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Sang-Chul Yoon*

Abstract

This paper examines a two-sector model of R&D-based endogenous growth, as a component of a broader study of servicization and its policy implications for a small open economy. The principal finding of this paper is that the expanding variety of intermediate services due to R&D contributes significantly to total factor productivity in the production of services, and thus a servicization with skill premium generally exists along a steady-state path. In addition, this paper derives an optimal policy for R&D subsidies to rule out the market failures due to R&D externality and market power in monopolistic competition conditions, and shows the Rybczynski effects of exogenous endowment changes.

Keywords: Servicization; Skill premium; Expanding variety; Optimal R&D policy; Rybczynski effect; Small open economy

JEL classifications: F11; J11; O14; O32

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I. Introduction

In recent decades, the majority of advanced economies have experienced structural changes toward a service economy during the process of digitally empowered economic growth observed as follows. First, the intermediate input sector, based in particular on knowledge and information, has expanded with increased economic growth.[1] Recently intermediate inputs, including knowledge-based services, are provided increasingly by newly created firms or spin-offs from manufacturing firms who are able to provide these services at lower cost or with higher quality (OECD, 2005). Second, the skilled labor force has been reallocated from the manufacturing sector to the service sector. For example, the OECD (2000) asserted that "services are a growing source of employment in the OECD area and demand for highly skilled white-collar workers is rising, although services are also an important source of low-skilled jobs." Third, the service sector has also been expanding, whereas the manufacturing sector has been contracting. For example, the OECD (2000; 2005) noted that "services account for about 70% of total economic activity in most OECD countries. Their growth has exceeded overall economic performance for decades, which has resulted in the share of services in total economic activity increasing over time. The rising trend can be expected to continue, or even accelerate, in light of the increasing prominence of knowledge-based, service-oriented activities in the OECD area." Blum (2008) remarked that "Since the late 1970s, the expansion of service sectors has occurred at the expense of manufacturing jobs and capital. If until then the "structural change" characterized the transition of the US economy from agrarian to industrialized, since then it characterizes an acceleration of the transition from an industrial to a post-industrial economy." Kapur (2012) reported that "In the US, over the 1948-2000 period the share of the private service sector in current-value GNP has risen steadily from 50.1% to 71.1%, while that of private manufacturing has fallen from 30.4% to 14.9%."

This growing relevance of services in the advanced economies has drawn an increasing amount of attention to both the causes of structural movements toward a service economy and to the issue of productivity in the service sector. In most earlier works regarding (non-traded) services, it has been hypothesized that productivity growth in services is lower than that in manufacturing, as services are unskilled labor-intensive and are resistant to technological change. Thus, the growing prominence of the service sector may result in reduced economic growth (Baumol, 1967; Baumol et al., 1985; Sasaki, 2007; Iacopetta, 2008). Contrary to the assertions of these earlier works, this paper projects, in an attempt to highlight the point made above, that economic growth in the majority of advanced economies increasingly depends on productivity growth in services, rather than in manufacturing.[2] In this paper, we assume that overall productivity growth

[1] Intermediate services and knowledge-based services as intermediate inputs will be used interchangeably in this analysis.

[2] Quah (1997) investigated that "the services sector is the most important in all advanced economies. In richer economies (those with per capita GDP of at least US $5,000), the services contribution to growth is always at least 40%. In almost all advanced economies it is services which figure most prominently in growth." Triplett and Bosworth (2003) found that US labor productivity in the services-producing sector has advanced at a 2.6 percent trend rate in 1995-2001, compared with 2.3 percent per year for the goods-

in the service sector and the rise of the service economy with skill premium is attributable to an increase in the variety of intermediate services as a consequence of R&D driven by information technology (IT).[3] With the advent of the New or Digital economy,[4] a positive link has been noted to exist between productivity in services and economic growth in the advanced economies. First, rapid communication and close contacts among innovators in different economies facilitate the process of innovation and the spread of new knowledge. The more profoundly knowledge stock is enhanced, the more productivity-enhancing new intermediate services each economy can develop. Second, based principally upon the advanced digital marketplaces, services have become more tradable, with the consequence that they are more prominently exposed to competition and are compelled to innovate in order to improve the quality of service offered. The Internet and e-Trade appear to be capable of making substantial contributions to economic growth, particularly in the service industries. Third, as new types of intermediate services, such as knowledge-based services, are central to the current wave of technological change, the 'service' functions of manufacturing--such as R&D, consulting, financing, marketing, accounting, etc.--can be much more specialized and thus much more readily outsourced. This widespread 'outsourcing' of services by manufacturing firms is one cause of the growing role of the service sector.[5] However, these relationships have received relatively little attention in the theoretical literature, and no satisfactory dynamic general equilibrium models have yet been presented.

This paper develops a two-sector endogenous growth model which allows for the observed characteristics of digitally empowered structural changes discussed above. Specifically, the driving force of economic growth is the expanding variety of intermediate services, including knowledge-based services, as a consequence of R&D. The introduction of new intermediate services specifically contributes to total factor productivity in the production of service (embedded) sector, and thus an uneven growth path with skill premium toward a service economy generally exists. In this dynamic framework, intermediate services are information or knowledge intensive which itself

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producing sector, and similarly multifactor productivity (MFP) growth in the services sector exceeded MFP growth in the goods-producing sector, post-1995 (1.5 percent per year, compared with 1.3 percent). OECD (2005) reported that "the contribution of the service sector to overall productivity growth has increased over the past ten years in some OECD countries, notably the United States, Australia and the United Kingdom. Strong aggregate productivity growth can in particular be attributed to high-growth service industries, such as finance, insurance and business services, as well as transport, storage and communications. These high-growth services contributed about one-third to aggregate productivity growth between 1990 and 2000 in several OECD countries." Jorgenson and Timmer (2011) discovered that "services now account for about three-quarters of value-added and hours worked and productivity growth in market services predominates over productivity growth in goods production in Japan and the US, although not in Europe." Kapur (2012) reported that "productivity growth in a number of service industries that are heavy ICT users has exceeded average productivity growth in manufacturing in recent years."

[3] Syrquin (1988) remarked that "the relative use of primary products as intermediates declines, while the uses of intermediates from heavy industry and services go up" and "the increase in the use of intermediate services is indicative of the dependence of industrial growth on a parallel expansion of modern services."

[4] See Atkeson and Kehoe (2007), Jalava and Pohjola (2002), and Pohjola (2002) for example.

[5] Fixler and Siegel (1999) reported that "outsourcing has played a major role in the rise of the service sector, and has led business services to a position of prominence." Schettkat and Yocarini (2006) also remarked that "outsourcing of service tasks from manufacturing industries increased."

suggests the increasing returns to scale (IRS) property, given the non-rival property of the knowledge. The marginal cost is trivial compared to the cost of the initial creation of the blueprint, thus, the effective development of intermediate services is not only critical to economic development but also essential for the growth of the service (embedded) sector in the economy. Furthermore, this study restricts itself to the case of a small open economy, which trades final products at exogenously-determined world prices and has access to the world capital market at exogenously-determined world interest rates.[6]

The relationship between economic growth and structural change has been subject to much attention over recent decades. Recent literatures regarding the industrialization issue include the work of Matsuyama (1991), Ishikawa (1992), Fung and Ishikawa (1992), and Laitner (2000). Matsuyama (1991) attempted to determine whether adjustment processes over real time help to 'select' the long-run outcome in a model of industrialization, where multiple stationary states exist as the result of increasing returns in the manufacturing sector. The global bifurcation technique is employed to determine when an underdevelopment trap exists and when a takeoff path exists. Ishikawa (1992) presented a simple dynamic model of industrialization, which allows for changes in both industrial structure and trade patterns during the process of economic growth. The source of endogenous growth in the producer service sector is 'learning by doing'. Fung and Ishikawa (1992) constructed a model that evaluated the dynamic growth pattern in a small open economy. The source of growth in this paper is the introduction of new intermediate goods as a consequence of R&D. Laitner (2000) presented a model in which a country's measured average propensity to save rises endogenously when its economy industrializes. The model illustrates that structural change explainable by Engel's law can systematically affect an economy's measured saving rate. Recently the servicization or post-industrialization issue was examined by Rowthorn and Ramaswamy (1998), Spilimbergo (1998), Blum (2008) and Buera and Kaboski (2009). Rowthorn and Ramaswamy (1998) demonstrated that deindustrialization is explained principally by factors internal to the advanced economies. Using a simple model, they also empirically assessed this relationship. Spilimbergo (1998) examined a Ricardian model in which the link between deindustrialization and trade was considered. He demonstrated that trade can reduce welfare if manufacturing activities with 'learning by doing' are move abroad. This effect results in a deceleration in the growth rate. Blum (2008) employed a multi-sector version of the Ricardo-Viner model of international trade in order to quantify empirically the effects of changes in the sectoral composition of the economy (i.e., the transition from an industrial to a post-industrial economy) on the US wage premium. He determined that alterations in the sectoral composition of the economy were the most critical force underlying the widening of the wage gap. Buera and Kaboski (2009) developed a non-homothetic model of specialized skill accumulation that leads to the rise of the service economy. However, the driving force of growth in this model is exogenous technical change.[7] They focused on the household's decision between home production and market production in explaining the rise of the service economy.

[6] In a dynamic context, the assumption of a small open economy simplifies the analysis. Thus, we can abstract from the complex intra-temporal and inter-temporal terms-of-trade considerations that hinder analysis of the more general, large-country case.

[7] Acemoglu and Guerrieri (2008) also presented a non-homothetic model with exogenous technological

Our model is closed to a two-sector model of Grossman and Helpman (1991), in that both present a standard R&D-based model of endogenous growth with an expanding variety of intermediate inputs. However, they do not contain the main contribution of the paper: unbalanced growth resulting from sector-specific intermediate services. Thus, their steady-state analysis is incapable of generating the above uneven growth paths we obtained. The principal contribution of this paper is to determine how unbalanced endogenous growth along a steady-state path is linked with a service economy with skill premium in a small open economy. In addition to this analysis, this paper provides policy implications—namely, that a positive but finite R&D subsidy can achieve the social optimum in the economy, and that an exogenous increase in high-skilled labor can speed economic growth.

This paper is organized as follows. Section 2 develops the basic framework, specifies its underlying assumptions, and solves for the dynamic equilibrium. Section 3 analyzes the relationships between endogenous growth and structural changes of the economy, and confirms the digitally empowered servicization path toward a service economy. Section 4 derives a positive and finite subsidy to R&D to attain an optimal growth path. Section 5 shows the Rybczynski relationship between endowment change and economic growth. Section 6 provides some concluding remarks.

II. The Model

We introduce a two sector dynamic model of endogenous growth with a variety of products. Consider a small open economy with two final sectors (a manufacturing sector, M , and a service (embedded) sector, S) under competitive conditions, and an intermediate input sector such as knowledge-based services, Z , under increasing returns to scale. Monopolistic competition prevails in the intermediate input market. The number of intermediate inputs can be augmented as a consequence of R&D. The productivity of high-skilled labor in R&D depends on the cumulative knowledge in the R&D technology. The economy is endowed with fixed stocks of two primary factors, high-skilled and low-skilled labors, which are denoted by H and L respectively. Both are assumed to be in fixed aggregate supply and physically internationally immobile. The world prices of the two final outputs, S and M , are p_s and p_m respectively. In the following we will take M as the numeraire, $p_m = 1$ and denote the relative price of S , p_s / p_m , by p . The source of economic growth in this model is the introduction of new intermediate inputs as a consequence of R&D, which in turn generates dynamic increasing returns to scale in the production of services and R&D. A small economy trades two final outputs at exogenously determined prices. Intermediate inputs are not traded in this model.[8]

change.

[8] The economy is not completely open because of this assumption. However, this assumption will be the driving force behind our interesting and realistic results. A similar two-country model with free trade in intermediate inputs can be used to show that both countries will grow at the same rate in the long run.

1. Consumer Preferences

We assume that the representative consumer maximizes a time-separable intertemporal utility function

$$U = \int_t^{\infty} e^{-\varphi(\kappa - t)} \log u\left(D^m(\kappa), D^s(\kappa)\right) d\kappa \tag{1}$$

in which φ is the individual rate of time preference and $D^i(\kappa)$ is demand of final product i in period κ. The instantaneous sub-utility function $u(\cdot)$ is non-decreasing, strictly quasi-concave, and positively linearly homogeneous. A representative consumer maximizes (1) subject to an intertemporal budget constraint. From this problem, as was shown in Grossman and Helpman (1991), we can derive the optimal path for expenditure as

$$\dot{\Psi} / \Psi = r - \varphi \tag{2}$$

in which $\Psi(t)$ is aggregate consumer expenditure and $r(t)$ the instantaneous interest rate at time t.[9] There is no possibility, in this case, for international borrowing or lending.

2. Production Technologies

The manufacturing sector

The manufacturing sector is a competitive, constant returns-to-scale industry which utilizes both low-skilled and high-skilled labor, with the production function

$$M = G^m(L, H_m) = L^{1-\alpha} H_m^{\alpha} \tag{3}$$

in which L is a specific factor and H_m is the employment of high-skilled labor in manufacturing sector. Let $c_m(w, v)$ be the unit cost in production M. Its price as the numeraire, which equals marginal cost, satisfies

$$1 = c_m(w, v) \tag{4}$$

in which w is the low-skilled wage rate and v the high-skilled wage rate.

The service (embedded) sector

The service (embedded) sector is produced with high-skilled labor and a continuum of intermediate services.[10] The intermediate services are assumed to be symmetric but

[9] In this analysis, an overdot represents a time derivative.

imperfect substitutes in the production of services. The perfectly competitive service sector also manifests constant returns to scale. The production function is assumed to take a sort of modified Cobb-Douglas appearance, as:

$$S = G^s(H_s, \Gamma) = H_s^{1-\beta}\Gamma^{\beta} \tag{5}$$

in which Γ is an index of aggregate intermediate usage in the service (embedded) sector, and H_s is employment of high-skilled labor in the service (embedded) sector. In particular, we assume that the index of aggregate intermediates use for the service (embedded) sector is given by

$$\Gamma = \left[\int_0^n z(\xi)^{\theta} d\xi\right]^{\frac{1}{\theta}} \tag{6}$$

in which $0 < \theta < 1$ is a positive monotone transformation of the elasticity of substitution, $z(\xi)$ denotes the amount of intermediate services utilized in the production of services S, and $n(t)$ is the measure of the number of varieties available at time t. Let $n^{-\sigma}c_s(v,q)$ denote the unit cost in production S in which q is the price of any intermediate services. Its price, which equals marginal cost, satisfies

$$p = n^{-\sigma}c_s(v,q) \tag{7}$$

in which $\sigma \equiv \beta(1-\theta)/\theta$, and $c_s(\cdot)$ is the cost function dual to the production functions.

The intermediate service sector

The intermediate services form a continuum of horizontally differentiated products. However, the feasible range of intermediate services is finite at any point in time, as a particular variety of the intermediate services developed in the research laboratory before it can be marketed. As in Ethier (1982), we assume that the output of final service (embedded) sector is an increasing function of the total number of specialized intermediate services utilized by a final service (embedded) sector. This specification captures the productivity gains from increasing degree of specialization in the production of final services. Therefore, prior to the production of an expanding variety of intermediate services, the firm must develop the production technique specific to that variety. After a production technique has been mastered, the firm can generate the selected intermediate services in accordance with an increasing-returns-to-scale production function. As demonstrated by Romer (1990), we assume that new blueprints, $\dot{n}$, are created using high-skilled labor and the existing stock of knowledge as follows:

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[10] OECD (1999) reported that "many rapidly growing new service activities (e.g. software, venture capital funds, etc.) employ highly qualified labor and are highly intensive in non-material investment. They belong to the most innovative activities and are based on technical progress (especially in information technology)."

$$\dot{n} = nH_n / a_{H_n} \tag{8}$$

in which H_n is the employment of high-skilled labor in the R&D sector, n is the current stock of knowledge capital, and a_{H_n} is the inverse productivity parameter. The model also assumes that monopolistic competition prevails in the intermediate services market. The resulting monopolistic competition price is a simple fixed markup over marginal production cost. Allow $c_z(v)$ to denote the unit cost of producing any variety of intermediate services using a common, increasing-returns-to-scale production technology. Then, profit maximization implies:

$$\theta q = c_z(v) = a_{H_z} v \tag{9}$$

in which a_{H_z} denote the units of skilled labor required in producing one unit of intermediate services. The resultant operating profits per variety for the representative innovating firm are determined by

$$\pi = (1-\theta) qz. \tag{10}$$

As all producers are similar, we consider the symmetric equilibrium. In the equilibrium, output per variety $z(\xi) = z$ and prices $q(\xi) = q$ for all $i \in [0, n(t)]$. If $Z = nz$ is the aggregate quantity of intermediate services employed in the production of final services, then by eq. (6), $\Gamma = n^{(1-\theta)/\theta} Z$.

The innovating firm enjoys free entry by the innovating firms into R&D. As the set of potential intermediate services is unbounded and as all such intermediate services are symmetric, a firm will never elect to develop an already-existing variety. With free entry, if resources are devoted to R&D at time t, the present discounted value of future operating profits must equal the current cost of introducing a new variety as follows:

$$\int_t^{\infty} e^{-[R(\kappa)-R(t)]} (1-\theta) qz d\kappa = a_{H_n} v / n \tag{11}$$

in which $R(\kappa)$ is the cumulative interest factor through time κ.

Differentiating this zero-profit condition with respect to t, we can write

$$r = \frac{(1-\theta) qzn}{a_{H_n} v} + \left[\frac{\dot{v}}{v} - \frac{\dot{n}}{n} \right]. \tag{12}$$

This equation is a no-arbitrage condition equating the rate of interest to the sum of the instantaneous profit rate for the representative firm and the capital gain on the value of the firm. The instantaneous value of any firm reflects the current cost of developing a new blueprint, thus the capital-gain term is reflective of the rate of change in development costs.

From the above eqs. (4), (7), and (9), we can solve for the prices of the primary and generated services as functions of the number of intermediate services and the prices of the traded final outputs. If n grows at constant rate $\eta(t) = \dot{n}/n$ and p is held to remain constant over time, then v and q will all grow at rate $\sigma\eta(t)$.

3. Equilibrium Dynamics

In this model we assume full employment and free high-skilled labor mobility among sectors. As in the previous work of Chang(1973), let a_{i_j} be the input-output coefficient denoting the units of i th factor required for the production of one unit of the j th good, $i = H, L$ and $j = s, m, z, n$, and define the total input-output coefficients $b_{i_s} \equiv a_{i_s} + a_{i_z} a_{z_s}$. Let us then define $a_{H_s}(\cdot) \equiv \partial c_s(\cdot)/\partial v$, $a_L(\cdot) \equiv \partial c_m(\cdot)/\partial w$, $a_{H_m}(\cdot) \equiv \partial c_m(\cdot)/\partial v$, $a_{H_z}(\cdot) \equiv \partial c_z(\cdot)/\partial v$, $a_{Z_s}(\cdot) \equiv \partial c_s(\cdot)/\partial q$. Now, using eqs. (4) and (7) and Shephard's lemma, the factor market clearing conditions for equilibrium can be expressed as follows:

$$a_{H_n}\eta + b_{H_s}\bar{S} + a_{H_m}M = H \tag{13}$$

$$a_L M = L \tag{14}$$

in which $\bar{S} = Sn^{-\sigma}$. The left-hand side of eq. (13) sums over the demand for high-skilled labor in the R&D sector, the direct and indirect demand for high-skilled labor in the S sector, and the demand for high-skilled labor in the M sector. This must necessarily equal the exogenous supply of high-skilled labor, H. Low-skilled labor is only a specific factor in the M sector.

In this specification, the constancy of η implies that $\bar{S}$ remains constant from eq. (13). Then, S grows at rate $\sigma\eta$. As there is no possibility for international borrowing or lending, the current account must balance at every time point. Hence, nominal spending $\Psi = pS + M$ grows at the rate $\mu\sigma g$, where $\mu = \dfrac{pS}{pS + M}$.[11] Using eqs. (2) and (12), we drive

[11] From the nominal spending equation, we have

$$\frac{\dot{\Psi}}{\Psi} = \frac{pS}{pS + M}\frac{\dot{S}}{S} + \frac{M}{pS + M}\frac{\dot{M}}{M}$$

where $\dot{S}/S = \sigma\eta$ and $\dot{M}/M = 0$.

$$\frac{(1-\theta)a_{z_s}q\overline{S}}{a_{H_n}v}=(1+\mu\sigma-\sigma)\eta+\varphi \tag{15}$$

Whenever eqs. (4), (7) and (9) have been utilized to solve for factor prices, eqs. (13), (14) and (15) determine $\overline{S}$, M and η.

III. Servicization with Skill Premium

This section analyzes structural change towards a service economy with skill premium during the process of R&D-based endogenous growth in a small open economy. Fig. 1 shows the manner in which the high-skilled and low-skilled wage rate, the price of intermediate inputs, and the factor allocation are determined. The unit cost curve of good M (eq.(4)) is provided in Fig. 1 (a). It is assumed that the unit cost curve of good M does not intersect the v axis. The unit cost curve of service S (eq.(7)) is drawn in Fig. 1 (b), and the relative price, v/q, (eq.(9)) is fixed at any point in time and also expressed in Fig. 1 (b).

[INSERT FIGURE 1 HERE]

Suppose that eq. (9) intersects the unit cost curve of service S at point d_s. Then, the high-skilled wage rate and the price of intermediate inputs are determined at d_s. Once the high-skilled wage rate is determined, the low-skilled wage rate is also determined by the unit cost curve of good M, MM. That is, with a given value of θ/a_{H_z} and a given value of q, eqs. (7) and (9) determine the high-skilled wage rate and the price of intermediate services. Hence, eq. (4) gives the low-skilled wage rate.

We assume that the high-skilled labor force is proportional to population N. We select γ for the high-skilled labor ratio of the whole population, such that the high-skilled labor force equals γN. Applying the implicit function theorem and Shephard's lemma to the unit cost functions of services S and manufacturing M and noting that $L=1-\gamma$ by normalizing $N=L+H=1$, we obtain

$$\frac{dv}{dq}=-\frac{\partial c^s}{\partial q}/\frac{\partial c^s}{\partial v}=-\frac{Z}{H_s} \tag{16}$$

$$\frac{dw}{dv}=-\frac{\partial c^m}{\partial v}/\frac{\partial c^m}{\partial w}=-\frac{H_m}{1-\gamma} \tag{17}$$

That is, the slope of the isocost line tangent to SS at d_x is equal to $-Z/H_s$ and the slope of isocost line tangent to MM at d_m is equal to $(1-\gamma)/H_m$. Taking into consideration the full employment condition for high-skilled labor, the high-skilled labor allocation is uniquely determined, even though this is not shown in the diagram.

1. Expanding Variety and Endogenous Growth with Skill Premium

We first define economic growth and then attempt to determine the manner in which economic growth is generated. We will observe that the expanding variety of intermediate inputs is the engine of economic growth in this model. The per capita GNP in terms of good M is utilized as an index of economic growth. As all prices of final outputs are fixed in this model, an increase in per capita GNP in terms of good M implies that it increases in terms of all final outputs. For a small open economy, an increase in per capita GNP is equivalent to an improvement in economic welfare.

First, we demonstrate that per capita GNP increases with increase in the high-skilled wage rate. Recalling $L+H=N=1$, per capita GNP in terms of M, G, is simply expressed by

$$G=\gamma v+(1-\gamma)w.$$

Using eq. (4), we can rewrite per capita GNP as a function of the high-skilled wage rate, v,

$$G(v)=\gamma v+(1-\gamma)w(v) \tag{18}$$

Thus

$$\frac{dG}{dv}=\gamma-H_m>0, \text{ for } 0<H_m<\gamma \tag{19}$$

and

$$\frac{d^2G}{dv^2}=-\frac{dH_m}{dv}>0 \tag{20}$$

which imply that per capita GNP rises with increase in the high-skilled wage rate.[12]

We next evaluate the changes in the growth rate of per capita GNP. From the relative price of v/q (eq.(9)), it can be observed that the price of intermediate inputs is a function of high-skilled wage rate. Thus, eq. (7) becomes

[12] Noting eq. (17) and the unit cost curve, MM, is strictly convex to the origin, we have $\frac{d^2w}{dv^2}=-\frac{dH_m}{dv}>0$. Hence, we get $\frac{dH_m}{dv}<0$.

$$p = n^{-\sigma} c_s(v, q(v)). \tag{21}$$

Taking the derivative of this equation with respect to time, we get

$$\dot{v} = v\sigma\eta \,. \tag{22}$$

Thus, the high-skilled wage rate rises at rate $\sigma\eta(t)$ over time.

This can be readily confirmed in Fig. 1. If the small open economy is diversified--that is, if the intermediate inputs are generated--then the high-skilled wage rate and the price of intermediate inputs, (which is determined at the intersection of eq. (9) with the unit cost function of service S), rises over time. The expanding variety of intermediate inputs increases the high-skilled labor productivity in the R&D sector. Hence, the high-skilled wage rate and the price of intermediate inputs rise. As is shown in the above Fig. 1, the new equilibrium is determined at d_s^*, in which v is raised and w is reduced. As a consequence, the skill premium can be said to exist.

Considering eqs. (19) and (22), the growth rate of per capita GNP, g, is given by

$$g = \frac{\dot{G}}{G} = \frac{\dot{v}(dG/dv)}{G} = \frac{v\sigma\eta(\gamma - H_m)}{G} \tag{23}$$

This is positive since $\eta > 0$ and $\gamma - H_m > 0$. The growth rate is positive if the economy is diversified.

The above analysis leads to the following proposition:

Proposition 1 *If the economy is diversified, then there is endogenous economic growth with skill premium in the presence of expanding variety of intermediate services as a result of R&D.*

2. Structural Change towards a Service Economy

We analyze structural change towards a service economy during the process of endogenous growth. We will show that servicization consistent with the phenomena noted in the introduction can actually attained within the process of R&D-based endogenous growth.

First, it is clear from eq. (20) that the amount of high-skilled labor employed by the manufacturing sector, M, declines. Hence, the manufacturing sector contracts during the process of endogenous growth. This is because, during the course of economic growth, the high-skilled wage rate offered by both the intermediate services sector and service (embedded) sector increases. Hence, high-skilled labor shifts from the manufacturing sector to the service (embedded) sector.

Second, since $\hat{S} > \hat{M}$ and $S = \bar{S}n^{\sigma}$, the industrial structure changes over time such that output of the manufacturing sector falls, but the output of the service (embedded) sector rises.[13] However, the economy will be diversified, even though the number of n increases over time.[14]

Third, it can also be observed in Fig. 1 that the unit cost curve of the service (embedded) sector shifts from SS to S^*S^* as the productivity in the service (embedded) sector increases. This is because the driving force of economic growth is the introduction of new intermediate services, such as knowledge-based services as a result of R&D.

Thus, the following proposition is obtained:

Proposition 2 *Endogenous growth with skill premium leads to an expansion of the service (embedded) sector and contraction of the manufacturing sector. However, the economy will not be specialized into the service (embedded) sector.*

IV. The Optimal R&D Policy

This section evaluates specifically the optimal policy to R&D subsidies to attain the positive externalities. There exist two market distortions in this economy. First, a production externality in the process of knowledge generation means that the private costs to conduct R&D may deviate from the costs associated with the social optimum. Second, the monopolistic competition results in less output of each intermediate service than one required under social optimum. The monopoly power causes the consumer price of these intermediate services to exceed the social opportunity cost. These distortions interact, because the monopoly rents provide private incentives for R&D in this economy. In this economy the market equilibrium consistently differs from the social optimum. In general the first-best equilibrium can be achieved via direct subsidies to both R&D and the production of intermediate services. However, the second-best equilibrium, which actually equals the social optimum, can be achieved via a subsidy of R&D in this model.

1. The Social Optimum

First of all, we consider the social equilibrium, which equals the second-best problem. The second-best problem involves the maximization of welfare for the representative consumer as the objective of the government. Given the linear homogeneity of $u(\cdot)$, the

[13] In this analysis, the circumflex over a variable means a logarithmic derivative, e.g., $\hat{S} = dS/S$.

[14] Let $\Phi(t)$ denote service-manufacturing ratio, $S(t)/M(t)$. Then the time path of $\Phi(t)$ is convex.

$$d\Phi(t)/dt = \frac{\bar{S}}{M}\sigma n^{\sigma}\eta > 0$$

$$d^2\Phi(t)/dt^2 = \frac{\bar{S}}{M}\left(\sigma^2 n^{\sigma-1}\dot{n}\eta + \sigma n^{\sigma}\dot{\eta}\right) > 0.$$

related indirect utility function has the form $V(p,\Psi)=\phi(p)\Psi(t)$. We can then derive the equilibrium as the solution to a social planning problem. The objective function can thus be written by using eq. (1) as follows:

$$U=\int_0^\infty e^{-\varphi t}\left[\log\phi(p)+\log\Psi(t)\right]dt=\frac{1}{\varphi}\log\phi(p)+\int_0^\infty e^{-\varphi t}\left[\delta\log n(t)+\log\overline{\Psi}(t)\right]dt \tag{24}$$

in which $\overline{\Psi}\equiv\left[n^{-\sigma}\mu+(1-\mu)\right]\Psi=n^{-\delta}\Psi$.[15] Using the definition of $\eta=\dot{n}/n$, we have

$$\log n(t)=\log n_0+\int_0^t\eta(\kappa)d\tau. \tag{25}$$

The constraints which are imposed by technology and by the assumed use of the market mechanism for allocating intermediates to all activities other than R&D can be expressed as intermediate service prices determined by eqs. (4), (7) and (9). These fix the production techniques. Then the high-skilled labor market clearing condition given by eq. (13) will determine $\overline{S}(t)$ as linear functions of the government's choice of $\eta(t)$. Multiplying eq. (13) by $\overline{v}\equiv vn^{-\sigma}$, eq. (14) by w, and adding these two together, we can obtain the resource constraint can be written as follows:

$$\left[1-(1-\theta)\beta\mu^*\right]\overline{\Psi}+a_{H_n}\overline{v}\eta=\overline{\Lambda} \tag{26}$$

in which $\mu^*=n^{-\sigma}\mu/\left[n^{-\sigma}\mu+(1-\mu)\right]$ and $\overline{\Lambda}\equiv\overline{v}H+wL$. In eq. (26), β is the share of intermediate services in the total production cost of services, and the current account must be balanced in a country that lacks access to international capital markets; namely, $\Psi=pS+M$. Hence we can interpret eq. (26) as requiring savings to be equal investment, as $\overline{\Psi}n^{\delta}$ represents expenditure, $a_{H_n}\overline{v}\eta n^{\delta}$ represents R&D costs, and $\left[\overline{\Lambda}+(1-\theta)\beta\mu^*\overline{\Psi}\right]n^{\delta}$ represents the total income, which equals factor income plus profits.

The second-best growth path maximizes the object function given by eq. (24) subject to the constraints expressed in eqs. (25) and (26). The solution to this maximization problem implies a time-invariant second-best growth rate η^* as follows:

$$\eta^*=\left(\overline{\Lambda}/a_{H_n}\overline{v}-\varphi/\delta\right)>0 \tag{27}$$

which actually coincides with the first-best growth rate in this model.[16]

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[15] It proves convenient to let $\left[n^{-\sigma}\mu+(1-\mu)\right]$ denote $n^{-\delta}$ at time t.

[16] In the first-best equilibrium, intermediate inputs should be priced at marginal cost instead of markup cost. Thus the θ in eq. (9) disappears in the first-best equilibrium and so the price of intermediate inputs and input-output coefficients differs from those in the second-best equilibrium. The first-best equilibrium can be achieved when eq. (24) is maximized subject to eqs. (25) and (26) in the presence of the first-best price of intermediate inputs and techniques of production inserted in eq. (26) where $\theta=1$. Except that different values for $\overline{\Lambda}$ and $\overline{v}$ from those used in the calculation of the second-best solution apply,

[INSERT FIGURE 2 HERE]

This can be illustrated graphically in Fig. 2. Given the constancy of the second-best growth rate, the objective utility function can be rewritten by substituting eq. (25) into eq. (24) as follows:

$$\varphi U = \log \phi(p) + \log \overline{\Psi} + \delta \log n_0 + (\delta / \varphi)\eta \,. \tag{28}$$

This equation defines an implicit trade-off between the initial level of spending and its rate of growth. As shown in Fig. 2, two representative indifference curves I & I^* can be drawn in $(\overline{\Psi}, \eta)$ space. The social planner maximizes eq. (28) subject to the linear budget constraint given by eq. (26). As a result, the social optimum can be achieved at the point A, where the indifference curve I^* is tangent to the budget line.

2. The Market Economy

On the other hand, the market equilibrium can be obtained where the no-arbitrage condition is coincident with the resource constraint line. Using the fact that intermediate services comprise a share $\beta\mu^*$ of the total production cost, we can rewrite the no-arbitrage condition eq. (15) as follows:

$$(1-\theta)\beta\mu^* \overline{\Psi} / a_{H_n} \overline{v} = (1 + \mu\sigma - \sigma)\eta + \varphi \tag{29}$$

As shown in Fig. 2, eq. (29) can be represented as the line XX. Graphically the market equilibrium rate of growth can thus be found at the point B, where the line XX intersects the budget line. Then the indifference curve I crosses the budget line at the point B.

Using eqs. (26) and (29), we have a steady state market equilibrium with

$$\eta = \left\{ \frac{(1-\theta)\beta\mu^* \overline{\Lambda}}{a_{H_n} \overline{v} \zeta} - \frac{\left[1-(1-\theta)\beta\mu^*\right]\varphi}{\zeta} \right\} > 0 \tag{30}$$

in which $\zeta = 1 + \mu\sigma - \sigma + (1-\mu)(1-\theta)\sigma\beta\mu^*$. This market equilibrium thus differ from the social optimum.

Comparing the market equilibrium eq. (30) with the social optimum eq. (27), we obtain

$$\left(\frac{(1-\theta)\beta\mu^*}{\zeta} \right)\eta^* - \eta = \frac{\varphi}{\zeta} \left\{ \left[1-(1-\theta)\beta\mu^*\right] - \frac{(1-\theta)\beta\mu^*}{\delta} \right\} > 0 \tag{31}$$

---

therefore, the first-best growth rate to this problem which represents social optimum is equal to the second-best growth rate.

This in turn gives us

$$\eta^* > \zeta\eta/(1-\theta)\beta\mu^* > \eta\,. \tag{32}$$

Therefore, the social optimum growth rate, η^*, exceeds the market-determined growth rate, η. This means that the market economy generates too little R&D, as the firm does not capture all the social benefits to its efforts.

3. The Optimal Policy to R&D Subsidies

The government can thus employ an R&D subsidy so as to achieve the second-best equilibrium that gives us the social optimum. This R&D subsidy alters only the no-arbitrage condition among all the equilibrium relationships.[17] Thus only the budget constraint expressed in eq. (26) continues to apply. Therefore, it follows that the effect of the R&D subsidy is to shift the XX line in Fig. 2 left and rotate it in counter-clockwise direction.

To understand this result, notice that there are three points B, A, and C in Fig. 2 where the line XX, XX^*, XX^{**} intersects the budget line respectively. First, without the R&D subsidy, the indifference curve I crosses at the point B, where the line XX intersects the budget line. Second, with the R&D subsidy, welfare increases monotonically as the market equilibrium moves from point B to point A along the budget line. At point A where the indifference curve I^* is tangent to the budget line, the R&D subsidy achieves the second-best allocation, which gives us the maximum utility achievable at given conditions. Only the optimal R&D subsidy brings the economy into point A. Third, further increases in the R&D subsidy reduce welfare as the market equilibrium moves upwards from point A to point C along the budget line. Fourth, too much R&D subsidies beyond the point C, where the indifference curve I crosses at the budget line, give us negative externalities in the model.

We thus obtain the following proposition:

Proposition 3 *The social optimum can be attained with a positive but finite subsidy to R&D. However, subsidies to R&D beyond the social optimum accelerate growth even further but at the expense of welfare. In particular, too much R&D subsidies result in negative externalities in this economy.*

---

[17] If an R&D subsidy is given to firm, only a_{H_n} in eq. (15) and thus eq. (29) can be replaced by a_{H_n}/J, where $(J-1)/J$, $J \geq 1$, is utilized to denote the fraction of R&D expenditures provided by the government. However, input prices determined by eqs. (4), (7), and (9), other input-output coefficients, and the requirement of current account balance remain unaffected.

This is true in spite of the fact that such R&D subsidies continue to speed up the growth rate. As a result, faster growth beyond the optimal rate is not desirable in this economy since it comes at a cost.

V. Endowment Change and Economic Growth

This section examines the effects of differences in the endowments of the two primary factors on economic growth and composition of output. These comparative dynamics analysis focus on the performance of the models that have the same economic structure, with the exception of the endowments of primary factors. As in section 2, eqs. (13), (14) and (15) determine $\bar{S}$, M, and η whenever eqs. (4), (7) and (9) have been utilized to solve for input prices. With the relationships between $\bar{S}$ and M, eqs. (13), (14) and (15) can be rewritten as follows:

$$M = -\frac{b_{H_s}}{a_{H_m}}\bar{S} + \frac{H - a_{H_n}\eta}{a_{H_m}} \tag{33}$$

$$M = \frac{L}{a_L} \tag{34}$$

$$\bar{S} = \frac{[(1+\mu\sigma-\sigma)\eta+\rho]a_{H_n}v}{(1-\theta)a_{Z_s}q} \tag{35}$$

In Fig. 3, we depict the equilibrium in $(\bar{S}, M)$ space. The line HH with slope $-b_{H_s}/a_{H_m}$ represents eq. (33) and the line LL shows eq. (34). The line TT depicts eq. (35).

[INSERT FIGURE 3 HERE]

As the locations of the HH and TT lines depend on η, variations in the innovation rate ensure that the three curves intersect at a single point A. This implies that production of S is the high-skilled labor intensive activity in the terms of direct-plus-indirect inputs, whereas the production of M is the low-skilled labor intensive activity. Thus, the HH curve is steeper than the LL curve.

1. The High-skilled labor driven Structural Change

Given this setup, we assess the effects of an exogenous increase in the endowments of high-skilled labor force. If the new equilibrium involves a diversified production of both final outputs, this endowment change does not change the equilibrium input prices. Hence, techniques of production do not change. If we hold, for the moment, η to be constant, the HH curve shifts out in a parallel fashion, as shown by the broken line $H'H'$ that intersects the line LL at point B. However, point B lies on the right hand side of the line TT, and thus the initial level of R&D activity is no longer consistent with equilibrium. At point B, the profit rate in the intermediate services sector exceeds the interest rate. High-skilled labor is drawn into R&D, which implies a higher rate of innovation and a reduction in resources available for production of final goods. The TT line shifts out and the HH line shifts in, thus a new equilibrium is established at a point between A and B—for example, C. This implies that an increase in the high-skilled labor force speeds growth, and that at given n, output of the high-skilled labor intensive activity expands, whereas output of the low-skilled labor intensive activity does not contract.

2. The Low-skilled labor driven Structural Change

On the other hand, we consider the effect of an exogenous increase in the low-skilled labor force. The LL line shifts up, as shown by the broken line $L'L'$, which intersects the HH at point D. As the point D lies left hand side of the TT line, the rate of innovation must necessarily decrease. The reallocation of resources from R&D causes the HH line to shift out and the TT line to shift in, thus they both intersect the new LL line at a point such as E. Therefore, an increase in L expands output in the low-skilled labor intensive industry, and shrinks output in the high-skilled labor intensive industry. The economy experiences slower growth, contrary to the case in which the endowment of high-skilled labor force expands.

The above analysis leads to:

Proposition 4 *An exogenous increase in the level of high-skilled labor generates an expansion in the service (embedded) sector and promotes growth. However, an exogenous increase in the level of low-skilled labor leads to a contraction in the service (embedded) sector and retards growth.*

These changes in the composition of final production reflect the Rybczynski effect in the model. This Rybczynski effect indicates that an exogenous increase in high-skilled labor can speed up economic growth.

VI. Conclusions

This paper investigates a two-sector endogenous growth model for the study of servicization with skill premium and its policy implications in a small open economy. In this economy, the driving force of economic growth is the expanding variety of intermediate services owing to R&D. The increasing variety of intermediate services specifically contributes to total factor productivity in the production of the service (embedded) sector, and thus an uneven growth with skill premium generally exists along a steady-state path. Since an uneven economic growth path with skill premium is generated endogenously, the model reveals interesting interactions between endogenous growth with skill premium and the structure of the economy. The unbalanced endogenous growth leads to a shift toward services and away from manufacturing, and this structural change accelerates servicization with skill premium. This result sheds light on the nexus of recent movements towards a servicization and wage premium to high-skilled labor in the advanced economies.

In this specification, we consider the policy implications of servicization with skill premium in which intermediate services due to R&D is playing an increasingly important role. First, we analyze an optimal policy of R&D subsidies in order to rule out the market failures caused by R&D externality and market power in monopolistic competition conditions. Our analysis derives that the social optimum can be achieved with a positive but finite subsidy to R&D. However, subsidies to R&D beyond the optimal path cause a further increase in the growth rate, but at the expense of welfare. Second, we evaluate the changes in the stocks of the two primary factors on the composition of output and on economic growth. An increase in the level of high-skilled labor leads to an expansion in the service (embedded) sector and promotes growth. However, an increase in the level of low-skilled labor causes a contraction in the service (embedded) sector and retards growth. The model demonstrates the Rybczynski effect in the composition of final production. These results are very relevant to the current issues about the R&D policy as well as the endowment policy in the servicization. The result of this analysis with regard to welfare indicates that the social optimum of the economy can be achieved with a positive but finite R&D subsidy. In addition, the Rybczynski effect of the model demonstrates that an exogenous increase in high-skilled labor due to immigration as well as an endogenous increase in high-skilled labor due to education can speed up economic growth.

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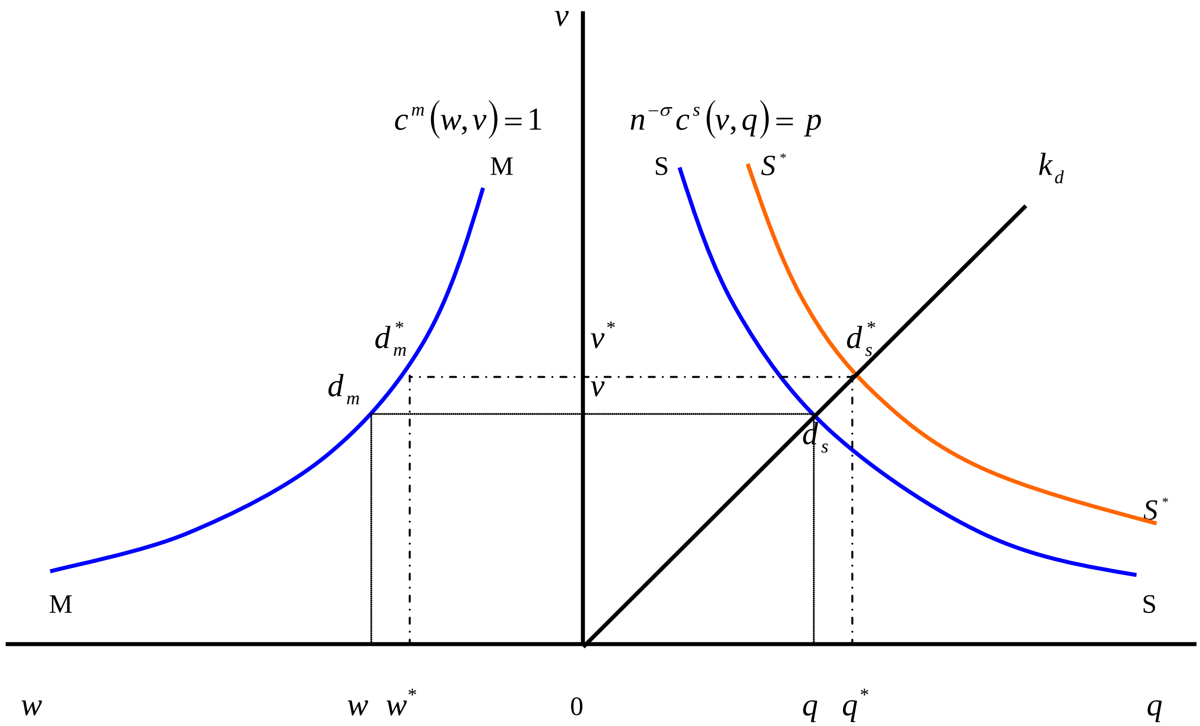

Fig. 1. The changing equilibrium of input factor prices and skill premium.

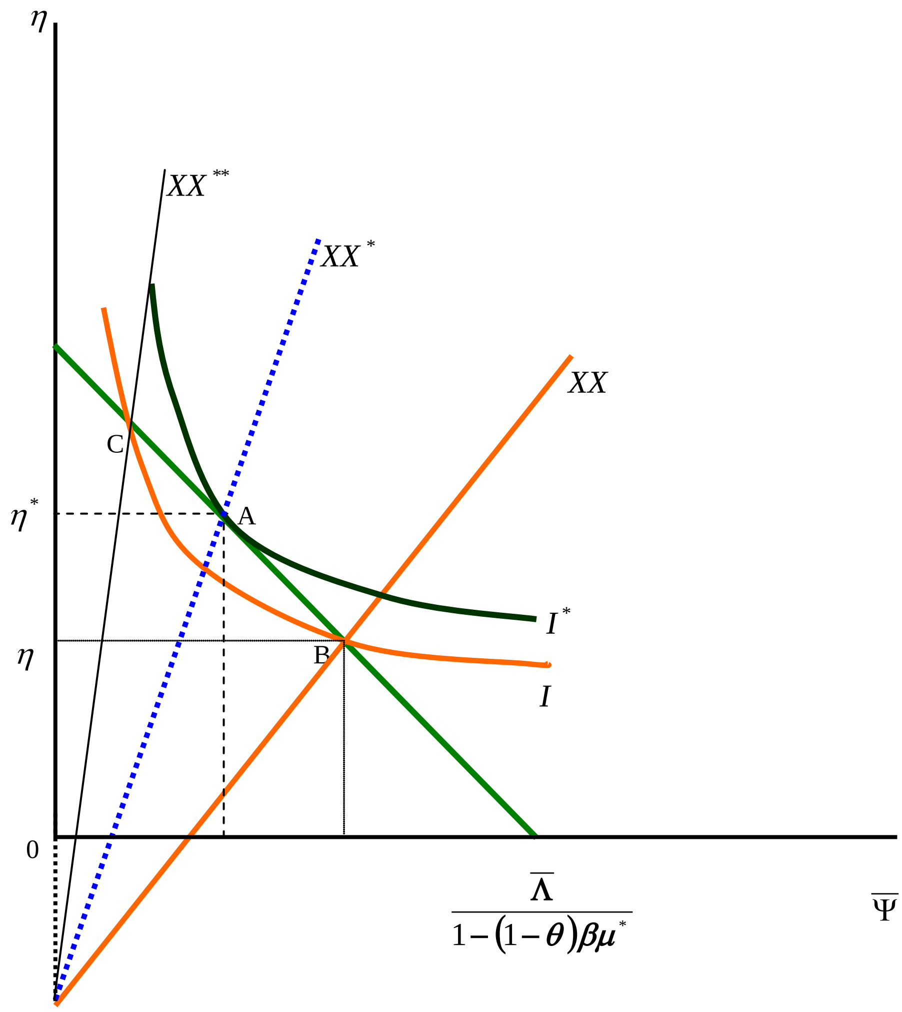

Fig. 2. The welfare effects of R&D subsidies.

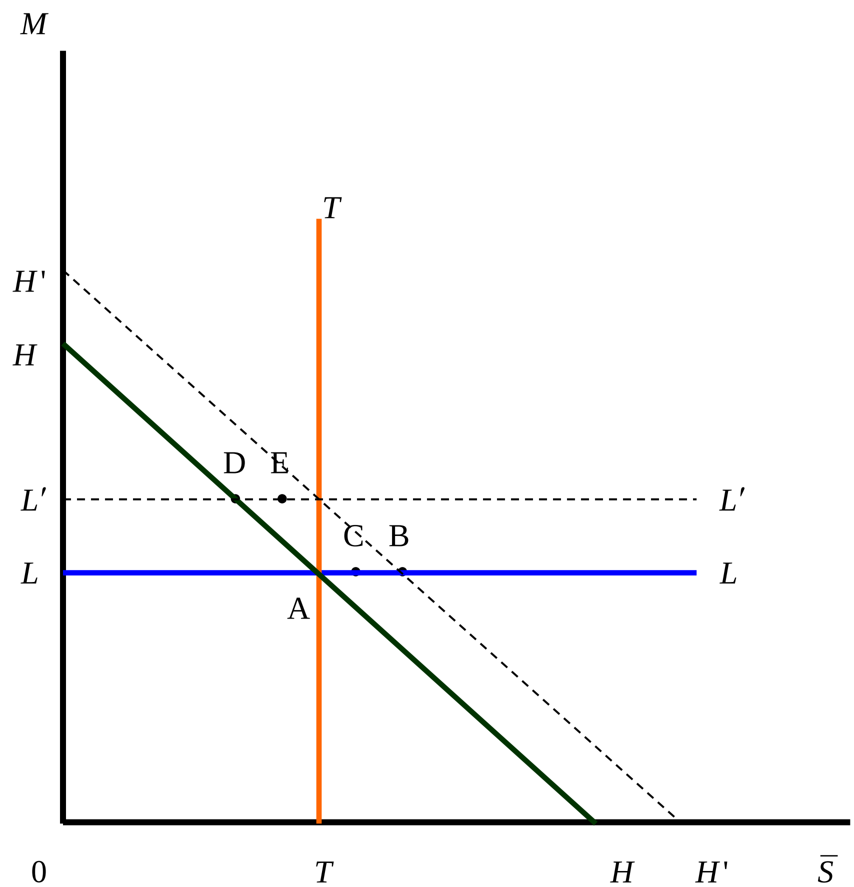

Fig. 3. The Rybczynski effects of exogenous endowment changes

Servicization and Its Policy Implications in a Small Open Economy

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