in Aghion, Howitt, and Violante (2002), we introduce the idea of generality of technology. In contrast to our model, however, they have modeled generality, both in relation to human capital (skill transferability) and physical capital (vintage compatibility).

II. The Model

We consider that an economy produces two final goods, M (the modern good) and R (the regular good), and n intermediate inputs that are technology-intensive, G_i, $i = 1,...,n$. We take good R as the numeraire, $p_y = 1$, and denote the relative price of M, p_x/p_y, by p. There are two factors of production, skilled and unskilled labor, denoted by S and L. Both are assumed to be physically immobile internationally. This paper is focused on the demand side, but supply factors are obviously of equal potential importance.

1. Demand

Consumers worldwide share identical, homothetic preferences. The representative consumer has an indirect utility function as follows:

$$U(C_M, C_R) = U(\mu(p)I^j / p, (1-\mu(p))I^j) \tag{1}$$

where C_M and C_R are consumption of a modern good and a regular good, respectively, and I^j is any individual j's income, and $\mu(p) \in (0,1)$ is the share of income that she spends on a modern good.[8] We model the shift in tastes explicitly by assuming that this share, μ, is a function of the relative price of modern good, p.[9] In equilibrium, the expenditure on the modern good equals the revenue of the modern sector, pM. This means that the changing relative price of M will affect the M sector share of total expenditure (or demand). The effects of a fall in relative price of modern goods on varying expenditure shares depend basically on the price elasticity of demand for the modern goods.[10] If the modern goods have a high (or low) price elasticity of demand, the falls over time in their relative prices will boost (or reduce) the share of total expenditure. The falls in the relative prices of modern good will leave the modern sector share of total expenditure unchanged only if a unitary price elasticity of demand, i.e., $\varepsilon_p = 1$ (the standard Cobb-Douglas case)

[8] As in Mitra and Trindade (2003), we introduce an indirect utility type model of changing demand shares.

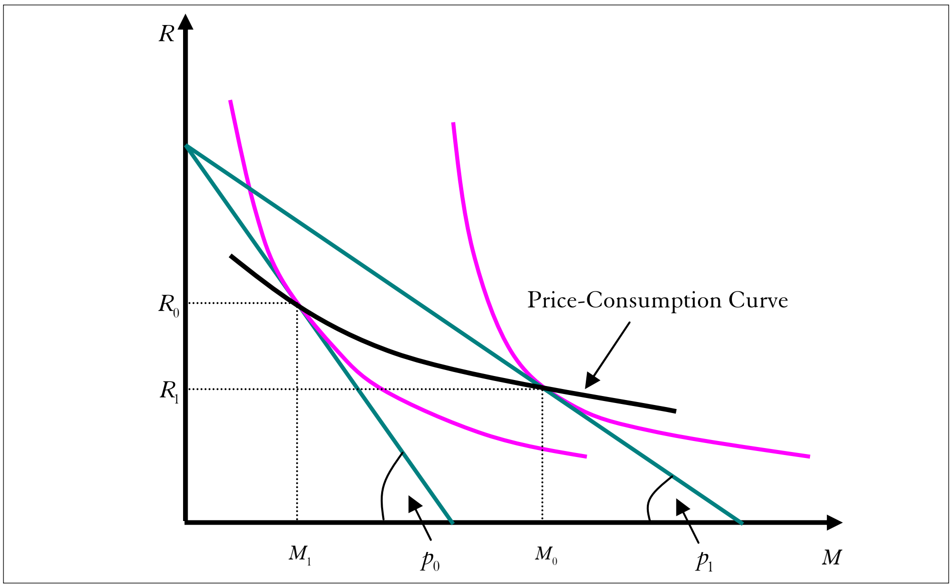
[9] The demand share can also depend on the income elasticity of demand. If the goods produced by the modern sectors are superior goods, the share, μ, will rise as economic growth continues. In contrast to Mitra and Trindade (2003), however, this effect will not be modeled here.

[10] Hence, we have

$$\left[\frac{d\left(\dfrac{pM}{pM+R}\right)}{\left(\dfrac{pM}{pM+R}\right)} \Big/ \frac{dp}{p}\right]\begin{Bmatrix} < \\ = \\ > \end{Bmatrix} 0 \Leftrightarrow \frac{d\left[pM(p)\right]}{dp} = T\left(1 + \frac{dM/M}{dp/p}\right) = M\left(1-\varepsilon_p\right)\begin{Bmatrix} < \\ = \\ > \end{Bmatrix} 0 \Leftrightarrow \varepsilon_p \begin{Bmatrix} > \\ = \\ < \end{Bmatrix} 1.$$

(DeLong, 2002). The case in this analysis will be the one in which the price elasticity of demand for modern good is elastic. That is, we assume that μ is a decreasing function of p. Figure 1 depicts a typical price-consumption curve, which has negative slope in the case where $\partial\mu / \partial p < 0$. The other cases can be analyzed without any difficulty.[11]

[Figure 1] Price-Consumption Curve in the case of $\varepsilon_p > 1$



Now we assume that national income consists of the skilled labor income and the unskilled labor income as follows:

$$pM + R = I(w,v) = wL + vS \tag{2}$$

where I is national income, w the reward to unskilled labor, and v the reward to skilled labor. Using Roy's identity, we can derive the demand functions for the modern good and the regular good. Then the demand for the modern good M^d is a function of w, v and p as follow:

$$M^d(w,v,p) = \mu(p)(wL + vS)/p \tag{3}$$

Similarly, the demand function for good R is,

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[11] The price-consumption curve has positive slope in the case where $\partial\mu / \partial p > 0$.

$$R^d(w,v) = (1-\mu(p))(wL+vS) \tag{4}$$

This form implies constant expenditure shares given the relative prices, p. Hence, a fixed share of income, $\mu(p)$, is spent on the modern good, whereas the remainder, $1-\mu(p)$, is spent on the regular good.

2. Supply

The model consists of two competitive sectors, one producing a regular good with skilled and unskilled labor under constant returns to scale and the other a modern good produced by costlessly assembling technology-intensive intermediate inputs. The intermediate input is produced under increasing returns and monopolistic competition. The production function in the regular good sector is specifically given by

$$R = H(L_R, S_R) = L_R^{1-\alpha} S_R^{\alpha} \tag{5}$$

$H(\cdot)$ is twice differentiable, increasing, and strictly quasi-concave.

The modern good sector uses the n intermediate inputs that are technology-intensive, $G_i (i=1,...,n)$, to produce the final good M. Given an n vector G of specialized inputs, the production function is

$$M = \left(\sum_{i=1}^{n} G_i^{\beta} \right)^{1/\beta}, 0 < \beta < 1 \tag{6}$$

where β is a positive monotone transformation of the elasticity of factor substitution.[12] In this functional form of the Dixit and Stiglitz (1977) representation, output of modern goods is an increasing function of the total number of intermediate inputs used by the producer.

The intermediate input, G_i, is produced only by skilled labor. The total skilled labor (S_i) used in producing G_i consists of a fixed input, F, and a variable input directly proportional to output G_i:

$$S_i = F + G_i \tag{7}$$

[12] As in Ethier (1982), the modern goods are costlessly assembled from intermediate inputs that are technology-intensive. With this CES form, different value of the parameter, β, can be used to represent technologies with vastly different substitutability between intermediate inputs. A higher value of β indicates that intermediate input can be more easily substituted for each other in the assembly of finished modern goods. Thus lower values of β correspond to greater "production differentiation" within the modern sector.

Note that skilled labor is used directly in the regular sector but only indirectly in the modern sector as it is used to produce the intermediate inputs which are the sole inputs to the modern sector.

Within an economy, skilled labor is mobile between the regular sector and the intermediate input sector. The existence of scale economies in the intermediate input sector limits the production of each intermediate input to at most one firm, since it is more profitable to produce a different variety than to share a market with another firm. Full employment of these factors requires:

$$S_R + \sum_{i=1}^{n} S_i = S \tag{8}$$

$$L_R = L \tag{9}$$

With identical technologies among all firms in the intermediate input sector, facing the same skilled wage rate, v, the optimal output produced by the intermediate input producers are all equal: $G_i = G$ for all $i = 1,\ldots,n$. Moreover, profit maximization requires that the marginal revenue equal the marginal cost which is the skilled wage rate:

$$q\left(1-\frac{1}{\varepsilon}\right) = v, \qquad i = 1,\ldots,n \tag{10}$$

where q is the price of an intermediate input and ε the elasticity of demand for an intermediate input, which can be approximated by $1/(1-\beta) > 1$ since the number of intermediate input varieties is assumed to be large.

Producers of the modern sector maximize profits by choosing the optimal intermediate inputs, taking the number of intermediate input firms (n), the relative price of good $M(p)$, and the price of an intermediate input (q) as given, subject to production function (6). The first-order condition is given by

$$p = qn^{-\sigma} \tag{11}$$

where $\sigma = (1-\beta)/\beta$.

Producers of the regular sector maximize profits by choosing the optimal input mix of skilled and unskilled labor. The first-order condition of profit maximization for a producer of good R is given by

$$v = \alpha L^{1-\alpha} S_R^{\alpha-1} \tag{12}$$

In the long run, intermediate input firms enter the intermediate input markets until all firms break even. For $i = 1,...,n$, we thus obtain

$$qG_i = vS_i = v(F + G_i) \tag{13}$$

Using (10) and (13), the output of a single intermediate input firm is constant and equals

$$G_i = (\varepsilon - 1)F \tag{14}$$

Substituting (14) into (13), we get the amount of skilled labor employed in the intermediate input sector i:

$$S_i = \varepsilon F \tag{15}$$

Combining this expression with the full employment condition (8), the number of intermediate input firms in the economy is determined as follows:[13]

$$n = \frac{1}{\varepsilon F}\left[S - S_R(v)\right] \tag{16}$$

Then we can get the supply of good M^s as a function of v and p by using (6), (11) and (16) (Appendix 1):

$$M^s(v, p) = \frac{v}{p}\left[S - S_R(v)\right] \tag{17}$$

3. Equilibrium

Now we can derive the Production Possibility Frontier (PPF), yielding all production combinations of modern good and regular good for which the factor market is cleared, by using (5), (16), and (17),

[13] In general, from the first-order condition of profit maximization for a producer of good R, we have

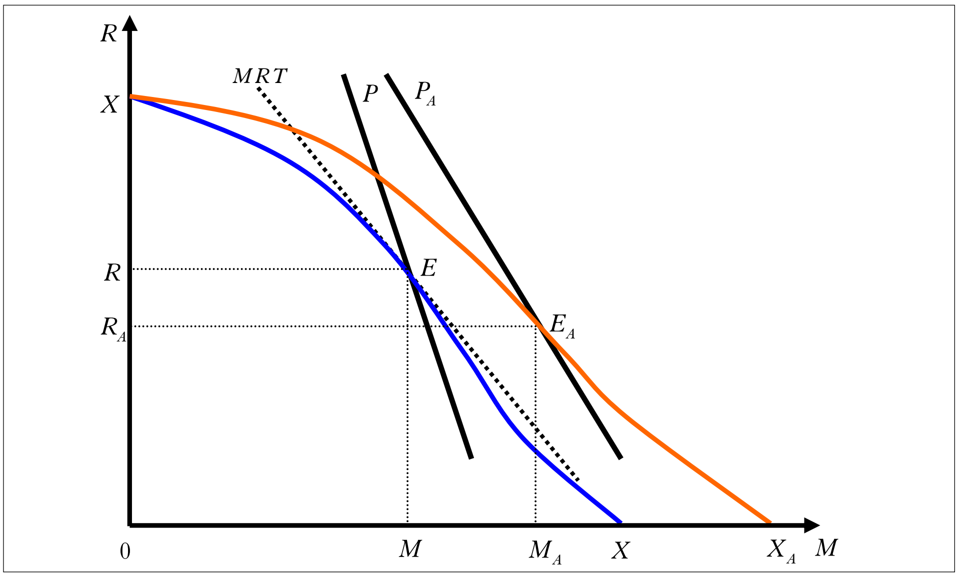
$$v = p_R H_{S_R}(L_R, S_R)$$

Hence, using $L_R = \overline{L}$ and $p_R = 1$, we have $S_R = S_R(v)$.

$$R = L^{1-\alpha}\left[S - \left(\frac{1}{\beta}(\varepsilon F)^{\sigma} M\right)^{1/(\sigma+1)}\right]^{\alpha} \equiv f(M) \tag{18}$$

with $f'(M) < 0$ (Appendix 2).[14] In Figure 2, *XX* is the PPF of the autarky. Note that we are dealing with a second-best PPF, as producers of M do not take into account the positive externality associated with the number of intermediate input varieties in the production of modern goods. That is, we assume that equilibrium occurs on the concave portion of the PPF in Figure 2.

[Figure 2] Technology adoption and production equilibrium in the case of $\varepsilon_p > 1$



The marginal rate of transformation (MRT) is given by $-f'(M)$ while the marginal rate of substitution (MRS) is given by p as there is no consumption externality. By using (11), (12) and (18), the ratio of both at the autarky equilibrium equals (Appendix 3)

$$\frac{MRT}{MRS} = \sigma + 1 > 1 \Leftrightarrow |MRT| < p \tag{19}$$

[14] With $f''(M)\begin{Bmatrix} > \\ - \\ < \end{Bmatrix}0$, the PPF is concave up to the unique inflexion point, $\tilde{M} = \beta(\varepsilon F)^{-\sigma}\left(\frac{\sigma S}{\sigma+1-\alpha}\right)^{\sigma+1}$, and is convex thereafter.

As a result, in autarky the economy will produce and consume too many regular goods and not enough modern goods.

Mathematically, the autarkic equilibrium can be obtained by equating the supply and demand of M good, i.e., $M^s(v,p) = M^d(w,v,p)$. The autarkic price, p (from (11)), the autarkic number of firms, n (from (16)), and the autarkic equilibrium skilled wage, v, and unskilled wage, w, are as follows (Appendixes 4 to 7):

$$p = \theta L^{1-\alpha} F^{\sigma} S^{\alpha-(1+\sigma)} \tag{20}$$

where $\theta = \beta^{-1}\alpha^{\alpha}\varepsilon^{\sigma}\mu^{-\sigma}(1-\mu)^{\alpha-1}(\alpha+\mu-\alpha\mu)^{1+\sigma-\alpha}$.

$$n = \left(\frac{\mu}{\alpha+\mu-\alpha\mu}\right)\left(\frac{S}{\varepsilon F}\right) \tag{21}$$

$$v = \alpha^{\alpha}(1-\mu)^{\alpha-1}(\alpha+\mu-\alpha\mu)^{1-\alpha} L^{1-\alpha} S^{\alpha-1} \tag{22}$$

$$w = (1-\alpha)\alpha^{\alpha}(1-\mu)^{\alpha}(\alpha+\mu-\alpha\mu)^{-\alpha} L^{-\alpha} S^{\alpha} \tag{23}$$

Using (4) and (17), the equilibrium production levels of good M and R are as follows (Appendixes 8 and 9):

$$M = \mu^{1+\sigma}\beta\varepsilon^{-\sigma}(\alpha+\mu-\alpha\mu)^{-(1+\sigma)} F^{-\sigma} S^{1+\sigma} \tag{24}$$

$$R = (1-\mu)^{\alpha}\alpha^{\alpha}(\alpha+\mu-\alpha\mu)^{-\alpha} L^{1-\alpha} S^{\alpha} \tag{25}$$

This equilibrium production point is shown by E in Figure 2.

III. Technology Adoption and Skill Premium

We consider a North-North model of technology adoption in which each advanced economy introduces new intermediate inputs which are imported by the other advanced economy. Thus we suppose that technology adoption driven by trade in intermediate inputs occurs between these two structurally identical economies at zero transportation cost.

Given this setup, we analyze how technology adoption and skill premium are linked in the knowledge economy. First, technology adoption driven by trade in intermediate inputs increases the number of input varieties in the M sector, which enhances the competitiveness of this sector. That is, technology adoption effectively integrates economically the G and M sectors in the world markets. Given the symmetric CES input structure, each economy will immediately exchange half of its intermediate input stock for half of the intermediate input stock of the other economy when technology adoption is allowed. Therefore, in aggregate, the number of G varieties rises from n to $2n$ initially. Then productivity of M sector in both economies grows via increases in n. Second, the higher productivity of M sector leads to the lower average cost for good M. This lower average cost of good M subsequently leads to the lower relative price for good M in the optimality condition. Hence, if the productivity of a M good is increased, the relative price for it will be lowered after technology adoption. Third, if and only if the new technology is GPT, this lower relative price for a M good ultimately leads to greater demand and thus a greater expenditure share for the M sector throughout the economy. This means that the expenditure share on the M good goes up after technology adoption. As a result, the wage to skilled labor in the G/M sector increases and so does the real wage of skilled labor. However, this is not the end of the story. Besides these gains, each economy will experience further gains from reallocation of factors between industries after technology adoption. Fourth, given the specification of our model, this skilled wage premium in the G/M sector accelerates skilled labor to shift from the R sector to the G/M sector. It increases resources devoted to the G sector and the size of the G/M sector. Since G is unchanged in the post-adoption equilibrium due to (14), the post-adoption number of G varieties in each economy will be further increased from n to $n_A(>n)$ as the skilled labor devoted to the G/M sector increases.

This means that if and only if the adopted technology is GPT, the number of G varieties in each economy is further increased from n to $n_A(>n)$ as skilled labor allocated to G/M sector increases. In other words, the higher the price elasticity of demand for M goods after technology adoption, the greater the number of G varieties developed for the M sector, and thus the stronger the forces pushing the expenditure share up as their price declines.[15] If the expenditure share on the M sector is further increased, the real wage of skilled labor in the post-adoption equilibrium will be increased.

This can also be seen mathematically. In the post-adoption equilibrium, the modern sector uses twice the post-adoption number of intermediate input varieties ($2n_A$), but half of its intermediate input varieties ($G_i/2$) to produce the final good M_A. More specifically, then, we have the post-adoption production function of

[15] If the price elasticity of demand for a modern good is smaller than 1, the stronger will be the forces pushing the expenditure share down as their price declines, and thus the lesser will be the number of intermediate input varieties developed for the modern sector. If the price elasticity of demand is unitary as the adoption of new technology continues with free input trade, the expenditure share will be the same as their price declines. Thus, the number of intermediate input varieties developed for the modern sector will not be changed.

M_A as

$$M_A = \left(\sum_{i=1}^{2n_A} \left(\frac{G_i}{2} \right)^{\beta} \right)^{1/\beta}, \quad 0 < \beta < 1 \tag{26}$$

With identical technologies among the supplier of intermediate inputs, who all face the same post-adoption skilled wage rate, v_A, the optimal outputs produced by the supplier of intermediate inputs are all equal: $G_i = G$ for all $i = 1, \dots, n_A$. The optimality condition for this problem is straightforward: at the optimal choice of output we must have marginal revenue equal to marginal cost. In terms of algebra, we can write the optimization condition as

$$q_A \left(1 - \frac{1}{\varepsilon} \right) = v_A, \qquad i = 1, \dots, n_A \tag{27}$$

where q_A is the post-adoption price of intermediate input. Producers of the modern sector maximize profits by choosing the optimal intermediate inputs, taking the post-adoption number of intermediate input varieties ($2n_A$), the post-adoption relative price of a modern good (p_A), and the post-adoption price of intermediate input (q_A) as given, subject to (26). The first-order condition is then given by

$$p_A = q_A (2n_A)^{-\sigma} \tag{28}$$

From (16), we have the number of intermediate input firms in the post-adoption equilibrium:

$$n_A = \frac{1}{\varepsilon F} \left[S - S_R(v_A) \right] \tag{29}$$

In the post-adoption equilibrium, as a consequence, we have a lower relative price, $p > p_A > 2^{-\sigma} p$.[16] In our model, then, the lower relative price for a modern good eventually leads to a greater modern sector share of total expenditure (or demand).

On the demand side, the post-adoption indirect utility function for the representative consumer is specifically given by

[16] In the post-adoption equilibrium, p_A does not decrease until $2^{-\sigma} p$ since μ increases as p decreases, i.e., $d\mu / dp < 0$. Meanwhile p_A should be less than p since $\infty > \varepsilon_p > 1$.

$$U_A(C_M, C_R) = U_A(\mu(p_A)I_A^{\,j} / p_A, (1-\mu(p_A))I_A^{\,j}) \tag{30}$$

where $\mu_A = \mu(p_A)$ and $\mu_A > \mu$. National income consists of the post-adoption skilled labor income and the post-adoption unskilled labor income as

$$p_A M_A + R_A = I_A = w_A L + v_A S \tag{31}$$

where w_A is the post-adoption reward to unskilled labor. Then the post-adoption demand for the modern good is a function of w_A, v_A and p_A as

$$M_A^d(w_A, v_A, p_A) = \mu_A(w_A L + v_A S) / p_A \tag{32}$$

The post-adoption supply of the modern good can be written as a function of v_A and p_A by using (26), (27), (28) and (29):

$$M_A^s(v_A, p_A) = \frac{v_A}{p_A}\left[S - S_R(v_A)\right] \tag{33}$$

Similarly, the post-adoption demand and supply functions for a regular good are respectively,

$$R_A^d(w_A, v_A) = (1-\mu_A)(w_A L + v_A S) \tag{34}$$

$$R_A^s(v_A) = L^{\alpha} S_R(v_A)^{1-\alpha} \tag{35}$$

Using (29), (33), and (35), we can now derive the post-adoption PPF as follows:

$$R_A = L^{1-\alpha}\left[S - \left(\frac{1}{\beta}\left(\frac{\varepsilon F}{2}\right)^{\sigma} M_A\right)^{1/(\sigma+1)}\right]^{\alpha} \equiv f(M_A) \tag{36}$$

with $f'(M_A) < 0$.[17] In Figure 2, XX_A where lies everywhere outside of XX locus except X is the PPF of the new frontier which results from technology

[17] With $f''(T_A)\begin{Bmatrix} > \\ = \\ < \end{Bmatrix} 0$, the PPF is concave up to the unique inflexion point, $\tilde{M}_A = \beta\left(\frac{\varepsilon F}{2}\right)^{-\sigma}\left(\frac{\sigma S}{\sigma+1-\alpha}\right)^{\sigma+1}$, and is convex thereafter.

adoption. In the post-adoption situation, the new equilibrium is illustrated by E_A in Figure 2.

The post-adoption equilibrium can be calculated by equating supply and demand for the modern good, i.e., $M_A^s(v_A, p_A) = M_A^d(w_A, v_A, p_A)$. Specifically, the relative price of post-adoption equilibrium p_A is given by

$$p > p_A = 2^{-\eta}\theta_A L^{1-\alpha}F^{\sigma}S^{\alpha-(1+\sigma)} > 2^{-\eta}p \tag{37}$$

Where $\theta_A = \beta^{-1}\alpha^{\alpha}\varepsilon^{\sigma}\mu_A^{-\sigma}(1-\mu_A)^{\alpha-1}(\alpha+\mu_A-\alpha\mu_A)^{1+\sigma-\alpha} > \theta$. The post-adoption number of intermediate input firms is as follows:

$$n_A = \left(\frac{\mu_A}{\alpha+\mu_A-\alpha\mu_A}\right)\left(\frac{S}{\varepsilon F}\right) > n \tag{38}$$

In the post-adoption equilibrium, skilled wage v_A and unskilled wage w_A are given as follows:

$$v_A = \alpha^{\alpha}(1-\mu_A)^{\alpha-1}(\alpha+\mu_A-\alpha\mu_A)^{1-\alpha}L^{1-\alpha}S^{\alpha-1} > v \tag{39}$$

$$w_A = (1-\alpha)\alpha^{\alpha}(1-\mu_A)^{\alpha}(\alpha+\mu_A-\alpha\mu_A)^{-\alpha}L^{-\alpha}S^{\alpha} < w \tag{40}$$

Using (16) and (17), the equilibrium production levels of good M_A and R_A are given in the following equations:

$$M_A = 2^{\sigma}\mu_A^{1+\sigma}\beta\varepsilon^{-\sigma}(\alpha+\mu_A-\alpha\mu_A)^{-(1+\sigma)}F^{-\sigma}S^{1+\sigma} > 2^{\sigma}M \tag{41}$$

$$R_A = (1-\mu_A)^{\alpha}\alpha^{\alpha}(\alpha+\mu_A-\alpha\mu_A)^{-\alpha}L^{1-\alpha}S^{\alpha} < R \tag{42}$$

In the post-adoption equilibrium, if and only if the new technology is GPT, the output of M_A increases and the output of R_A decreases in each economy. Under the conditions of $(w-w_A)L < (v_A-v)S$, each economy's income increases with technology adoption.[18] This result shows that technology adoption is Pareto-superior to autarky. Furthermore, our two-country model illustrates an inverse relationship between expenditure and price. That is, the fall in relative price of modern goods results in increased sectoral demand shares in our indirect utility function. This gives us Proposition 1.

[18] In the case of $(w-w_A)L > (v_A-v)S$, however, each economy's income decreases with the technology adoption.

Proposition 1. *If and only if the new technology is GPT, technology adoption increases the skill premium in spite of the relative price decline of modern goods that are skill-intensive.*

Hence this analysis shows that in spite of the fall of relative price for modern goods, the post-adoption skilled labor wage is increased while the post-adoption unskilled wage is lowered.

IV. Concluding Remarks

This paper introduces an indirect utility function with non-constant expenditure shares to highlight how technology adoption and skill premium are linked in the knowledge economy. We pay attention to a North-North model of technology adoption between structurally identical economies, and formulate the idea of generality of technology in relation to the price elasticity of demand. The model explicitly shows that if and only if the new technology is GPT, technology adoption can affect the skill premium in the knowledge economy. A key insight of this paper is that if and only if the new technology is GPT, technology adoption increases the skill premium in spite of the relative price decline of skill-labor intensive modern goods. The reason is that the price elasticity of demand for a modern good is elastic. If and only if the demand for modern good is elastic, the relative price decline in modern good increases the modern sector share of total expenditure, and thus leads to increased rewards to skilled labor. However, the wage of unskilled labor is reduced as skilled labor shifts the regular sector to the intermediate input / modern sector.

These results are relevant to the current issues about technology adoption driven by trade in intermediate inputs. It is quite clear that technology adoption by itself can account for the rise of the skill premium as well as significant welfare gains. The welfare result of this model implies the possibility of significant gains from technology adoption driven by trade in intermediates. The skill premium result of this analysis suggests that the better education and training for unskilled workers rather than the higher barriers for technology adoption driven by trade in intermediates can be the alternative public policy to narrow the gap between skills.

Appendix: Derivation of Results

1. Derivation of the Supply of Good M

Since ε can be approximated by $1/(1-\beta)$, the first-order condition (11), by using (10), can be expressed as

$$n = (v/\beta p)^{-\frac{1}{\sigma}} \tag{A1}$$

Using (14), (16), and (A1), we can rewrite (6) as

$$\begin{aligned} M &= \left(\sum_{i=1}^{n} G_i^{\beta}\right)^{1/\beta} = (nG_i^{\beta})^{1/\beta} = n^{1/\beta} G_i = n^{\frac{1}{\beta}-1} n(\varepsilon-1)F \\ &= n^{\sigma}\left[\frac{1}{\varepsilon F}(S - S_R(v))\right](\varepsilon-1)F = \left(\frac{v}{\beta p}\right)\beta\left[S - S_R(v)\right] \\ &= \frac{v}{p}\left[S - S_R(v)\right] \end{aligned}$$

2. Derivation of the Production Possibility Frontier (PPF)

Using (16), (A1), and (5), we can rewrite (17) as

$$\begin{aligned} M &= \frac{v}{p}\left[S - S_R(v)\right] = \frac{v}{p}\varepsilon F n = \beta n^{\sigma}\varepsilon F n = \beta\varepsilon F n^{\sigma+1} \\ &= \beta\varepsilon F\left[\frac{1}{\varepsilon F}(S - S_R(v))\right]^{\sigma+1} \\ &= \beta\varepsilon F\left[\frac{1}{\varepsilon F}\left(S - \left(R/L^{1-\alpha}\right)^{\frac{1}{\alpha}}\right)\right]^{\sigma+1} \equiv f(R) \quad \text{with} \quad f'(R) < 0\,. \end{aligned} \tag{A2}$$

Rewriting (A2) with respect to R, we obtain the following expression:

$$R = L^{1-\alpha}\left[S - \left(\frac{1}{\beta}(\varepsilon F)^{\sigma} M\right)^{1/(\sigma+1)}\right]^{\alpha} \equiv f(M) \quad \text{with} \quad f'(M) < 0\,.$$

3. Derivation of the Ratio of MRT / MRS

Using (A1), (12), and (5), we can have

$$\begin{aligned}\frac{1}{p} &= \beta v^{-1} n^{\sigma} = \beta\left[\frac{1}{\varepsilon F}(S - S_R(v))\right]^{\sigma} v^{-1} \\ &= \beta\left[\frac{1}{\varepsilon F}(S - S_R(v))\right]^{\sigma} \alpha^{-1} L^{\alpha-1} S_R^{1-\alpha} \\ &= \alpha^{-1}\beta\left(\frac{1}{\varepsilon F}\right)^{\sigma}\left[S - \left(R \big/ L^{1-\alpha}\right)^{\frac{1}{\alpha}}\right]^{\sigma} L^{\frac{\alpha-1}{\alpha}} R^{\frac{1-\alpha}{\alpha}} \end{aligned} \quad \text{(A3)}$$

Differentiating (A2) with respect to R, we can obtain the following expression:

$$-f^{'}(R) = (\sigma+1)\alpha^{-1}\beta\left(\frac{1}{\varepsilon F}\right)^{\sigma}\left[S - \left(R \big/ L^{1-\alpha}\right)^{\frac{1}{\alpha}}\right]^{\sigma} L^{\frac{\alpha-1}{\alpha}} R^{\frac{1-\alpha}{\alpha}} \quad \text{(A4)}$$

From (A3) and (A4), we can obtain the ratio of MRT / MRS at the autarky equilibrium as

$$\begin{aligned}\frac{MRT}{MRS} \equiv \frac{-f^{'}(R)}{1/p} &= \frac{(\sigma+1)\alpha^{-1}\beta\left(\frac{1}{\varepsilon F}\right)^{\sigma}\left[S - \left(R \big/ L^{1-\alpha}\right)^{\frac{1}{\alpha}}\right]^{\sigma} L^{\frac{\alpha-1}{\alpha}} R^{\frac{1-\alpha}{\alpha}}}{\alpha^{-1}\beta\left(\frac{1}{\varepsilon F}\right)^{\sigma}\left[S - \left(R \big/ L^{1-\alpha}\right)^{\frac{1}{\alpha}}\right]^{\sigma} L^{\frac{\alpha-1}{\alpha}} R^{\frac{1-\alpha}{\alpha}}} \\ &= \sigma + 1 > 1\,. \end{aligned}$$

4. Derivation of 'v'

In the autarky equilibrium, the reward of skilled labor, v, can be calculated by equating supply and demand for the modern good, i.e., $M^{s}(v, p) = M^{d}(w, v, p)$. From (17) and (3), we obtain

$$\frac{v}{p}\left[S - S_R(v)\right] = \mu(p)(wL + vS)/p$$

$$(1-\mu(p))vS = \mu(p)wL + vS_R = \mu(p)wL + v\left[\frac{\alpha}{(1-\alpha)}\frac{w}{v}L\right]$$

$$\frac{v}{w} = \left(\frac{\alpha + \mu - \alpha\mu}{1 - \alpha - \mu + \alpha\mu} \right) \frac{L}{S} \tag{A5}$$

Using (A5) and $w = (1-\alpha)\left(\frac{\alpha - \alpha\mu}{\alpha - \alpha\mu + \mu} \right)^{\alpha} L^{-\alpha} S^{\alpha}$, we can obtain the autarkic skilled wage as

$$v = \alpha^{\alpha}(1-\mu)^{\alpha-1}(\alpha + \mu - \alpha\mu)^{1-\alpha} L^{1-\alpha} S^{\alpha-1}.$$

5. Derivation of 'w'

From the first-order conditions for the production of the regular good, R, we obtain

$$w = (1-\alpha) L^{-\alpha} S_R^{\alpha} \tag{A6}$$

$$v = \alpha L^{1-\alpha} S^{\alpha-1} \tag{A7}$$

From (A6) and (A7), we obtain

$$S_R = \frac{\alpha}{(1-\alpha)} \frac{w}{v} L \tag{A8}$$

Substituting (A5) into (A8), we have

$$S_R = \left(\frac{\alpha - \alpha\mu}{\alpha - \alpha\mu + \mu} \right) S \tag{A9}$$

Substituting (A9) into (A6), we get

$$w = (1-\alpha)\left(\frac{\alpha - \alpha\mu}{\alpha - \alpha\mu + \mu} \right)^{\alpha} L^{-\alpha} S^{\alpha}.$$

6. Derivation of 'n'

Substituting (A9) into (16), we obtain

$$n=\frac{1}{\varepsilon F}(S-S_R)=\frac{1}{\varepsilon F}\left[S-\left(\frac{\mu}{\alpha+\mu-\alpha\mu}\right)S\right]$$
$$=\left(\frac{\mu}{\alpha+\mu-\alpha\mu}\right)\frac{S}{\varepsilon F}$$

7. Derivation of 'p'

Substituting (21) and (22) into (A1), we obtain

$$p=\beta^{-1}vn^{-\sigma}$$
$$=\beta^{-1}(\alpha^{\alpha}(1-\mu)^{\alpha-1}(\alpha+\mu-\alpha\mu)^{1-\alpha}L^{1-\alpha}S^{\alpha-1})\left[\left(\frac{\mu}{\alpha+\mu-\alpha\mu}\right)\frac{S}{\varepsilon F}\right]^{-\sigma}$$
$$=\theta L^{1-\alpha}F^{\sigma}S^{\alpha-(1+\sigma)}\quad\text{where}\quad\theta=\beta^{-1}\alpha^{\alpha}\varepsilon^{\sigma}\mu^{-\sigma}(1-\mu)^{\alpha-1}(\alpha+\mu-\alpha\mu)^{1+\sigma-\alpha}.$$

8. Derivation of 'M'

Substituting (20), (23) and (A5) into (3), we obtain

$$M=\mu(p)(wL+vS)/p=\mu wS\left(\frac{L}{S}+\frac{v}{w}\right)/p$$
$$=\mu^{1+\sigma}\beta\varepsilon^{-\sigma}(\alpha+\mu-\alpha\mu)^{-(1+\sigma)}F^{-\sigma}S^{1+\sigma}\quad.$$

9. Derivation of 'R'

Substituting (23) and (A5) into (4), we obtain

$$R=(1-\mu(P))(wL+vS)=(1-\mu)wS\left(\frac{L}{S}+\frac{v}{w}\right)$$
$$=(1-\mu)^{\alpha}\alpha^{\alpha}(\alpha+\mu-\alpha\mu)^{-\alpha}L^{1-\alpha}S^{\alpha}.$$

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