Sustained Comparative Advantage and Semi-Endogenous Growth

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Abstract

This paper constructs a two-country (Home and Foreign) general equilibrium model of Schumpeterian growth without scale effects. The scale effects property is removed by introducing a distinct specification in the knowledge production function which generates semi-endogenous growth. In this model of semi-endogenous growth, an increase in the rate of population growth rate raises Home's relative wage and lowers its range of goods exported to Foreign. An increase in the size of innovations increases Home's relative wage but with an ambiguous effect on its comparative advantage. The model generates a unique steady-state equilibrium in which there is complete specialization in both goods and R&D production within each country.

JEL Classification: F10, O3, O4

Key words: Comparative advantage, Trade, Schumpeterian growth, Scale effects, R&D races.

1 Introduction

Many models of endogenous growth and trade emphasize the role of continual product innovation based on R&D investment in determining the pattern of trade between countries. Grossman and Helpman (1991*a*, *b*, *c*) have developed models where innovations lead to either improvements in the quality of existing products ("quality ladders" models) or increase in the variety of the goods ("love for variety" models). Taylor (1993) has extended the continuum Ricardian model of Dornbusch et al. (1977) based on the "quality ladders" approach by Grossman and Helpman. All these studies exhibit the scale effect property. Jones (1995*a*) has argued that the scale effects property of earlier endogenous growth models is inconsistent with post-war time series evidence from all major advanced countries that shows an exponential increase in R&D resources and a more-or-less constant rate of per-capita GDP growth. The theoretical literature on trade and growth without scale effects has focused either on structurally identical economies engaging in trade with each other or on the context of North-South models of trade and growth.[1] This paper develops a two-country general equilibrium framework without scale effects to determine the equilibrium relative wages and the pattern of trade between countries.

My approach borrows from Taylor's work (1993) in that industries differ in research technologies and in the set of technological opportunities available for each industry. In his model, the presence of heterogeneous research technologies (captured by different productivity in R&D services), can make the pattern of R&D production to be different from the pattern of goods production within each country. As a result, there is a case for trade between countries in R&D services.

In the present model, there are two countries that may differ in relative size: Home and Foreign. The population in each country grows at a common positive and exogenously given rate and labor is the only factor of production. There is a continuum of industries producing final consumption goods. I assume heterogeneity across industries and countries in R&D but not in

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[1] For example, Dinopoulos and Syropoulos (2004) have developed a two-country general equilibrium model of endogenous Schumpeterian (R&D based) growth without scale effects to examine the effect of globalization on economic growth when countries differ in population size and relative factor endowments. Temple (1999) provides an excellent discussion about the lessons that can be learned from the new growth evidence. For a survey of the literature on North-South trade and economic growth, see Chui, Levine, Murshed and Pearlman (2002).

manufacturing. Labor in each industry can be allocated between the two economic activities, manufacturing of high-quality goods and R&D services, which are used to discover new products of higher quality. As in Grossman and Helpman (1991*c*) version of the quality-ladders growth model, the quality of each final good can be improved through endogenous innovation. The arrival of innovations in each industry is governed by a memoryless Poisson process whose intensity depends positively on R&D investments and negatively on the rate of difficulty of conducting R&D.

The model has a steady-state equilibrium in which the rate of innovation does not depend on the scale of the economy. Therefore, the model is consistent with post-war time series evidence provided by Jones (1995*a*). In the present model, scale effects are removed by assuming that innovating becomes more difficult as products improve in quality and become more complex, as in Segerstrom (1998).[2] As a result, economic growth is semi-endogenous, which makes the present model more tractable.

The present paper contributes to the trade and growth theory by utilizing a semi-endogenous growth model to analyze comparative advantage between countries. Several comparative-steady-state results in Taylor's (1993) model change with the removal of the scale effects property. For example, in his model, the direction of the effect of the size of innovations (which can vary across industries) on the pattern of goods production, R&D production, the pattern of trade, and the relative wage depends on the assumption that the size of innovations is

[2] Jones's criticism has stimulated the development of two classes of scale-free endogenous growth models. Jones (1995*b*), Kortum (1997), Segerstrom (1998) and Li (2003) have developed "semi-endogenous" growth models. Young (1998), Aghion and Howitt (1998, chapter 12), Dinopoulos and Thompson (1998), Peretto (1998), Howitt (1999) and Segerstrom (2000) have developed "fully-endogenous" growth models. First-generation growth models (for example Taylor (1993)) exhibit the counter-factual scale-effects property.

heterogeneous. Under the heterogeneity assumption, the increase in the inventive step creates a deficit in the balance of payments for Home because it raises the royalties' payments that Home has to pay for using the front-line technology.[3] Balance of payments is maintained through two adjustments; Home raises its goods trade balance by increasing the range of goods produced at Home and it reduces its reliance on imported R&D by conducting more itself. Removing part of this heterogeneity in his model, by eliminating Home's relative advantage in goods versus R&D, results in zero trade in R&D and no effect of the size of innovations on the pattern of trade and Home's relative wage.[4] On contrast, in the present model, an increase in the size of innovations raises Home's relative wage with an ambiguous effect on its comparative advantage.

The analysis in the present model generates new additional findings. Under the TEG (temporary effects on growth) specification, the model generates a unique steady-state equilibrium in which there is complete specialization in both goods and R&D production within each country. Trade between the two countries occurs only in goods and not in R&D services. In contrast to the work of Grossman and Helpman (1991*c*), factor price equalization does not hold in the steady-state equilibrium under the TEG specification (Proposition 1). In addition, Home's relative wage depends positively on the consumer's subjective discount rate and the population

[3] Taylor (1993) divides the world's available technologies into two sets: the set of front line technologies and the set of backward technologies. Frontline technologies are those that are minimum cost given the prevailing wage rate. He further assumes that when an innovator located in Foreign succeeds in the global R&D races and discovers the front line technology, it has two options: it can either implement this improvement on the foreign technology or it can go multinational and carry the innovation abroad to a wholly owned subsidiary. This subsidiary would then pay the foreign firm a royalty.

[4] Eliminating the across country heterogeneity in his model, results in factor price equalization and indeterminate pattern of trade in both goods and R&D.

growth rate and it depends negatively on the R&D difficulty growth parameter (Proposition 2). The range of goods Home produces and exports depends positively on the R&D difficulty growth parameter and it depends negatively on the consumer's subjective discount rate and the population growth rate (Proposition 3). The global level of R&D investment, under the TEG specification is completely determined by the exogenous rate of population growth and the R&D difficulty growth parameter. Specifically, the global innovation rate is higher when the population of consumers grows faster or when R&D difficulty increases more slowly over time (Proposition 4).

Most of the comparative steady-state results are robust when the PEG (permanent effects on growth) specification is assumed instead of the TEG specification. [5] However, the effect of the size of innovations on Home's comparative advantage is positive under the PEG specification, while it is ambiguous under the TEG specification.

The remaining paper is organized as follows. Section 2 outlines the features of the model. Section 3 describes the steady state equilibrium of the model under the TEG specification and section 4 presents the comparative steady state results under the TEG specification. Section 5 concludes this paper by summarizing the key findings and suggesting possible extensions. The algebraic details and proofs of all propositions in this paper are relegated to Appendix.

[5] In a working paper, Petsas (2008), I derive the steady-state equilibrium and comparative steady-state analysis for the PEG specification and show how the results change if one uses the PEG specification, which corresponds to a fully-endogenous growth model.

2 The Model

This section develops a two-country, dynamic, general-equilibrium model with the following features. Each country engages in two activities: the production of final consumption goods and research and development. Each of the two economies is populated by a continuum of industries indexed by $\theta \in [0, 1]$. A single primary factor, labor, is used in both goods and R&D production for any industry. In each industry θ, firms are distinguished by the quality *j* of the products they produce. Higher values of *j* denote higher quality and *j* is restricted to taking on integer values. At time $t = 0$, the state-of-the-art quality product in each industry is $j = 0$, that is, some firm in each industry knows how to produce a $j = 0$ quality product and no firm knows how to produce any higher quality product. The firm that knows how to produce the state-of-the-art quality product in each industry is the global leader for that particular industry. At the same time, challengers in both countries engage in R&D to discover the next higher-quality product that would replace the global leader in each industry. If the state-of-the-art quality in an industry is *j*, then the next winner of an R&D race becomes the sole global producer of a *j*+1 quality product. Thus, over time, products improve as innovations push each industry up its "quality ladder," as in Grossman and Helpman (1991*c*). I assume for simplicity, that all firms in the global economy know how to produce all products that are at least one step below the state-of-the-art quality product in each industry. This assumption, which is standard in most quality-ladders growth models, prevents the incumbent monopolist from engaging in further R&D. For clarity, I adopt the following conventions regarding notation. Henceforth, superscripts "h" and "f" identify functions and variables of "Home" and "Foreign" countries, respectively. Functions and variables without superscripts are related to the global economy, while functions and variables with subscripts are related to activities and firms within an industry.

2.1 Household Behavior

Let $N^i(t)$ be country i's population at time t. I assume that each country' s population is growing at a common constant, exogenously given rate $g_N = \dot{N}^i(t)/N^i(t) > 0$. In each country there is a continuum of identical dynastic families that provide labor services in exchange for wages, and save by holding assets of firms engaged in R&D. Each individual member of a household is endowed with one unit of labor, which is inelastically supplied. I normalize the measure of families in each country at time 0 to equal unity. Thus, the population of workers at time t in country i is $N^i(t) = N_0^i e^{g_N t}$.

Each household in country i maximizes the discounted utility[6]

$$U = \int_0^\infty e^{-(\rho - g_N)t} \log u(t) dt, \tag{1}$$

where $\rho > 0$ is the constant subjective discount rate. In order for U to be bounded, I assume that the effective discount rate is positive (i.e., $\rho - g_N > 0$). Expression log u(t) captures the per capita utility at time t, which is defined as follows:

$$\log u(t) \equiv \int_0^1 \log[\sum_j \lambda^j q(j,\theta,t)] d\theta. \tag{2}$$

In equation (2), $q(j,\theta,t)$ denotes the quantity consumed of a final product of quality j (i.e., the product that has experienced j quality improvements) in industry $\theta \in [0,1]$ at time t. Parameter $\lambda > 1$ measures the size of quality improvements (i.e., the size of innovations).

[6] Barro and Sala-i-Martin (1995 Ch.2) provide more details on this formulation of the household's behavior within the context of the Ramsey model of growth.

At each point in time t, each household allocates its income to maximize (2) given the prevailing market prices. Solving this optimal control problem yields a unit elastic demand function for the product in each industry with the lowest quality-adjusted price

$$q^i(j,\theta,t) = \frac{c^i(t)N^i(t)}{p^i(j,\theta,t)}, \tag{3}$$

where $c^i(t)$ is country i's per capita consumption expenditure, and $p^i(j,\theta,t)$ is the market price of the good considered in country i. Because goods within each industry adjusted for quality are by assumption identical, only the good with the lowest quality-adjusted price in each industry is consumed. The quantity demanded of all other goods is zero. The global demand for a particular product is given by aggregating equation (3) across the two countries to obtain

$$q(j,\theta,t) = \sum_{i=h,f} q^i(j,\theta,t). \tag{4}$$

Given this static demand behavior, the intertemporal maximization problem of country i's representative household is equivalent to

$$\max_{c^i(t)} \int_0^\infty e^{-(\rho - g_N)t} \log c^i(t)dt, \tag{5}$$

subject to the intertemporal budget constraint $\dot{a}^i(t) = r^i(t)a(t) + w^i(t) - c^i(t) - g_N a^i$, where $a^i(t)$ denotes the per capita financial assets in country i, $w^i(t)$ is the wage income of the representative household member in country i, and $r^i(t)$ is country i's instantaneous rate of return at time t. The solution to this maximization problem obeys the well-known differential equation

$$\frac{\dot{c}^i(t)}{c^i(t)} = r^i(t) - \rho, \tag{6}$$

Equation (6) implies that a constant per-capita consumption expenditure is optimal when the instantaneous interest rate in each country equals the consumer's subjective discount rate ρ.

2.2 Product Markets

In each country firms can hire labor to produce any final consumption good $\theta \in [0,1]$. Let $L^i(\theta, t)$ and $Q^i(\theta, t)$ respectively denote the amounts of labor devoted in manufacturing of final consumption good θ in country *i* and the output of final consumption good θ in country *i*. The production function of the final consumption good θ in country *i* is given by the following equation

$$Q^i(\theta, t) = \frac{L^i(\theta, t)}{\alpha_Q}, \qquad (7)$$

where α_Q is the unit labor requirement associated with each final consumption good θ. For simplicity, I assume that the unit labor requirement is equal to 1, which implies that one unit of labor is required to manufacture one unit of the good. I also assume that each vertically differentiated good must be manufactured in the country in which the most recent product improvement has taken place. That is, I rule out international licensing and multinational corporations.[7]

The assumptions that goods within an industry are identical when adjusted for quality and Bertrand price competition in product markets imply that the monopolist in each industry engages in limit pricing. The assumption that the technology of all inferior quality products is public knowledge imply that the quality leader charges a single price, which is λ times the lowest manufacturing cost between the two countries:

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[7] Taylor (1993) incorporates multinational corporations in a model of endogenous growth and trade. In his model, innovations are always implemented on front line production technologies (i.e, that is technologies that are minimum cost given the prevailing wage rates) and when innovation and implementation occur at different countries, the resulting transactions are considered as imports and exports of R&D.

$$p = \lambda \min\{w^h, w^f\}. \tag{8}$$

I choose the wage of foreign labor, w^f, as the numeraire of the model by setting:

$$w^f \equiv 1. \tag{9}$$

I also assume that the wage of home labor, w^h, which is also Home's relative wage, ω, is greater than one[8]

$$w^h = \omega > 1. \tag{10}$$

Assumption (10) implies that the price of every top quality good is equal to

$$p = \lambda. \tag{11}$$

It follows that the stream of profits of the incumbent monopolist that produces the state-of-the-art quality product in Home will be equal to

$$\pi^h(\theta,t) = (\lambda - \omega)q = \left(\frac{\lambda - \omega}{\lambda}\right)E(t), \tag{12}$$

while the stream of profits of the incumbent monopolist that produces the state-of-the-art quality product in Foreign will be equal to

$$\pi^f(\theta,t) = (\lambda - 1)q = \frac{(\lambda - 1)}{\lambda}E(t), \tag{13}$$

where $E(t) = [c^h(t)N^h(t) + c^f(t)N^f(t)]$ is the world expenditure on final consumption goods.

2.3 R&D Races

Labor is the only input engaged in R&D in any industry $\theta \in [0,1]$. Let $L_R^i(\theta, t)$ and $R^i(\theta,t)$ respectively denote the amounts of labor devoted in R&D services in industry θ in country *i* and

[8] In proposition 1, I provide sufficient conditions under which this assumption holds.

the output of R&D services in industry θ in country *i*. The production function of R&D services in industry θ in country *i* exhibits constant returns and is given by the following equation

$$R^i(\theta,t) = \frac{L_R^i(\theta,t)}{\alpha_R^i(\theta)}, \tag{14}$$

where $\alpha_R^i(\theta)$ is the unit labor requirement in the production of R&D services associated with the final consumption good θ in country *i*. The presence of heterogeneous research technologies in the present model allows us to determine the pattern of R&D services first and then the pattern in the trade of manufacturing goods.[9]

The continuum of products $\theta \in [0,\ 1]$ is indexed by decreasing home relative unit labor requirement in R&D. If $\theta_2 > \theta_1$ for any θ_1 and $\theta_2 \in [0,1]$, then $\frac{\alpha_R^f(\theta_1)}{\alpha_R^h(\theta_1)} > \frac{\alpha_R^f(\theta_2)}{\alpha_R^h(\theta_2)}$ should hold. Following Dornbusch et al. (1977), the continuous and decreasing relative unit labor requirement in R&D for each good θ is defined as follows

$$A(\theta) = \frac{\alpha_R^f(\theta)}{\alpha_R^h(\theta)} \text{ and } A'(\theta) < 0. \tag{A.1}$$

In each industry θ there are global, sequential and stochastic R&D races that result in the discovery of higher-quality final products. A challenger firm k that is located in country $i \in \{h, f\}$ targeting a quality leader in country $i \in \{h, f\}$ engages in R&D in industry θ and discovers the next higher-quality product with instantaneous probability $I_k^i(\theta,t)dt$, where dt is an infinitesimal interval of time and

[9] Taylor (1993) has introduced heterogeneity in the research technologies and in the technological opportunity for improvements in technologies. The presence of heterogeneous research technologies makes trade in R&D services between countries possible.

$$I_k^{\,i}(\theta, t) = \frac{R_k^i(\theta, t)}{X(t)}, \tag{15}$$

where $R_k^i(\theta, t)$ denotes firm *k*'s R&D outlays and *X(t)* captures the difficulty of R&D in industry θ at time *t*. I assume that the returns to R&D investments are independently distributed across challengers, countries, industries, and over time. Therefore, the industry-wide probability of innovation can be obtained from equation (14) by summing up the levels of R&D across all challengers in that country. That is,

$$I^i(\theta, t) = \sum_k I_k^i(\theta, t) = \frac{R^i(\theta, t)}{X(t)}, \tag{16}$$

where $R^i(\theta, t)$ denotes total R&D services in industry θ in country *i*. Variable $I^i(\theta, t)$ is the effective R&D.[10] The arrival of innovations in each industry follows a memoryless Poisson process with intensity $I(\theta,t) = \sum_i R^i(\theta,t) \big/ X(t)$ which equals the global rate of innovation in a typical industry. The function *X(t)* has been introduced in the endogenous growth literature after Jone's (1995*a*) empirical criticism of R&D based growth models generating scale effects.

Scale effects are ruled out by following Segerstrom (1998) in which R&D becomes more difficult over time because "the most obvious ideas are discovered first." This results in a model of semi-endogenous growth, in which long-run growth rate is proportional to the exogenous rate of population growth and it is not affected by any standard policy instruments. In this model, R&D starts being equally difficult in all industries ($X(\theta,0) = 1$ for all θ), and the level of R&D difficulty grows according to

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[10] The variable $I^i(\theta, t)$ is the intensity of the Poisson process that governs the arrivals of innovations in industry θ in country *i*.

$$\frac{\dot{X}(t)}{X(t)} = \mu[I^h(\theta,t) + I^f(\theta,t)] = \mu I(\theta,t), \tag{17}$$

where $\mu > 0$ is a constant.

The stock-market valuation of temporary monopoly profits equals the flow of its global monopoly profits π^i discounted by the market interest rate r, by the probability of default, which is captured by the Poisson arrival rate of further innovation I and by the growth of the stock valuation.

$$V^i(\theta, t) = \frac{\pi^i(\theta, t)}{r(t) + I(\theta, t) - \frac{\dot{V}^i(\theta, t)}{V^i(\theta, t)}}. \tag{18}$$

A typical challenger *k* located in country *i* chooses the level of R&D investment $R_k^i(\theta, t)$ to maximize the expected discounted profits

$$V^i(\theta, t)\frac{R_k^i(\theta, t)}{X(t)}dt - w^i\alpha_R(\theta)R_k^i(\theta, t)dt, \tag{19}$$

where $I_k^i dt = [R_k^i(\theta, t)/X(t)]dt$ is the instantaneous probability of discovering the next higher-quality product and $w^i\alpha_R(\theta)R_k^i(\theta,t)$ is the R&D cost of challenger *k* located in country *i*.

Free entry into each R&D race drives the expected discounted profits of each challenger down to zero and yields the following zero profit condition:

$$V^i(t) = w^i\alpha_R(\theta)X(t). \tag{20}$$

The pattern of R&D production across the two countries can be determined by utilizing equations (18) and (20). Evaluating these equations on the competitive margin in R&D production, $\widetilde{\theta}$, I can obtain the R&D schedule (i.e., the schedule of relative labor productivities in goods) as follows

$$\omega = RD(\tilde{\theta}) = \frac{\lambda A(\tilde{\theta})}{\lambda + A(\tilde{\theta}) - 1}, \tag{21}$$

where $RD(\tilde{\theta})$ is continuous and decreasing in $\tilde{\theta}$. For low values of θ, Home has higher relative labor productivity than Foreign, and thus it earns higher wage. Therefore, Home has comparative advantage in producing and conducting R&D the final goods with lower θ and Foreign has comparative advantage in producing and conducting R&D the final goods with higher θ. The R&D schedule can be depicted in Figure 1.

Lemma 1. *Under assumption* (A.1) *and for any value of the relative wage, $\omega < \lambda$, there exists an industry $\tilde{\theta}$ defined by equation* (21) *such that*

(a) $\omega = RD(\tilde{\theta})$ *schedule is downward sloping, i.e., $RD'(\tilde{\theta}) < 0$,*

(b) *firms are indifferent between conducting R&D in Foreign or in Home*,

(c) *for each industry $\theta \in [0, \tilde{\theta})$, only Home conducts R&D,*

(d) *for each industry $\theta \in (\tilde{\theta}, 1]$, only Foreign conducts R&D.*

One can find the results from Lemma 1 in Dornbusch et al. (1977). However, the derivation of Lemma 1 differs between the present model and the one in Dornbusch et al. (1977). In their model, the results from Lemma 1 come from the assumption of perfect competition in all markets. In the present model, the intuition behind Lemma 1 results from the zero profit conditions regarding R&D. If in industry θ, R&D is undertaken by Home, then the zero profit conditions for R&D imply that Foreign has negative profits in this particular industry (see equations (18) and (20)). The larger the range of goods that home exports, the lower home's comparative advantage in R&D. The decreasing mutual R&D condition suggests that Home firms have higher discount profits than foreign firms for the goods in the range $\theta \in [0, \tilde{\theta})$. Foreign challengers would not be able to finance their R&D costs in the range of industries

$\theta \in [0,\tilde{\theta})$ and choose not to engage in R&D since this would yield negative profits. The reverse is true for those industries that Foreign undertakes R&D. Home has negative profits in the industries $\theta \in (\tilde{\theta},1]$, so it does not engage in R&D in those industries. Thus, both countries sustain their comparative advantage.

2.4 Labor Markets

Consider first the Home labor market. All workers are employed by firms in either production or R&D activities. Taking into account that each industry leader charges the same price p and that consumers only buy goods from industry leaders in equilibrium, it follows from (7) that total employment of labor in production in Home is $\int_0^{\tilde{\theta}} Q^h(\theta,t)d\theta$. Solving equation (14) for each industry leader's R&D employment $L_R^h(\theta,t)$ and then integrating across industries, total R&D employment by industry leaders in Home is $\int_0^{\tilde{\theta}} R^h(\theta,t)\alpha_R^h(\theta)d\theta$. Thus, the full employment of labor condition for Home at time t is given by

$$N^h(t) = \int_0^{\tilde{\theta}} Q^h(\theta,t)d\theta + \int_0^{\tilde{\theta}} R^h(\theta,t)\alpha_R^h(\theta)d\theta . \qquad (22)$$

I can derive in a similar way the full employment of labor condition for Foreign at time t and obtain

$$N^f(t) = \int_{\tilde{\theta}}^1 Q^f(\theta,t)d\theta + \int_{\tilde{\theta}}^1 R^f(\theta,t)\alpha_R^f(\theta)d\theta . \qquad (23)$$

Equations (22) and (23) complete the description of the model.

3 Steady-State Equilibrium

In this section I derive the steady-state equilibrium under the TEG specification proposed by Segerstrom (1998), which is described according to equation (17).

Assuming that the relative wage, ω, is constant over time at the steady-state equilibrium, equation (20) implies that $\dot{V}^i(\theta,t)/V^i(\theta,t)=\dot{X}(t)/X(t)=g_N$. That is, the expected global discounted profits of a successful innovator at time *t* in country *i*, $V^i(t)$, and the level of R&D difficulty, *X(t)*, grow at the constant rate of population growth, g_N. In the steady-state equilibrium, the market interest rate, *r*, must be equal to the subjective discount rate, ρ.[11]

Combining equations (18) and (20), I obtain the following zero profit conditions for Home and Foreign respectively:

$$\frac{\left(\frac{\lambda-\omega}{\lambda}\right)E(t)}{(\rho+I(\theta,t)-g_N)}=\omega\alpha_R^h(\theta)X(t), \qquad \forall\theta\in[0,\tilde{\theta}), \tag{24}$$

$$\frac{\frac{(\lambda-1)}{\lambda}E(t)}{(\rho+I(\theta,t)-g_N)}=\alpha_R^f(\theta)X(t), \qquad \forall\theta\in(\tilde{\theta},1], \tag{25}$$

In a steady-state equilibrium all per capita variables are constant. Therefore, the level of R&D difficulty grows at the same rate of population growth, $\dot{X}(t)/X(t)=\dot{N}(t)/N(t)=g_N$. This last result, combined with equation (17) yields

$$I=\frac{g_N}{\mu}. \tag{26}$$

Integrating equation (24) over $[0,\tilde{\theta})$ and equation (25) over $(\tilde{\theta},1]$ (after taking into account equation (26)), and combining the labor markets clearing condition, yields a second schedule in (θ,ω) space, the mutual resource schedule

$$\omega=MR(\tilde{\theta})=\frac{\overline{N}^f(t)\lambda\tilde{\theta}g_N}{\overline{N}^h(t)(1-\tilde{\theta})[\mu S+g_N(\lambda-1)]+\overline{N}^f(t)\tilde{\theta}[g_N-S\mu]}, \tag{27}$$

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[11] This property depends on the particular specification of consumer preferences.

where $S = (\rho + \frac{g_N}{\mu} - g_N)$, $\overline{N}^h(t) = N^h(t)/N(t)$, and $\overline{N}^f(t) = N^f(t)/N(t)$.

The mutual resource schedule states that the relative wage ω, which clears labor markets in both countries, is an increasing function of the range of goods $\tilde{\theta}$ produced in Home. If the range of goods produced by Home increases, Home's relative demand for labor (both in manufacturing and R&D) increases. The excess demand for labor drives the level of the relative wage higher. The mutual resource condition can be depicted in Figure 1. The vertical axis measures Home's relative wage, ω, and the horizontal axis reflects the measure of industries, θ. The intersection of the downward sloping *RD*($\tilde{\theta}$) schedule and the upward sloping *MR*($\tilde{\theta}$) schedule at point E determines the steady-state equilibrium relative wage, ω^*, and the marginal industry $\tilde{\theta}^*$ in which both countries undertake production in goods and R&D services.

Therefore, I arrive at:

Proposition 1. *If $\omega < \lambda$ and for any $\theta \in [0,1]$, $\alpha_R^f(\theta) > \alpha_R^h(\theta)$, then there exists a unique steady-state equilibrium such that*

(a) *Home's relative wage, ω^*, is greater than one*,

(b) *Home has a sustained comparative advantage in the range of industries $\theta \in [0, \tilde{\theta}^*)$. In each industry $\theta \in [0, \tilde{\theta}^*)$, only Home conducts R&D, produces, and exports the state of the-art product*,

(c) *Foreign has a sustained comparative advantage in the range of industries $\theta \in (\tilde{\theta}^*, 1]$. In each industry $\theta \in (\tilde{\theta}^*, 1]$, only Foreign conducts R&D, produces, and exports the state of the-art product*.

The results from this proposition can be found in other models. The static continuum Ricardian model developed by Dornbusch et al. (1977) and the dynamic learning-by-doing model introduced by Krugman (1987) produce similar features with the equilibrium depicted in Figure 1. Proposition 1 identifies the unique steady-state equilibrium level of Home's relative wage and the marginal industry by utilizing the mutual R&D and resource conditions. The pattern of trade in goods is determined by comparative advantage across industries since no multinational firms and trade in R&D sector are allowed[12]. In addition and in contrast to earlier work, the model predicts that the pattern of trade is determined by additional factors such as population growth and the R&D difficulty parameter.[13]Factor price equalization is not a property of the equilibrium depicted in Figure 1. Finally, in contrast to the work of Taylor (1993), trade in R&D services does not occur.

4 Comparative Steady-State Analysis

In this section I examine the comparative static properties of the steady-state equilibrium presented in Figure 1. By totally differentiating the equilibrium conditions (21) and (27) one can obtain propositions 2 and 3:

Proposition 2. If $\alpha_R^f(\theta) > \alpha_R^h(\theta)$ for all $\theta \in [0,1]$ and $\overline{N}^h / \overline{N}^f > \widetilde{\theta} / (1-\widetilde{\theta})$, *then Home's relative wage,* ω^**, depends*

[12] Taylor (1993) developed a model a model where there is heterogeneity in research technologies and allowed for trade in R&D services as well.

[13] Earlier models of Schumpeterian growth in open economies analyzed the relationship between trade patterns and long-run growth. These models identified the economic determinants of sustained comparative advantage in high-technology industries.

(a) *positively on Foreign's relative size,* $\overline{N}^f(t)$*, the size of innovations,* λ*,* the *consumer's subjective discount rate,* ρ*, and the population growth rate,* g_N.

(b) *negatively on the Home's relative size,* $\overline{N}^h(t)$ *and the R&D difficulty growth parameter* μ.

Proposition 3. If $\alpha_R^f(\theta) > \alpha_R^h(\theta)$ for all $\theta \in [0,1]$ *and* $\overline{N}^h / \overline{N}^f > \tilde{\theta} / (1-\tilde{\theta})$*, then the range of goods Home produces, conducts R&D, and exports,* $\tilde{\theta}^*$*, depends*

(a) *positively on Home's relative size,* $\overline{N}^h(t)$ *and the R&D difficulty growth parameter* μ.

(b) *negatively on Foreign's relative size,* $\overline{N}^f(t)$*, the consumer's subjective discount rate,* ρ*, and the population growth rate,* g_N.

(c) *ambiguously on the size of innovations,* λ.

These comparative steady-state properties can be derived graphically by utilizing Figure 1. An increase in Foreign's relative size, $\overline{N}^f(t)$, or a decrease in home's relative size, $\overline{N}^h(t)$, shifts the MR schedule in Figure 1 upward (not shown) and the equilibrium point E to the left along curve RD. The increase in relative wage works as a mechanism to restore the equilibrium. An increase in the population growth rate, g_N, shifts the MR schedule upward in Figure 1 and increases the relative wage from ω^* to ω^{**}. The increase in the population growth rate, g_N, has two effects on the value of the expected discounted profits of a successful innovator in both countries (see equations (24) and (25)). First, the increase in the population growth rate, g_N, has a positive direct effect on the discounted expected global profits. Second, it has a negative indirect effect through the global innovation rate, I, (see equation (26). An increase in the growth rate of population will result in a higher rate of innovation, which in turn, will result in higher demand for labor. The assumption of full labor employment condition in both countries will require a higher relative wage at home (MR shifts up). As a result, it decreases Home's comparative and absolute (if any) advantage in both goods and R&D production. An increase in the consumer's subjective discount rate, ρ, or an decrease in the R&D difficulty growth parameter μ, shifts the *MR* schedule in Figure 1 upward (not shown) and increases the relative wage while it decreases Home's comparative and absolute (if any) advantage in both goods and R&D production.

Finally, an increase in the size of innovations shifts both the RD and MR schedule up in Figure 1. Thus, the increase in the size of innovation will raise Home's relative wages. The upward shift of the RD curve can be seen from the RD condition (equation 21). As the size of innovations increases, Home's relative profit from manufacturing increases, while its relative R&D labor cost remains the same. At the marginal industry $\tilde{\theta}^*$, Home firms have (compared to Foreign firms) higher profits from manufacturing than before. As a result, the relative wage should increase to offset the increase in the labor cost. The increase in the size of innovations will also affect the labor conditions, causing an upward shift in the MR condition. Thus, while the increase in the size of innovations increases the equilibrium wage to ω^{**}, its effect on $\tilde{\theta}^*$ is ambiguous. In Taylor's (1993) model, the effect of the size of innovations (which can vary across industries) creates a deficit in the balance of payments for Home because it raises the royalties' payments that Home has to pay for using the front-line technology. Balance of payments is maintained through two adjustments; Home raises its goods trade balance by increasing the range of goods produced at Home and it reduces its reliance on imported R&D by conducting more itself. Removing part of this heterogeneity in his model, by eliminating Home's relative advantage in goods versus R&D, results in zero trade in R&D and no effect of the size of innovations on the pattern of trade and Home's relative wage.

Proposition 4. *In the semi-endogenous growth model, the global R&D investment,* I*, depends positively on the R&D difficulty growth parameter,* μ*, and negatively on the population growth rate,* g_N*.*

The level of R&D investment, I, is completely determined by the exogenous rate of population growth $g_N > 0$ and the R&D difficulty growth parameter $\mu > 0$. The balanced-growth innovation rate is higher when the population of consumers grows more rapidly or when R&D difficulty increases more slowly over time. These results are standard in the endogenous growth literature without scale effects. [14]

7 Conclusions

The previous literature on "quality ladders" framework that analyzed Ricardian models of trade exhibits the scale effects property. In this paper, I have developed a model of trade based on "quality-ladders" growth without scale effects to analyze how the pattern of trade and the relative wage are determined in steady-state equilibrium. The model explores its comparative steady state properties of the equilibrium under the TEG specification regarding the R&D difficulty. The absence of scale effects generates novel and interesting results. Several comparative-steady-state results in Taylor's (1993) model change with the removal of the scale effects property. In the present model, for example, the effect of the size of innovations on the pattern of trade is ambiguous when the scale effects property is removed. The analysis in the present model generates new additional findings. Under the TEG specification, the model generates a unique steady-state equilibrium in which there is complete specialization in both goods and R&D production within each country. In contrast to previous models (Grossman and Helpman (1991*c*), and Taylor (1993)), the comparative steady state exercises in the present model highlight the

[14] See Segerstrom (1998) for more details on this.

effects of population growth and the R&D difficulty on relative wages. I find that the direction of the effect of population growth rate on Home's relative wage, the pattern of goods and R&D production, and the pattern of trade between the two countries is not affected by the fact that the TEG specification is assumed (compared to the PEG specification). On contrast, the effect of the size of innovation on the pattern of goods and R&D production, and the pattern of trade between the two countries is ambiguous by the fact that the TEG specification is assumed (as opposed to the PEG specification). Given the relatively simplicity of the model, this dynamic formulation provides a useful framework to examine other issues. For example, the introduction of trade instruments and their effect on the pattern of trade between countries can be examined under the TEG specification. Alternatively, a North-South model of trade might yield interesting implications.

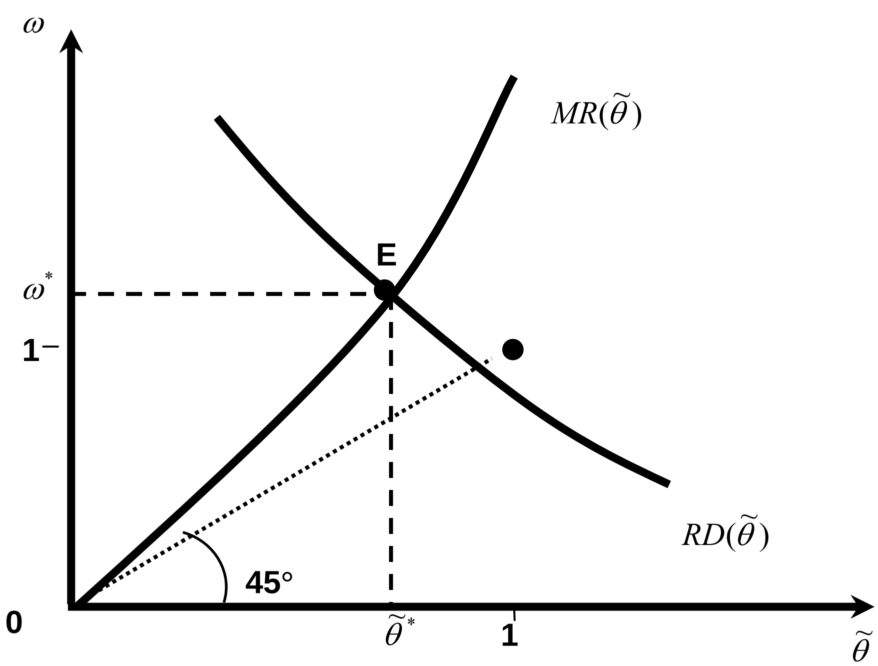

Figure 1. Steady-State Equilibrium.

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APPENDIX

PROOFS OF PROPOSITIONS

A.1 Proof of Lemma 1

A.1 Lemma 1

Lemma 1 results from equations (18) and (20) (after taking into account equations (12) and (13)). Then, from the zero profit conditions, one can obtain the mutual R&D condition:

$$\omega = RD(\tilde{\theta}) = \frac{\lambda A(\tilde{\theta})}{\lambda + A(\tilde{\theta}) - 1} \tag{A.1}$$

The slope of the mutual R&D condition is given by

$$\frac{d\omega}{d\theta} = RD'(\tilde{\theta}) = \frac{\overbrace{\lambda(\lambda-1)}^{+}\overbrace{A'(\tilde{\theta})}^{-}}{\underbrace{(\lambda + A(\tilde{\theta}) - 1)^2}_{+}} < 0\,. \tag{A.2}$$

Dividing equations (24) and (25) in the main text, I obtain the following equation:

$$\frac{\lambda - \omega}{\lambda - 1} = \frac{\omega \alpha_R^h(\tilde{\theta})}{\alpha_R^f(\tilde{\theta})}$$

The left hand side of the above equation is the relative profit from manufacturing at home and the right hand side reflects the relative labor cost of R&D at home. The relative wage at the marginal industry $\tilde{\theta}$ should satisfy the above equation, so that none of the countries have relative advantage. In other words, at the marginal industry $\tilde{\theta}$ firms in both countries are indifferent in engaging in R&D. It follows that $\omega < \lambda$ and $\lambda > 1$ should hold.

$$\frac{d\omega}{d\lambda} = \frac{A(\tilde{\theta})[A(\tilde{\theta}) - 1]}{[\lambda + A(\tilde{\theta}) - 1]^2} ><0?$$

If $A(\tilde{\theta})>1$, which implies that $\alpha_R^f(\tilde{\theta}) > \alpha_R^h(\tilde{\theta})$, then $d\omega/d\lambda > 0$. In proposition 1 below, I provide a sufficient condition under which $A(\tilde{\theta})>1$.

A.2 Proofs of Propositions 1, 2, and 3 Under the TEG Specification

A.2.1 Derivation of mutual resource condition

Next, I derive the mutual resource schedule (equation (27)) under the TEG specification.

Integrating equation (24) over $[0,\tilde{\theta})$ and equation (25) over $(\tilde{\theta},1]$ (after taking into account equation (26)), I obtain the following zero profit conditions for Home and Foreign, respectively

$$\frac{(\lambda-\omega)E(t)\tilde{\theta}}{\lambda} = S\omega X(t)A^h(\tilde{\theta}), \tag{A.3}$$

$$\frac{(\lambda-1)E(t)(1-\tilde{\theta})}{\lambda} = SX(t)A^f(\tilde{\theta}) . \tag{A.4}$$

where $S=(\rho+g_N/\mu-g_N)$ and $A^h(\tilde{\theta})=\int_0^{\tilde{\theta}}\alpha_R^h(\theta)d\theta$ and $A^f(\tilde{\theta})=\int_{\tilde{\theta}}^1\alpha_R^f(\theta)d\theta$.

Next, by substituting out for X(t) using the zero-profit conditions (equations (A3) and (A4)), the full employment of labor conditions at home and foreign (equations (22) and (23)) could be written as functions of ω, $\tilde{\theta}$, and $E(t)$:

$$N^h(t)=\frac{E(t)\tilde{\theta}}{\lambda}+\frac{(\lambda-\omega)E(t)\tilde{\theta}g_N A^h(\tilde{\theta})}{\lambda S\omega A^h(\tilde{\theta})\mu}, \tag{A.5}$$

$$N^f(t)=\frac{(1-\tilde{\theta})E(t)[\mu S+g_N(\lambda-1)]}{\lambda\mu S}. \tag{A.6}$$

Solving (A5) for E(t) and substituting the result into (A6) yields the mutual resource schedule:

$$\omega=MR(\tilde{\theta})=\frac{\overline{N}^f(t)\lambda\tilde{\theta}g_N}{\overline{N}^h(t)(1-\tilde{\theta})[\mu S+g_N(\lambda-1)]+\overline{N}^f(t)\tilde{\theta}[g_N-S\mu]}. \tag{A.7}$$

$$\frac{\partial MR(\tilde{\theta})}{\partial\tilde{\theta}}=\frac{\overline{N}^f\overline{N}^h\lambda g_N[\mu(\rho-g_N)+g_N\lambda)]}{\{\overline{N}^h(1-\tilde{\theta})[\mu S+g_N(\lambda-1)]+\overline{N}^f\tilde{\theta}[g_N-S\mu]\}^2}>0. \tag{A.8}$$

Since the sign of the expression in (A8) is positive, the mutual resource condition curve is upward-sloping in (θ,ω).

A.2.2 Proposition 1

In order for Home's relative wage to be greater than one (assumption (10) in the main text), the mutual R&D schedule (given by equation (21) should live above the $\omega=1$ line. That is, for any $\theta\in[0,1]$, if $\alpha_R^f(\theta)>\alpha_R^h(\theta)$ holds, then $A(\theta)>1$ implies

$$(\lambda-1)A(\theta) > \lambda - 1 \Leftrightarrow \lambda A(\theta) > \lambda + A(\theta) - 1 \Leftrightarrow \frac{\lambda A(\theta)}{\lambda + A(\theta) - 1} > 1 \Leftrightarrow \omega(\theta) = RD(\theta) > 1. \qquad \text{(A.9)}$$

(A9) implies that $\frac{d\omega}{d\lambda} > 0$.

The intersection of the R&D condition and mutual resource curves yield the unique steady-state equilibrium values of the marginal industry $\tilde{\theta}^*$ and the relative wage at home ω^*. From Lemma 1, it follows that home and foreign have sustained comparative advantage in R&D in the industries $[0, \tilde{\theta})$ and $(\tilde{\theta}, 1]$ respectively. Since I rule out international licensing and multinational corporations, this will imply that each vertically differentiated good must be manufactured in the country in which the most recent product improvement has taken place. Thus, the home country conducts R&D, produces, and exports the state of the art product for each industry $\theta \in [0, \tilde{\theta}^*)$ while the foreign country conducts R&D, produces, and exports the state of the art product for each industry $\theta \in (\tilde{\theta}^*, 1]$.

A.2.3 Proposition 2

I can write the two equilibrium relationships governing Figure 1 in a more general form as follows:

$\omega \equiv RD(\tilde{\theta}, \lambda)$, where $RD_1 < 0$, $RD_2 > 0$, (A.10)

$\omega \equiv MR(\tilde{\theta}, \overline{N}^f, \overline{N}^h, \mu, \lambda, \rho, g_N)$, where $MR_1 > 0$, $MR_2 > 0$, $MR_3 < 0$, (A.11)

$MR_4 < 0$, $MR_5 > 0$, $MR_6 > 0$, $MR_7 > 0$.

The following condition has to hold in order to sign MR_4 through MR_7*:*

$MR_4 < 0$, $MR_5 > 0$, $MR_6 > 0$, and $MR_7 > 0$ if and only if $\frac{\overline{N}^h}{\overline{N}^f} > \frac{\tilde{\theta}}{(1-\tilde{\theta})}$

I totally differentiate equations (21) and (27) in the main text and obtain the following system of two equations in the differentials of two endogenous variables as follows:

$$d\omega - RD_1 d\tilde{\theta} = RD_2 d\lambda$$

$$d\omega - MR_1 d\tilde{\theta} = MR_2 d\overline{N}^f + MR_3 d\overline{N}^h + MR_4 d\mu + MR_5 d\lambda + MR_6 d\rho + MR_7 dg_N \qquad \text{(A.12)}$$

I can write the system (A.12) in the reduced form as follows:

$$\begin{bmatrix} 1 & -RD_1 \\ 1 & -MR_1 \end{bmatrix} \begin{bmatrix} d\omega \\ d\tilde{\theta} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & RD_2 & 0 & 0 \\ MR_2 & MR_3 & MR_4 & MR_5 & MR_6 & MR_7 \end{bmatrix} \begin{bmatrix} d\overline{N}^f \\ d\overline{N}^h \\ d\mu \\ d\lambda \\ d\rho \\ dg_N \end{bmatrix}, \quad \text{(A.13)}$$

I calculate the determinant of the matrix of the endogenous variables (which I denote with Δ) as follows:

$$\Delta = \begin{vmatrix} 1 & -RD_1 \\ 1 & -MR_1 \end{vmatrix} = RD_1 - MR_1 < 0. \quad \text{(A.14)}$$

Using the system of equations given by (A.14) and by employing the Cramer's rule, I establish the comparative steady-state results for the TEG specification regarding ω. I calculate the determinant of the matrix formed by replacing the second column of the matrix of the endogenous variables in (A.13) with the corresponding column vector of the exogenous variable in consideration. Thus, I obtain the following results:

$$\frac{d\omega}{dN^f} = \frac{RD_1 MR_2}{\Delta} > 0, \quad \frac{d\omega}{dN^h} = \frac{RD_1 MR_3}{\Delta} < 0, \quad \frac{d\omega}{d\mu} = \frac{RD_1 MR_4}{\Delta} < 0,$$

$$\frac{d\omega}{d\lambda} = \frac{RD_1 MR_5 - MR_1 RD_2}{\Delta} > 0, \quad \frac{d\omega}{d\rho} = \frac{RD_1 MR_6}{\Delta} > 0, \quad \frac{d\omega}{dg_N} = \frac{RD_1 MR_7}{\Delta} > 0.$$

The signs of the above equations prove Proposition 2.

A.2.4 Proposition 3

Using the system of equations given by (A.13), I establish the comparative steady-state results for the TEG specification regarding $\tilde{\theta}$. I calculate the determinant of the matrix formed by replacing the first column of the matrix of the endogenous variables in (A.13) with the corresponding column vector of the exogenous variable in consideration. Thus, I obtain the following results:

$$\frac{d\tilde{\theta}}{dN^f} = \frac{MR_2}{\Delta} < 0, \quad \frac{d\tilde{\theta}}{dN^h} = \frac{MR_3}{\Delta} > 0, \quad \frac{d\tilde{\theta}}{d\mu} = \frac{MR_4}{\Delta} > 0, \quad \frac{d\tilde{\theta}}{d\lambda} = \frac{MR_5 - RD_2}{\Delta} >< 0?$$

$$\frac{d\tilde{\theta}}{d\rho} = \frac{MR_6}{\Delta} < 0, \quad \frac{d\tilde{\theta}}{dg_N} = \frac{MR_7}{\Delta} < 0.$$

The signs of the above equations prove Proposition 3.

A.2.5 Proposition 3

It follows from equation (26) in the main paper.

A.2.6 Comparison of Comparative Steady-State Analysis Under PEG and TEG

First, I derive the mutual resource schedule for the PEG specification:

$$\omega = MR(\tilde{\theta}) = \frac{[\overline{N}^f + k(\rho - g_N)A^f(\tilde{\theta})]\tilde{\theta}}{[\overline{N}^h + k(\rho - g_N)A^h(\tilde{\theta})](1-\tilde{\theta})}$$

By making the following assumption: $\overline{N}^h(t)/\overline{N}^f(t) < A^h(\tilde{\theta})/A^f(\tilde{\theta})$, I can derive the comparative steady-state results for the PEG specification (the proofs of these results are available in the working paper (Petsas, 2008):

i) Home's relative wage, ω^*, depends positively on Foreign's relative size, $\overline{N}^f(t)$, the size of innovations, λ, the consumer's subjective discount rate, ρ, and the population growth rate, g_N; it depends negatively on Home's relative size, $\overline{N}^h(t)$ and the R&D difficulty parameter, k.

ii) The range of goods Home produces, conducts R&D, and exports, $\tilde{\theta}^*$, depends positively on Home's relative size, $\overline{N}^h(t)$, the R&D difficulty parameter, k, and on the size of innovations, λ; it depends negatively on Foreign's relative size, $\overline{N}^f(t)$, the consumer's subjective discount rate, ρ, and the population growth rate, g_N.

Thus, most of the comparative steady-state results are robust when the PEG specification is assumed instead of the TEG specification. The effect of the size of innovations on Home's comparative advantage is positive under the PEG specification, while it is ambiguous under the TEG specification.