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Quality heterogeneity and global economic growth

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ABSTRACT

This paper develops a fully endogenous, variety-expansion growth model with firm-specific quality heterogeneity, limit pricing, and an endogenous distribution of markups. Firms with high-quality products engage in exporting, firms with intermediate-quality products serve the domestic market, and inefficient firms with low-quality products exit the market. Trade liberalization, measured by a reduction in trade costs or a decline in foreign market entry costs, generates a reallocation of resources from low-quality to high-quality products and exit of inefficient firms. However, it has ambiguous effects on the average global quality level, long-run growth, and welfare. An increase in the rate of population growth or in the intensity of trade-related knowledge spillovers accelerates economic growth. The laissez-faire equilibrium is inefficient, and this leaves room for welfare-improving government intervention.

1. Introduction

Several firm-level empirical studies have convincingly argued that the existence of large and persistent productivity and/or product-quality differences among firms within narrowly defined product categories accounts for observed trade patterns in monopolistically competitive markets.[2] These studies have shown that more productive (high-quality product) firms charge lower (higher) prices and are more likely to enter foreign markets after paying large fixed export costs.

This paper analyzes the long-run effects of trade on growth and welfare in markets exhibiting quality heterogeneity, market entry costs, and trade costs. We consider a global economy consisting of two structurally identical countries where new varieties are discovered through resource-using R&D investments. Labor is the only factor of production and grows at a constant rate. We assume that the productivity of researchers depends positively on domestic and foreign intertemporal knowledge spillovers as in Rivera-Batiz and Romer (1991), and negatively on market size measured by the number of

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 [1] Tel.: +1 352 392 8150.
 [2] See Clerides et al. (1998), Bernard and Jensen (1999), Aw et al. (2000), Schott (2004), Hummels and Skiba (2004), Hummels and Klenow (2005), and Hallak (2006) among many others.

consumers buying each product as in Dinopoulos and Segerstrom (1999). These two assumptions deliver fully endogenous growth which depends on virtually all parameters including those that capture the effects of trade liberalization.[3]

The R&D process, which uses labor and available knowledge, is stochastic in the sense that a firm must incur an instantaneous fixed cost in order to draw its product quality from a known distribution.[4] Therefore, firms discover products with different quality levels. Each surviving firm faces a unit-elastic demand curve and competes in a Bertrand fashion against a competitive fringe of imitators producing a generic low-quality product. As in quality-ladders growth models, firms optimally charge a limit price, which is proportional to the quality of their products, and drive the competitive fringe out of the market. Consequently, firms with higher-quality products charge higher prices and enjoy higher markups and profits. Production of each discovered variety exhibits increasing returns due to an instantaneous fixed cost and a constant marginal cost. Exporting requires additional costs that take the form of an instantaneous fixed cost and a per-unit trade cost. The model delivers an endogenous partition of firms which is based on two distinct minimum quality levels: a domestic cutoff quality level and a higher, export cutoff quality level. Only firms whose product quality exceeds the export cutoff quality level serve both markets. Firms whose product quality is between the two cutoff quality levels serve only the domestic market. Finally, firms whose product quality is below the domestic cutoff quality level exit the market.

Having developed a fully endogenous growth model with heterogeneous firms, we then explore the nexus among trade, long-run growth, and welfare. We analyze the growth effects of three types of trade openness: a move from autarky to restricted (or free) trade; a reduction in trade costs (or ad valorem tariffs); and a decline in fixed export costs. We highlight the presence of three distinct but interdependent channels that transmit the effects of trade on long-run growth and steady-state welfare. The first channel consists of the intensity (strength) of international knowledge spillovers. An increase in the latter improves the productivity of researchers engaged in the discovery of new varieties and accelerates long-run growth. The second channel captures the effects of expected instantaneous fixed costs on the incentives to innovate. This novel channel is based on quality uncertainty and is absent from endogenous-growth models with homogeneous (symmetric) firms. Quality uncertainty implies that firms engaged in R&D activities to discover new products do not know in advance their exporting status which depends on the quality of their products. Thus entry into the innovation process depends inversely on the level of expected instantaneous costs required to enter the domestic and foreign markets. These costs in turn depend on the domestic and export cutoff quality levels which are responsive to trade policies. In contrast, in growth models with symmetric firms, each firm faces a constant and deterministic instantaneous fixed cost of discovering a new variety which is not affected by openness. The third channel operates through trade-induced effects on the average global quality level. In quality-ladders growth models with homogeneous firms and no trade costs the average quality level is an exogenous parameter, which captures the innovation size, and is not affected by trade liberalization measures. In contrast, the present model delivers an endogenous global quality level which depends on trade costs, the domestic and export cutoff quality levels. Trade liberalization policies that raise the average global quality level increase the average limit price, reduce the demand for surviving products, and the demand for labor in manufacturing. These demand changes induce a resource movement from production of varieties to R&D activities and generate a pro-growth effect.

The simultaneous presence of these three interdependent mechanisms renders the effects of trade on long-run growth and welfare ambiguous. This structural ambiguity stems from the fact that the impact of each form of trade openness is generally transmitted through all channels and creates pro-growth and anti-growth tensions. For instance, a move from autarky to trade increases the intensity of trade-related knowledge spillovers (a pro-growth effect), has an ambiguous effect on the average global quality (an ambiguous growth effect), and increases the level of expected instantaneous fixed costs (an anti-growth effect). Therefore the net growth effect depends on the magnitude of the model's parameters, and it is in principle ambiguous. Similar considerations apply to other forms of trade liberalization. In contrast, an increase in the intensity of trade-related knowledge spillovers, or an increase in the rate of population growth unambiguously raises long-run growth. Finally, an increase in the subjective discount rate unambiguously reduces long-run growth.

We explore the nature of growth-trade ambiguity by analyzing several special cases. Following the standard practice of several studies on trade and heterogeneous firms, all special cases assume that quality levels are drawn from a Pareto distribution. We begin by analyzing a move from autarky to restricted trade. We show that exposure to trade increases long-run growth under two additional conditions: first, loosely speaking, instantaneous fixed costs are ranked in ascending order starting with domestic market entry costs, followed by foreign market entry costs, and ending with fixed costs of variety creation; second, the magnitude of the intensity of trade-related knowledge spillovers is sufficiently large (or equals the endogenous fraction of traded varieties as in Baldwin and Robert-Nicoud, 2008). We then study the effect of a further exposure to trade on long-run growth. For example, we show that when firms face identical domestic and foreign market

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[3] Modern growth theory consists of three distinct approaches. Earlier endogenous growth theory implies that growth can be affected by a variety of policies, but exhibits the scale-effects property. This counterfactual property implies that positive population growth drives long-run per-capita growth to infinity. Semi-endogenous growth theory which removes the scale-effects property by incorporating diminishing returns to the stock of knowledge. This theory predicts that per-capita long-run growth depends positively only on the exogenous rate of population growth. Fully endogenous growth theory which removes the scale-effects property by assuming constant returns to the stock of knowledge. It implies that policy-related parameters affect the rate of long-run growth. Ha and Howitt (2007) offer more details on the differences and the empirical implications of these distinct approaches to modern growth theory.

[4] The product innovation process is similar to that in Melitz (2003) and Dinopoulos and Unel (2009). However, their models assume firms cannot benefit from technologies developed by other producers. As a result, the long-run growth rate is zero.

entry costs; and the intensity of knowledge spillovers equals the endogenous share of traded varieties, a reduction in trade costs increases long-run growth (see Section 3 for more details).

We also analyze the relationship between trade and steady-state welfare. The latter depends positively on per-capita consumption expenditure and on long-run growth. Therefore, the trade-welfare relationship inherits the aforementioned trade-growth indeterminacy. We illustrate the welfare effects of trade liberalization by employing simulation analysis. Our analysis suggests that trade is welfare improving under the parameter restrictions that resolve the trade-growth ambiguity. We view this as an optimistic finding. We also establish that the laissez-faire equilibrium is socially suboptimal.

This paper is related to a growing literature that investigates the effects of trade on growth in the presence of heterogeneous firms. Baldwin and Robert-Nicoud (2008) and Unel (2010) generalize Melitz's (2003) model by introducing a growth mechanism which is based on first-generation endogenous growth models. They find that exposure to trade has an ambiguous effect on long-run growth as in the present model. However, the growth-trade ambiguity in their model can be traced to different specifications of trade-related knowledge spillovers. In addition, their model generates constant markups, thanks to Dixit and Stiglitz (1977) preferences, and therefore does not take into account the growth effect of trade liberalization that operates through changes in the average markup (or the average quality level). Moreover, their model abstracts from growth effects related to changes in the rate of population growth (as opposed to changes in the level of population).

Gustafsson and Segerstrom (2010) develop a model of semi-endogenous growth and productivity heterogeneity which generates constant markups due to the use of Dixit and Stiglitz (1977) preferences. Trade liberalization does not affect long-run productivity growth. The short-run effects of trade liberalization work through the size of intertemporal knowledge spillovers. Weak (strong) knowledge spillovers promote (retard) short-run productivity growth and steady-state welfare. In contrast, our paper highlights the ambiguous long-run effects of trade liberalization that operate through several mechanisms including intertemporal knowledge spillovers.

In another related study, Haruyama and Zhao (2008) introduce firm-specific productivity heterogeneity in a quality-ladders growth model. In their model, trade liberalization unambiguously raises the long-run growth rate of total factor productivity under a scale-sensitive R&D production function. Under a scale-invariant R&D process, their model generates semi-endogenous long-run growth unaffected by trade liberalization. This paper differs from theirs in several aspects.[5] The most notable difference is that in our model growth is generated by variety expansion, whereas in their model it is driven by an increase in the average quality of fixed set of goods. Our analysis complements their main finding by establishing that trade liberalization has an ambiguous effect on the long-run growth.

The rest of the paper is organized as follows. Section 2 introduces the elements of the model and establishes the uniqueness of the steady-state equilibrium. Section 3 analyzes the long-run effects of trade liberalization. Section 4 investigates the welfare implications of the model, and Section 5 offers some concluding remarks.

2. The model

We consider a global economy consisting of two structurally identical countries. Each country is populated by a continuum of firms whose products have different quality levels. Labor is the only factor of production and grows at a constant rate. The creation of new varieties is governed by an R&D process, which is similar to that proposed by Melitz (2003): the quality level of each discovered variety is drawn from a probability distribution with positive support after each entrant incurs an instantaneous fixed R&D cost. In addition, each firm faces fixed instantaneous domestic market entry costs, fixed instantaneous foreign market entry costs, and fixed per-unit trade costs .

2.1. Consumer behavior

The representative household is modeled as a dynastic family whose size grows over time at constant rate $n > 0$. Normalizing the initial number of family members to one, the population level at time t is $L_t = e^{nt}$. The preferences of the representative household are given by the following intertemporal utility function:

$$U = \int_0^\infty e^{-(\rho-n)t} \ln u_t \, dt, \tag{1}$$

where $\rho - n > 0$ denotes the effective discount rate and $\ln u_t$ denotes each consumer's instantaneous utility function. The latter is given by the following Cobb–Douglas function over a continuum of goods indexed by ω:

$$\ln u_t = M_{ct} \ln M_{ct} + \int_0^{M_{ct}} \ln\left[\lambda(\omega)\frac{q_t(\omega)}{L_t}\right] d\omega, \tag{2}$$

where $\lambda(\omega)$ denotes the *time-invariant* product quality, $q_t(\omega)$ is the aggregate consumption of brand ω, and M_{ct} denotes the mass of varieties available for consumption.

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[5] Their setup focuses on productivity heterogeneity, whereas the present model highlights quality heterogeneity. Furthermore, it is worth mentioning that our modeling of the R&D process also differs from theirs.

The first term of (2) directly captures the individual's love of varieties and its inclusion into the utility function is necessary to ensure that consumers demand all available products in the market (i.e., sum of the domestic and foreign products available for consumption). Growth models based on variety accumulation employ a constant elasticity of substitution (CES) instantaneous utility function which ensures that the introduction of new varieties does not drive the instantaneous utility level below zero. In contrast, it is well known that under Cobb–Douglas preferences, per-capita expenditure is divided equally among all available varieties. Therefore, as the measure of varieties increases, per-capita quantity consumed $q_t(\omega)/L_t$ declines and can drive the term in square brackets in (2) below unity. If this happens, the integral term of (2) becomes negative, and in the absence of the first term consumers will not demand all goods. Thus, the additional term in the instantaneous utility constitutes a sufficient condition under which the consumer buys all available varieties.[6]

The household maximization problem can be solved in two steps. First, each consumer maximizes the instantaneous utility function (2) subject to the budget constraint $\int_0^{M_{ct}} p_t(\omega)[q_t(\omega)/L_t]\,d\omega \le E_t$, where $p(\omega)$ is the corresponding price of the brand and E_t is the *per-capita* consumption expenditure. The solution to this maximization problem yields the following expression for the market demand for a typical variety:

$$q_t(\omega) = \frac{E_t L_t}{p_t(\omega) M_{ct}}. \tag{3}$$

This optimal consumption rule implies that the aggregate demand for a product increases in aggregate consumer expenditure $E_t L_t$; and decreases in its own price $p_t(\omega)$ and in the number of all varieties available for consumption $M_{ct} = M_{dt} + M_{xt}$, where M_{dt} denotes the number of all domestically produced (and consumed) varieties and M_{xt} denotes the measure of imported varieties. The latter equals the number of exported varieties as well due to the assumption of two identical countries.

Second, the household maximizes (1) subject to the intertemporal budget constraint

$$\int_0^{\infty} e^{-(R_t - nt)} E_t\, dt \le \mathcal{A}_0,$$

where $R_t - nt$ is the effective cumulative discount factor and $\mathcal{A}_0$ is the present value of the household wealth. The optimal spending path is given by the following Euler equation:

$$\frac{\dot{E}_t}{E_t} - \frac{\dot{M}_{ct}}{M_{ct}} = r_t - \rho, \tag{4}$$

where r_t is the instantaneous interest rate. In our subsequent analysis, we will drop the time index to simplify the notation, and we will do so when this causes no notational confusion.

2.2. Product markets

There is a continuum of firms, each choosing to produce a different variety. We assume that production of one unit of each good requires one unit of labor.[7] Firms wishing to export must incur per-unit trade costs. Iceberg trade costs (such as transport costs and/or tariffs) are modeled in the standard fashion: $\tau > 1$ units of output must be produced at home in order for one unit to arrive at its destination.

The aggregate quantity demanded, which is given by Eq. (2), implies that expenditure per variety is identical across varieties and independent of product quality. Since the elasticity of demand for each variety is unity, each firm has incentives to charge an infinite price and produce an infinitesimally small quantity independently of the quality level. To prevent this from happening, we assume that once a product is consumed in a market, a generic, lower-quality version of the product can be produced by a competitive fringe. The production of generic products is characterized by constant returns to scale where one unit of labor produces one unit of output. We assume that the generic version of a product cannot be produced in a country unless the original product is sold there.[8] We normalize the quality level of each generic good to unity independently of the quality level of the copied product and the location of production.

Since each brand is associated with a unique quality level, hereafter we shall label products based on their quality level. Let $p_d(\lambda)$ and $p_x(\lambda)$ denote the consumer price prevailing in the domestic and foreign markets respectively, and assume that competition within each product occurs in a Bertrand fashion. The possibility of costless imitation forces firms to maximize profits by charging a (limit) price no higher than $p_d(\lambda) = p_x(\lambda) = w\lambda$. Because both countries are structurally identical, the wage rate w is equal across countries and, hereafter, is normalized to unity (i.e., $w = 1$). The price competition drives domestic and foreign imitators out of the market and ensures that firms with higher-quality products charge higher prices.[9]

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[6] The condition $\max(f_d, f_x) > 2/(\rho - n)$, where f_d is the instantaneous fixed costs of home-market entry and f_x is instantaneous fixed costs of foreign market entry, guarantees that consumers buy all available varieties. Section 4 provides more details on the derivation of this condition.

[7] This assumption is made to simplify the subsequent analysis. The main results will not change, even if we assume that the unit-cost of producing each variety increases in its quality level.

[8] Alternatively, we can assume technology diffuses instantly across countries: once a product is developed, its low-quality generic version can be produced by a competitive fringe in any country. The analysis based on this assumption yields qualitatively similar results and is available upon request.

[9] Segerstrom et al. (1990) and Grossman and Helpman (1991, chapter 4), for example, provide excellent discussion on how such copying technology can generate the aforementioned optimal limit-pricing rule.

Thus consider two firms, say 1 and 2, producing products with quality levels λ_1 and λ_2. The limit-pricing rule and (3) yield

$$\frac{q(\lambda_1)}{q(\lambda_2)} = \frac{p(\lambda_2)}{p(\lambda_1)} = \frac{\lambda_2}{\lambda_1}, \tag{5}$$

where we again drop time subscript t to simplify notation. Thus, firms with higher-quality products charge higher prices and sell lower quantities. However, all firms earn the same revenue $p(\lambda)q(\lambda)$ as in the standard quality-ladders growth model.

Under this limit-pricing rule, an exporting firm's domestic (home market) and export (foreign market) profit flows $\pi_{dt}(\lambda)$ and $\pi_{xt}(\lambda)$, respectively, are given by

$$\pi_{dt}(\lambda) = [p_d(\lambda) - 1]q_{dt}(\lambda) = (1 - \lambda^{-1})EL/M_{ct}, \tag{6}$$

$$\pi_{xt}(\lambda) = [p_x(\lambda) - \tau]q_{xt}(\lambda) = (1 - \tau\lambda^{-1})EL/M_{ct}, \tag{7}$$

where the quantities demanded by domestic and foreign consumers $q_{dt}(\lambda)$ and $q_{xt}(\lambda)$ are given by (3) and $p_d(\lambda) = p_x(\lambda) = \lambda$. These operating profit flows exclude the initial market entry fixed (sunk) costs.

We assume that the probability of default is zero. Therefore the discounted value of operating profits earned in the home (domestic) and foreign (export) markets (denoted by v_{dt} and v_{xt}, respectively) are given by

$$v_{it}(\lambda) = \int_t^\infty e^{-[R_s - R_t]} \pi_{is}(\lambda) ds, \quad i = d,x, \tag{8}$$

where R_t is the cumulative interest factor from time 0 to time t.

Differentiating (8) with respect to time delivers a more intuitive expression that defines the discounted value of profit flow v_{it}:

$$\pi_{it}(\lambda) + \dot{v}_{it}(\lambda) = r_t v_{it}(\lambda), \quad i = d,x.$$

The left-hand-side equals the return to equity in a firm with quality level λ: owners of this firm earn the flow of profits $\pi_{it}dt$ during the infinitesimal interval of time dt and the capital gain $dv = \dot{v}_{it}dt$. Because there is no risk of default for a surviving product once its quality is known, the total return to firm's equity must be equal to the flow of money generated by an equal-size investment earning the market interest rate $r_t v_{it}dt$. Solving the above expression for the discounted value of operating profits yields

$$v_{it}(\lambda) = \frac{\pi_{it}(\lambda)}{r_t - \dot{v}_{it}/v_{it}}. \tag{9}$$

The discounted value of profits earned by a surviving firm equals the flow of profits π_{it} discounted by the market interest rate r_t minus the growth rate of v_{it}. In the absence of population growth, $\dot{v}_{it} = 0$ in the long-run, and (9) yields $v_{it} = \pi_{it}(\lambda)/r_t$ as in Romer (1990). Using the aforementioned notation, observe that a firm serving only the domestic market earns a profit-flow $\pi_{dt}(\lambda)$ and corresponding discounted profits $v_{dt}(\lambda)$ at time t, whereas a firm serving both the domestic and foreign markets earns a profit flow $\pi_{dt}(\lambda) + \pi_{xt}(\lambda)$, and corresponding discounted profits $v_{dt}(\lambda) + v_{xt}(\lambda)$.

2.3. Entry and exit decision

The presence of substantial market entry costs has been documented by several empirical studies (e.g., Roberts and Tybout, 1997; Bernard and Jensen, 2004). In addition, Romer (1994, p. 24) offers the following example for the type of fixed costs associated with exporting: "One can think, for example, of the information a foreign retailer must collect about quality, reliability, and capacity of suppliers before it can begin to buy garments assembled in a new country. The retailer would have to establish new financial relationships for clearing transactions and new shipping and communication links for moving goods. It would have to learn about the local legal, regulatory, and tax environment and it would have to investigate the nature of political risk. It would also need to invest in long term implicit and explicit contractual relationships for the trading relationship to be successful."

In our model, a firm has to decide whether or not to discover a blueprint and where to sell its product. This decision is based on three distinct instantaneous sunk costs: R&D costs $f_e\phi_t$ to allow the firm to learn its quality level and create a blueprint; R&D costs $f_d\phi_t$ to learn how to produce and sell its product in the domestic market; and additional R&D costs $f_x\phi_t$ to learn how to sell the good in the foreign market. These three sunk costs can be interpreted as different unit labor requirements since labor is used as the numeraire ($w=1$). Individual firms treat these sunk costs as parameters, but they can change over time due to changes in the size of the market measured by the level of population or due to international knowledge spillovers.

The first component of each type of sunk costs (f_e, f_d, or f_x) is a fixed parameter as in Melitz (2003). The common component ϕ_t, which governs the evolution of fixed costs over time and delivers fully endogenous growth, is defined as

$$\phi_t = \frac{L_t}{(1+\theta)M_{dt}}, \tag{10}$$

where L_t is each country's labor force. The denominator of (10) captures the effect of the stock of knowledge on the intertemporal component of sunk costs. The stock of knowledge enhances research productivity and reduces learning costs, as in Romer (1990) and Rivera-Batiz and Romer (1991). In a trading world, it is reasonable to assume that the discovery of new

varieties abroad contributes also to the effective local stock of knowledge. For example, local researchers can study the embodied knowledge in imported goods or the distribution systems that importers build to market and sell their products. Also, exposure to international trade could increase the number of contracts between domestic and foreign producers, who could then expand the flow of knowledge between countries (see Grossman and Helpman, 1991; Coe and Helpman, 1995).[10]

In what follows, we employ two specifications of intertemporal knowledge spillovers. First, following Gustafsson and Segerstrom (2010) we assume that the effective stock of knowledge in each economy equals $M_{Lt} + \theta M_{Ft}$, where M_{Lt} is the measure of home varieties produced locally and M_{Ft} is the measure of foreign varieties produced abroad. Parameter $\theta \in [0,1]$ measures the strength of foreign knowledge spillovers, i.e., the effective contribution of a foreign variety to the local stock of knowledge. The absence of foreign knowledge spillovers corresponds to $\theta = 0$, and the case of perfect international spillovers corresponds to $\theta = 1$. Structural symmetry between the two countries implies $M_{Lt} = M_{Ft} = M_{dt}$, where M_{dt} is the measure of varieties produced in each country. Of course, a fraction of locally produced varieties is shipped abroad in the form of exports. Second, following Baldwin and Robert-Nicoud (2008) we assume that the effective stock of knowledge in each country equals $M_{Lt} + M_{It}$, where M_{It} is the measure of imported varieties. Again, structural symmetry between the two countries implies that the measure of imported varieties equals the measure of exported varieties $M_{It} = M_{xt} = \zeta_x M_{dt}$, where ζ_x is the fraction of traded (imported or exported) varieties. This specification of international spillovers delivers an expression for the denominator of (10) equal to $(1 + \zeta_x)M_{dt}$. Consequently, the second specification yields an endogenous strength (intensity) of international knowledge spillovers which equals the fraction of traded varieties and can be affected by trade liberalization measures.

The function ϕ_t reveals two competing economic forces that shape the magnitude of instantaneous fixed costs. First, the numerator of (10) captures the notion that firms in larger markets face higher fixed costs. These fixed costs make the learning process more difficult and capture the presence of diseconomies of scale. The latter can arise from higher costs of setting up distribution systems in larger markets; larger advertising expenditures; the spreading of talent and other specialized resources too thin in larger markets; higher costs associated with coordination failures; and costs associated with the internal flow of information in larger firms. Following the fully endogenous growth literature, we assume that the difficulty of learning is proportional to the size of each country's market measured by its level of population.[11] The assumption that ϕ_t is linear in L_t is based on the notion that the stock of knowledge exhibits constant returns which is consistent with several fully endogenous growth models (see, for instance, Young, 1998; Dinopoulos and Thompson, 1998; Dinopoulos and Segerstrom, 1999; Howitt, 1999).

Each variety is associated with a quality level λ, which is randomly drawn from a common distribution $g(\lambda)$, and an associated cumulative distribution $G(\lambda)$. Introduction of a new product in each market, however, requires the innovator to pay additional sunk costs of adapting the variety to the market standards and regulations. Upon developing a new product, the innovator checks the associated quality level λ. If the firm's quality level is low such that the discounted sum of profits earned from local sales is less than the domestic market entry cost $f_d \phi_t$, then the firm exits the market. If the firm's discounted sum of profits earned from local sales is greater than $f_d \phi_t$, then it will bear these once-for-all sunk costs and the associated flow of variable costs in order to enter successfully the domestic market. If the quality level is high enough to also cover the foreign market entry costs $f_x \phi_t$, then the innovator incurs $(f_d + f_x)\phi_t$ fixed costs at time t in order to serve both the local and foreign markets. Consequently, unlike Melitz's (2003) model where firms incur fixed domestic and export costs in each period of time and face an exogenous probability of default in each period, in the present model infinitely lived firms face once-and-for-all (instantaneous) fixed costs. These assumptions are not crucial for our results, but deliver more tractability and follow more closely the endogenous growth theory.

Inspection of (6) and (7) reveals that $\pi_d(\lambda)$ and $\pi_x(\lambda)$ increase monotonically in the product quality level λ. Consequently, v_d and v_x also increase monotonically in λ. Furthermore, Eqs. (6) and (7) imply that $\pi_d(1) = \pi_x(\tau) = 0$, which in turn ensure that $v_d(1) = v_x(\tau) = 0$. Thus, among the observed quality levels, there exist two cutoff quality levels λ_d and λ_x such that

$$v_d(\lambda_d) = f_d \phi_t, \tag{11}$$

$$v_x(\lambda_x) = f_x \phi_t. \tag{12}$$

These equations define the domestic and export cutoff quality levels λ_d and λ_x. We will later impose sufficient and reasonable conditions to guarantee that the domestic cutoff quality level is strictly less than the export cutoff quality level. Consequently, firms in each country are partitioned in three distinct groups. Firms that discover products with quality $\lambda < \lambda_d$ cannot profitably serve even the local market and exit. Firms that discover intermediate-quality products, such that $\lambda_d \leq \lambda < \lambda_x$, serve only the local (domestic) market. Consequently, only firms that discover products with a quality level $\lambda_x \leq \lambda$ serve profitably the foreign market.

The above considerations imply that the ex-post distribution of surviving product quality levels $\mu(\lambda)$ is the conditional distribution of $g(\lambda)$ on the interval $[\lambda_d, \infty)$

$$\mu(\lambda) = \begin{cases} \dfrac{g(\lambda)}{1 - G(\lambda_d)} & \text{if } \lambda > \lambda_d \\ 0 & \text{otherwise} \end{cases} \tag{13}$$

And the ex-ante probability that one of these successful firms will export is given by

$$\zeta_x = \frac{1-G(\lambda_x)}{1-G(\lambda_d)}. \tag{14}$$

The law of large numbers implies that ζ_x also equals the ex-post fraction of incumbent firms that export. Thus, the measure of firms that successfully export is $M_x = \zeta_x M_d$. Structural symmetry across the two countries implies that the mass of varieties available for consumption in each market is given by $M_c = M_d + M_x = (1+\zeta_x)M_d$. Based on these cutoff quality levels, the value of a surviving firm with product quality λ is given by

$$v(\lambda) = \begin{cases} v_d(\lambda) & \text{if } \lambda_d \leq \lambda \leq \lambda_x, \\ v_d(\lambda) + v_x(\lambda) & \text{if } \lambda_x \leq \lambda. \end{cases} \tag{15}$$

The model generates ex-post quality heterogeneity which delivers heterogeneous limit prices, heterogeneous quantities produced, heterogeneous markups, and heterogeneous discounted profits according to (15). However, firms are ex-ante identical and the incentives to create new varieties, which in turn fuel economic growth, are based on ex-ante calculations that involve a comparison of expected costs to expected discounted benefits. We assume that there is free-entry into the creation of new varieties which drives the expected discounted profits down to zero. Armed with the product survival probability density $\mu(\lambda)$, given by (13), we state the innovation free-entry condition as

$$[1-G(\lambda_d)]\left[\int_{\lambda_d}^{\infty} v(\lambda)\mu(\lambda)\, d\lambda - (f_d\phi + \zeta_x f_x\phi) \right] = f_e\phi, \tag{16}$$

where the time index has been omitted from functions and variables. If a firm draws a quality level higher than or equal to λ_d, it earns a discounted stream of profits $\bar{v} = \int_{\lambda_d}^{\infty} v(\lambda)\mu(\lambda)\, d\lambda$ minus the expected instantaneous costs of entering the local and foreign markets $f_d\phi + \zeta_x f_x\phi$; therefore, the expected discounted benefits of drawing a "winning variety" with quality level $\lambda \geq \lambda_d$ and serving the local, or both the local and foreign markets, is given by the left-hand-side of (16). The value of net expected discounted benefits of producing and marketing a product must be equal the costs of discovering the product, which is equal to the right-hand-side of (16).

Performing the integration and collecting terms one can rewrite the above free-entry condition (16) as

$$\int_{\lambda_d}^{\infty} v(\lambda)\mu(\lambda)\, d\lambda = \bar{f}\phi, \tag{17}$$

where the left-hand-side of (17) captures the expected discounted benefits of creating a surviving product and the right-hand-side equals the expected instantaneous fixed costs of discovering a new variety and successfully entering the local and foreign markets. The term $\bar{f}$ is the instantaneous component of these fixed costs and is defined by

$$\bar{f} = \frac{f_e}{1-G(\lambda_d)} + f_d + \zeta_x f_x. \tag{18}$$

The first term in (18) captures the expected costs to develop a successful variety f_e times the inverse of the probability of drawing a product with quality higher or equal to the production cutoff quality level λ_d, which equals the expected number of attempts at developing a surviving product. The second term represents the instantaneous cost of entering the local market. The third term is the expected instantaneous costs of becoming a successful exporter.

The level of expected instantaneous fixed costs defined in (18) constitutes a novel mechanism which transmits the effects of trade openness on long-run growth and steady-state welfare. It is obvious from the free-entry condition (17) that higher expected instantaneous fixed costs $\bar{f}$ require higher expected discounted profits and therefore reduce the incentives to innovate. In traditional growth models, where firms do not face ex-post fixed market entry costs, instantaneous fixed costs are exogenous (e.g., $\bar{f} = f_e$) and all discovered products are produced and sold in every market. In the presence of fixed domestic and foreign market entry costs, the ex-ante decision to innovate depends on the expected instantaneous costs $\bar{f}$ defined in (18). Because each firm is uncertain about the quality of its product, it has to take into account the probabilities that it will not be able to survive and exit, serve the domestic market only, and serve both the domestic and foreign markets. These probabilities depend on the domestic and export cutoff quality levels which are endogenous, and therefore are affected by trade openness. The level of expected instantaneous costs increases in the expected number of attempts at developing a successful product $[1-G(\lambda_d)]^{-1}$ and the probability ζ_x that a firm becomes an exporter and thus incurs additional foreign market entry costs.

2.4. Evolution of varieties

The economy-wide flow of new varieties is determined as follows. Denote with L_e the aggregate (economy-wide) amount of labor devoted to the discovery of new varieties. The discovery of a surviving single variety requires $(1/\phi\bar{f})dt$ labor costs, where dt denotes an infinitesimal interval of time. Therefore, the aggregate flow of varieties produced in each economy is given by $dM_d = (L_e/\phi\bar{f})dt$ which can be written as $\dot{M}_d = L_e/\phi\bar{f}$. Substituting the value of ϕ from (10) in this expression yields

the growth rate of varieties

$$\gamma \equiv \frac{\dot{M}_d}{M_d} = \frac{(1+\theta)}{\bar{f}}\frac{L_e}{L}. \tag{19}$$

According to Eq. (19), the growth rate of varieties increases in the strength of international knowledge spillovers θ and in the number of researchers devoted to innovative R&D L_e; and it decreases in the effective expected fixed cost per variety $\bar{f}$, defined by (18), and the R&D difficulty, measured by the level of population L.

A few remarks on the interpretation of (19) and its relation to the rest of the literature are in order. First, Melitz (2003) and Dinopoulos and Unel (2009) among many others abstract from long-run growth considerations and analyze a long-run equilibrium where the mass of varieties is constant over time (i.e., $\gamma = 0$). Second, Romer (1990) and Rivera-Batiz and Romer (1991) assume that the R&D difficulty is constant over time, i.e., $L_t = \bar{L}$ where $\bar{L}$ is a parameter. This restriction introduces the undesirable scale-effects property which renders the long-run growth of varieties infinite in the presence of positive population growth. Jones (1995a) convincingly shows that the scale-effects property of earlier endogenous growth models is inconsistent with the time-series evidence from several advanced countries. To remove the scale-effects property from our model, we assume that the development of a new variety depends on the average stock of knowledge $(1+\theta)M_d/L_t$, rather than the aggregate stock of knowledge $(1+\theta)M_d$. This specification is similar in spirit to that employed by Lucas (1988), where economic growth is based on human capital accumulation and each producer benefits from knowledge spillovers captured by the average human capital. In addition, this specification of R&D difficulty delivers fully endogenous growth and differs from semi-endogenous growth models. The latter assume that R&D difficulty is proportional to $[(1+\theta)M_d]^{1-\psi}$ with $\psi < 1$, and deliver exogenous long-run growth that depends only on parameter ψ and the rate of population growth n (Jones, 1995b; Segerstrom, 1998).

Although the evidence against earlier endogenous growth models is convincing, there is an ongoing debate on the empirical relevance of semi-endogenous versus fully endogenous growth models. On one hand, Ha and Howitt (2007) argue that long-run trends in R&D and total factor productivity growth in the US are more supportive of fully endogenous growth theory than semi-endogenous growth theory. On the other hand, Jones (1995a) observes that the growth rate of per-capita GDP in the US has been remarkably stable over time during the period 1880–1987. Gustafsson and Segerstrom (2010) argue that the evidence on the stability of per-capita GDP growth, despite several pro-growth policy changes such as post-war trade liberalization and globalization, does not support the main predictions of fully endogenous growth theory.[12]

2.5. Aggregation and labor markets

The next step of the analysis is to derive the full-employment condition in each country. The assumption of structural symmetry between the two countries suffices to analyze only the home economy. To this end, we first represent key variables in a more compact way. The aggregate quantity demanded at home consists of two parts: the demand for domestically produced goods and the demand for imported goods. The latter equals the demand for exported goods as well. Thus the aggregate quantity demanded by home consumers can be written as

$$Q = \int_{\lambda_d}^{\infty} q(\lambda)M_d\mu(\lambda)\,d\lambda + \int_{\lambda_x}^{\infty} q(\lambda)M_d\mu(\lambda)\,d\lambda = \frac{M_d}{M_c}\frac{EL}{\tilde{\lambda}_d} + \frac{M_x}{M_c}\frac{EL}{\tilde{\lambda}_x}, \tag{20}$$

where $\tilde{\lambda}_i$ ($i = d,x$) is given by

$$\tilde{\lambda}_i \equiv \tilde{\lambda}(\lambda_i) = \left[\frac{1}{1-G(\lambda_i)}\int_{\lambda_i}^{\infty} \lambda^{-1}g(\lambda)\,d\lambda\right]^{-1}. \tag{21}$$

Thus, $\tilde{\lambda}_d$ is the weighted harmonic mean of the quality levels of all produced goods and can be interpreted as the average domestic quality level. Similarly, $\tilde{\lambda}_x$ is the weighted harmonic mean of the quality levels of exported varieties and can be interpreted as the average export quality.

As also noted by Dinopoulos and Unel (2009), since λ_i is the minimum quality level of all products with $\lambda \in [\lambda_i,\infty)$, it must be lower than the average quality level of all products within this quality range, i.e., $\lambda_i < \tilde{\lambda}_i$. Moreover, (18) indicates that an increase in λ_i forces producers with low-quality products to exit the market. This in turn increases the corresponding average quality level, i.e., $\tilde{\lambda}_i$. These properties are summarized below.

$$\lambda_i < \tilde{\lambda}_i, \quad \partial\tilde{\lambda}_i/\partial\lambda_i > 0, \quad \text{for } i = d,x. \tag{22}$$

We assume that labor markets are perfectly competitive, and therefore labor is fully employed in each instant in time. The aggregate supply of labor is L, whereas the aggregate demand for labor comes from fixed costs associated with different R&D activities and manufacturing of final consumption goods. Labor devoted to effective R&D, which includes instantaneous fixed market entry costs, is given by $L_e = \gamma\bar{f}L/(1+\theta)$ (see Eq. (19)). The demand for labor employed in manufacturing is derived as follows. One unit of labor produces one unit of output. Consequently, each surviving firm serving its local market hires $q(\lambda)$

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[12] We also analyzed a semi-endogenous growth version of our paper and found that exposure to trade does not affect the long-run growth rate, but has an ambiguous level effect on welfare. These results are qualitatively similar to those in Gustafsson and Segerstrom (2010), and are available upon request.

workers; and each firm serving the export market hires $\tau q(\lambda)$ workers (in order to deliver $q(\lambda)$ units abroad), where $q(\lambda) = EL/\lambda M_c$ is the quantity demanded. Therefore the aggregate quantity of labor demanded in each country is given by

$$L_p = \int_{\lambda_d}^{\infty} q(\lambda) M_d \mu(\lambda)\, d\lambda + \int_{\lambda_x}^{\infty} \tau q(\lambda) M_d \mu(\lambda)\, d\lambda = \frac{M_d}{M_c}\frac{EL}{\tilde{\lambda}_d} + \tau \frac{M_x}{M_c}\frac{EL}{\tilde{\lambda}_x} = \frac{EL}{\tilde{\lambda}}, \tag{23}$$

where $\tilde{\lambda}$ is the (distance-adjusted) weighted average quality of all products competing in each market, and it is given by

$$\tilde{\lambda} = \left\{ \frac{1}{M_c}[M_d \tilde{\lambda}_d^{-1} + M_x(\tau^{-1}\tilde{\lambda}_x)^{-1}] \right\}^{-1} = [1 + \zeta_x][\tilde{\lambda}_d^{-1} + \zeta_x(\tau^{-1}\tilde{\lambda}_x)^{-1}]^{-1}, \tag{24}$$

where ζ_x, defined by (14), is the ex-post fraction of varieties exported (and imported). In view of (23), the full-employment of labor condition $L_e + L_p = L$ can be written as

$$\frac{\gamma \overline{f}}{1+\theta} + \frac{E}{\tilde{\lambda}} = 1, \tag{25}$$

where $\overline{f}$ and $\tilde{\lambda}$ are defined by (18) and (24), respectively.

The average global quality level $\tilde{\lambda}$ constitutes another mechanism that carries the effects of trade on long-run growth. One can interpret $\tilde{\lambda}$ as the effective quality level measured in units of labor of a representative firm which serves the home country. This firm produces M_d varieties at home, employing one unit of labor per unit of output, and M_x varieties in the foreign country, employing $\tau > 1$ units of labor per unit of output. Thus, for any given level of trade costs and per-capita consumption expenditure, an increase in the average global quality level allows this firm to charge a higher price, and therefore reduce the quantity produced and the demand for manufacturing labor. It is obvious from (25) that a ceteris-paribus increase in $\tilde{\lambda}$ lowers the fraction of labor devoted to manufacturing of final goods $L_p/L = E/\tilde{\lambda}$ and thus raises the fraction of labor engaged in R&D L_e/L. Consequently, for any level of per-capita consumption expenditure and expected instantaneous fixed costs, an increase (decline) in the average global quality level generates a pro-growth (anti-growth) effect. In traditional quality-ladders growth models a similar resource-reallocation effect operates through changes in per-capita consumption expenditure because the global quality level is an exogenous parameter which equals the size of innovations. In contrast, the present model delivers an endogenous average quality level which depends on the two cutoff quality levels and the level of trade costs.

2.6. Steady-state equilibrium

This section describes the basic properties of steady-state (balanced-growth) equilibrium, where all endogenous variables grow at constant, but not necessary equal, rates over time. We start by requiring that the steady-state variety growth rate $\gamma = \dot{M}_d/M_d$ must be constant over time. In addition, observe that the fraction $\zeta_x = [1 - G(\lambda_x)]/[1 - G(\lambda_d)]$, which is the share of exported varieties, must be constant over time. Otherwise the economy ends up with all varieties exported or no trade. These two requirements imply that the steady-state growth rates of exported and consumed varieties are constant over time, i.e., $\dot{M}_c/M_c = \dot{M}_x/M_x = \gamma$. They also imply that the following variables are constant over time: the two cutoff quality levels λ_d and λ_x; the average quality levels $\tilde{\lambda}_d, \tilde{\lambda}_d$, and $\tilde{\lambda}$; and the expected instantaneous fixed cost $\overline{f}$. Taking all these considerations into account, observe that the full employment condition (25) implies that per-capita expenditure must be constant over time.

Since the cutoff quality levels λ_d and λ_x are time invariant, one can derive the following steady-state expressions[13] for discounted profits earned by a surviving firm producing a product of quality λ:

$$v_d(\lambda) = \frac{\pi_d(\lambda)}{\rho - n} = \frac{(1 - \lambda^{-1})EL}{(\rho - n)M_c}, \tag{26}$$

$$v_x(\lambda) = \frac{\pi_x(\lambda)}{\rho - n} = \frac{(1 - \tau\lambda^{-1})EL}{(\rho - n)M_c}, \tag{27}$$

where the profit flows π_d and π_x, defined by (6) and (7) were substituted as well. Substituting (26) and (27) into the zero-profit conditions (11) and (12), respectively, and dividing the two resulting equations yields

$$\lambda_x = \frac{\tau}{1 - (1 - \lambda_d^{-1})f_x/f_d}. \tag{28}$$

Eq. (28) shows the exporting cutoff quality level λ_x as a function of the domestic cutoff quality level λ_d and the model's parameters. Several remarks are in order. First, the denominator of (28) must be non-negative, and therefore we must have that $\lambda_d \in (1, k)$, where $k = 1/[1 - f_d/f_x]$. Second, according to (28), λ_x is an increasing function of the domestic cutoff quality level λ_d the variable trade costs τ and the ratio of overhead fixed costs f_x/f_d. Finally, (28) indicates that when $f_x \geq f_d$ and $\tau > 1$, the export cutoff quality level λ_x is strictly greater than the domestic cutoff quality level λ_d.

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[13] Substituting (10) into (11) and (12), and differentiating the resulting expression with respect to time yields $\dot{v}_i/v_i = n - \gamma$. In addition, Eq. (4) implies $r_t = \rho - \gamma$, since per-capita expenditure is time invariant. Inserting these two expressions in the denominator of (9) yields (26) and (27).

The next step is to solve for the steady-state value of the domestic cutoff quality level. The innovation free-entry condition (17) can be written as

$$\frac{1}{1-G(\lambda_d)}\int_{\lambda_d}^{\infty} v_d(\lambda)g(\lambda)\,d\lambda + \frac{1}{1-G(\lambda_d)}\int_{\lambda_x}^{\infty} v_x(\lambda)g(\lambda)\,d\lambda = \overline{f}\phi, \tag{29}$$

and can further be expressed as[14]

$$f_d H(\lambda_d,1) + f_x H(\lambda_x,\tau) = f_e, \tag{30}$$

where $H(\lambda_i,\alpha)$ (for $i=d,x$ and $\alpha=1,\tau$, respectively) is defined as follows:

$$H(\lambda_i,\alpha) = [1-G(\lambda_i)]\left[\frac{1-\alpha\tilde{\lambda}_i^{-1}}{1-\alpha\lambda_i^{-1}} - 1\right]. \tag{31}$$

Eqs. (28) and (30) constitute a system of two equations in two unknowns, the cutoff quality levels λ_d and λ_x. The function $H(\lambda_i,\cdot)$ is strictly decreasing in λ_i.[15] In addition, λ_x is an increasing function of λ_d, and therefore these two equations yield a unique solution for (λ_d,λ_x). The following proposition summarizes these results.

Proposition 1. *Let $k=1/(1-f_d/f_x)$, and assume that $f_x \geq f_d > 0$. In the steady-state equilibrium, there exist unique and time-invariant domestic and export cutoff levels λ_d and λ_x which satisfy Eqs. (28) and (30) such that $\lambda_d > 1, \lambda_x > \tau$, and $\lambda_x > \lambda_d$.*

Having determined the steady-state values of domestic and export cutoff levels, one can easily determine the values of several endogenous variables. Eq. (14) pins down the time-invariant endogenous fraction of traded varieties ζ_x. Another variable of interest is the market profitability. Using the profit flows (6) and (7), one can write the aggregate profits of all surviving firms in each country as

$$\Pi = \int_{\lambda_d}^{\infty} \pi_d(\lambda)M_d\mu(\lambda)\,d\lambda + \int_{\lambda_x}^{\infty} \pi_x(\lambda)M_d\mu(\lambda)\,d\lambda = (1-\tilde{\lambda}^{-1})EL, \tag{32}$$

where $\tilde{\lambda}$ is given by (24). It follows from (32) that market profitability can be measured by the average markup $1-\tilde{\lambda}^{-1}$, which is *time-invariant* and increasing in $\tilde{\lambda}$.[16]

In Melitz (2003) and Dinopoulos and Unel (2009), the absence of economic growth and consumer savings implies that, in the steady-state equilibrium, aggregate profits finance R&D investment, and therefore, per-capita expenditure equals the wage of labor, i.e., $E=w=1$. In the present model, consumers save, the market interest rate depends on endogenous growth $(r=\rho-\gamma)$, and therefore per-capita expenditure can be written as[17]

$$E = \frac{(\rho-n)\overline{f}}{(1+\theta)(1-\tilde{\lambda}^{-1})}. \tag{33}$$

Per-capita consumption expenditure E increases in the effective discount rate $\rho-n$ and the expected innovation costs $\overline{f}$; and decreases in the intensity of international knowledge spillovers θ and market profitability measured by the average markup $1-\tilde{\lambda}^{-1}$.

3. Global growth and trade

Substituting (33) into the full employment condition (25) delivers the following expression for long-run growth:

$$\gamma = \frac{1+\theta}{\overline{f}} - \frac{\rho-n}{\tilde{\lambda}-1}. \tag{34}$$

This equation identifies four distinct determinants of long-run growth. First, growth increases in the intensity of international knowledge spillovers θ. For instance, a move from autarky to restricted case implies that the intensity of knowledge spillovers increases from zero to a positive value θ; and in the case $\theta=\zeta_x$, trade liberalization increases the measure of traded varieties and the intensity of international knowledge spillovers. In both cases long-run growth accelerates due to the higher productivity of R&D researchers. Second, growth decreases in the effective discount rate $\rho-n > 0$, because a higher discount rate decreases the benefits of variety creation by lowering the level of expected discounted profits. Third, an increase in the expected instantaneous fixed costs $\overline{f}$ reduces growth by increasing the costs of variety creation. Finally, for any given levels of

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[14] Substituting (26) and (27) (evaluated at the cutoff quality levels) into (11) and (12), respectively, yields $EL/M_c = (\rho-n)f_d\phi/[1-\lambda_d^{-1}]$ and $EL/M_c = (\rho-n)f_x\phi/[1-\tau\lambda_x^{-1}]$. Inserting these expressions back into (26) and (27), and the resulting expressions into (29), yields (30).

[15] See Appendix for details on the properties of $H(\lambda,\alpha)$.

[16] To see that the average markup is $1-\tilde{\lambda}^{-1}$, notice that each incumbent firm's domestic markup (measured by the price marginal-cost margin) is given by $(p-1)/p = 1-\lambda^{-1}$. Integrating over all such firms yields that the average domestic markup (denoted by pcm_d) is equal to $1-\tilde{\lambda}_d^{-1}$. Since an exporter incurs a marginal cost τ, it earns a price marginal-cost margin $(p-\tau)/p = 1-\tau\lambda^{-1}$. Hence, the average export markup (denoted by pcm_x) is equal to $pcm_x = 1-\tau\tilde{\lambda}_x^{-1}$. It follows that the average markup is $[M_d pcm_d + M_x pcm_x]/[M_d + M_x] = 1-\tilde{\lambda}^{-1}$.

[17] The free-entry innovation condition (17) implies that aggregate discounted profits must equal to aggregate instantaneous innovation costs: $\Pi/(\rho-n) = M_d\overline{f}\phi$. Substituting (32) and (10) into this equation yields (33).

$\overline{f}, \theta$, and E, a rise in the average global quality level $\tilde{\lambda}$ raises long-run growth: an increase in $\tilde{\lambda}$ increases per-capita resources devoted to R&D by lowering per-capita labor allocated in manufacturing $E/\tilde{\lambda}$.

We now analyze the long-run growth effects of trade. To this end, we start with addressing the general-equilibrium effects of a move from autarky to (restricted or free) trade. As the level of trade costs approaches infinity (i.e., $\tau \to \infty$), the domestic cutoff quality level approaches its closed-economy value λ_d^A and its value is determined by $f_d H(\lambda_d^A, 1) = f_e$. A comparison between $f_d H(\lambda_d^A, 1) = f_e$ and Eq. (30) reveals that the autarkic cutoff quality level λ_d^A is strictly less than the open-economy domestic cutoff quality level λ_d. In other words, trade increases the average domestic quality level by forcing the firms producing low-quality products to exit. This is the pro-competitive effect of trade and the economic intuition behind this result is the following. Exposure to trade provides new profit opportunities to exporting firms that manufacture high-quality products. These firms demand more labor in order to produce more units and serve the foreign market. The increased demand for labor induces a reallocation of resources from production of lower-quality products towards production of high-quality products. To see this note that any given aggregate supply of labor can sustain more higher-quality products, because for any level of expenditure, a firm with a higher-quality product charges a higher price, produces less output, and employs less labor than a firm with a lower-quality product (see Eq. (5)). This reallocation of labor reduces the demand for each product as the aggregate expenditure EL is spread among more varieties available for consumption. Thus, the net discounted profits of the firm with product quality level λ_d^A become negative. As a result, a higher cutoff quality level (higher price) is required to restore the break-even condition (11). A higher domestic cutoff quality level corresponds to a higher average domestic quality level $\tilde{\lambda}_d^A$.

Next, consider the effect of a move from autarky to restricted trade on the average global quality level $\tilde{\lambda}$. Setting $\zeta_x = 0$ in Eq. (24) yields the average autarkic quality level $\tilde{\lambda} = \tilde{\lambda}_d^A$. Inspection of Eq. (24) indicates that the ranking between the average global quality level $\tilde{\lambda}$ and average autarkic quality level $\tilde{\lambda}_d^A$ is ambiguous because it depends on the level of variable trade costs τ and the fraction of traded varieties ζ_x. A move from autarky to trade increases the component of the average global quality level that depends on the average domestic quality level but reduces the trade-related component of global quality by introducing trade costs. Since the average global markup is an increasing function of $\tilde{\lambda}$, a move from autarky to trade has an ambiguous impact on the average markup.[18]

Setting $\zeta_x = 0$, Eqs. (18) and (24) deliver $\overline{f}^A = f_e + f_p/[1 - G(\lambda_d^A)]$. As a result, the closed-economy growth rate is given by

$$\gamma^A = \frac{1}{\overline{f}^A} - \frac{\rho - n}{\tilde{\lambda}_d^A - 1}. \tag{35}$$

Subtracting this equation from (34) yields

$$\gamma - \gamma^A = \left[\frac{1+\theta}{\overline{f}} - \frac{1}{\overline{f}^A} \right] - \left[\frac{1}{\tilde{\lambda} - 1} - \frac{1}{\tilde{\lambda}_d^A - 1} \right] (\rho - n). \tag{36}$$

Because the expected instantaneous fixed costs of variety creation under trade exceed the corresponding costs under autarky (that is, $\overline{f} > \overline{f}^A$), the sign of the first term on the right-hand-side of (36) is ambiguous. In addition, since exposure to trade has an ambiguous effect on the global average quality level, the sign of the second term on the right-hand-side is also ambiguous. Thus, a move from autarky to trade has an ambiguous impact on long-run growth.

The model is also well suited to address the growth effects of further exposure to trade (i.e., a reduction in τ or f_x). Indeed, Eqs. (28) and (30) have identical forms with Eqs. (9) and (17) in Dinopoulos and Unel (2009) who demonstrate that a reduction in trade costs increases the domestic cutoff quality level λ_d, decreases the export cutoff quality level λ_x, and consequently, increases the share of exported varieties ζ_x. Thus, further exposure to trade has an ambiguous effect on the average global quality level $\tilde{\lambda}$ (see (24)).[19] Eq. (18) indicates that a reduction in variable trade costs τ increases the expected instantaneous costs $\overline{f}$. However, a reduction in foreign market entry costs f_x has an ambiguous effect on the expected instantaneous costs $\overline{f}$, because while $f_e/[1 - G(\lambda_d)]$ and ζ_x increase, f_x decreases.

Eq. (34) reveals that long-run growth increases in the intensity of trade-related knowledge spillovers θ and decreases in the effective discount rate $\rho - n$.[20] Combined with Proposition 1 and the above discussion, we can now state the effects of trade openness on long-run growth.

Proposition 2. *A move from autarky to (restricted) trade or further exposure to trade, captured by a reduction in variable trade costs ($\tau \downarrow$) or a reduction in foreign market entry costs ($f_x \downarrow$), has an ambiguous effect on the average global quality $\tilde{\lambda}$ and long-run growth rate γ. Furthermore, long-run growth γ increases in the intensity of trade-related knowledge spillovers θ, and decreases in the effective discount rate $\rho - n$.*

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[18] Results in Harrison (1994) support this finding. Using plant-level data from Cote d'Ivoire, she finds that markups, measured as profits over sales, increased in five out of nine sectors and fell in the rest following the 1985 trade liberalization reform (see Table 5 in Harrison, 1994).

[19] Using (22) together with $d\lambda_d/d\tau < 0, d\lambda_d/df_x < 0, d\lambda_x/d\tau > 0$, and $d\lambda_x/d\tau > 0$ implies that $d\tilde{\lambda}_d^{-1}/d\tau > 0, d\tilde{\lambda}_d^{-1}/df_x > 0, d[\zeta_x \tilde{\lambda}_x^{-1}]/d\tau < 0$ and $d[\zeta_x \tilde{\lambda}_x^{-1}]/df_x < 0$. Thus, it follows from Eq. (24) that the signs of $d\tilde{\lambda}/d\tau$ and $d\tilde{\lambda}/df_x$ are ambiguous.

[20] The equilibrium values of λ_d, λ_x, and $\overline{f}$ are independent of θ and $\rho - n$.

3.1. The anatomy of growth ambiguities

Proposition 2 reveals the complex relationship between trade openness and long-run growth. The complexity arises from the presence of trade costs and the endogenous distribution of quality levels. This subsection takes a closer look at the sources of the ambiguity between trade and growth by analyzing several special cases. Each of these cases is based on sensible parameter restrictions in an effort to resolve the ambiguous relationship between trade and growth and unveil the relevant economic intuition.

Following the literature on trade with heterogeneous firms, all special cases assume that the quality levels are drawn from a Pareto distribution with shape parameter κ:

$$G(\lambda) = 1 - \lambda^{-\kappa}, \tag{37}$$

where the lower bound of this distribution is normalized to one without loss of generality. The Pareto distribution has a finite variance when $\kappa > 2$, and we assume this condition is satisfied. This distribution function has a nice property that $\tilde{\lambda}_i / \lambda_i = (\kappa + 1)/\kappa$, for $i = d,x$. In other words, the average quality level for domestically produced (exported) products is proportional and greater than the domestic (export) cutoff quality level.

Case 1: $\underline{f_e + f_d} \geq f_x \geq f_d; \theta = \zeta_x$. We begin by analyzing the growth effects of a move from autarky to (restricted) trade under two additional assumptions: the domestic market entry cost is less than the foreign market entry cost, which in turn cannot exceed the sum of fixed R&D and domestic market entry costs; and the intensity of trade-related knowledge spillovers equals the share of traded varieties. The latter assumption has been adopted by Coe and Helpman (1995) and Baldwin and Robert-Nicoud (2008) among others. Using (37), the average global quality $\tilde{\lambda}$ is given by

$$\tilde{\lambda} = \left\{ \frac{1}{1+\zeta_x}(\tilde{\lambda}_d^{-1} + \tau\zeta_x\tilde{\lambda}_x^{-1}) \right\}^{-1} = \frac{(1+\zeta_x)\tilde{\lambda}_d}{1+\zeta_x(\tau\lambda_x^{-1}/\lambda_d^{-1})} \geq \tilde{\lambda}_d, \tag{38}$$

where the last inequality follows from (28) under the assumption $f_x \geq f_d$. Since $\lambda_d > \lambda_d^A$ and $\tilde{\lambda} \geq \tilde{\lambda}_d$, it follows that the sign of the bracket in front of term $(\rho - n)$ in Eq. (36) is negative. In words, a move from autarky to trade results in a higher average quality level and a reallocation of per-capita labor from manufacturing of final-consumption goods to R&D investment. Thus, if $(1+\theta)/\bar{f} > 1/\bar{f}^A$, then a move from autarky to trade is pro-growth. This last condition further implies that

$$1 + \theta > \frac{\bar{f}}{\bar{f}^A} \iff 1 + \theta > \frac{f_e\lambda_d^\kappa + f_d + \zeta_x f_x}{f_e(\lambda_d^A)^\kappa + f_d} > 1 + \zeta_x \left[\frac{f_x}{f_e(\lambda_d^A)^\kappa + f_d} \right],$$

where the second inequality follows from $\lambda_d > \lambda_d^A$. Assumptions $\theta = \zeta_x$ and $f_e + f_d \geq f_x$ (recall that $\lambda_d^A > 1$ and $\kappa > 1$) guarantee that the above inequality holds and therefore the first term on the right-hand-side of Eq. (36) is positive.[21]

Thus, under these restrictions, a move from autarky to restricted (or free trade) accelerates long-run growth. We offer the following economic intuition behind this novel result. First, consider the effects of trade openness on the average global quality level. On the one hand, trade expands the size of the market and intensifies the resource competition among firms. As a result, inefficient firms producing low-quality products exit the market. This pro-competitive trade effect increases the average global quality level and raises long-run growth. On the other hand, the presence of variable trade costs dampens the pro-growth impact of trade. When $f_x > f_d$, the pro-competitive effect dominates the trade-cost effect and increases the average global quality. Notice that if $f_x = f_d$ in Eq. (28), then $\tau\lambda_d/\lambda_x = 1$ and Eq. (38) yields $\tilde{\lambda} = \tilde{\lambda}_d$. This means that the two aforementioned effects balance each other and a move from autarky to trade does not affect the average global quality level.

Second, consider the effect of trade on instantaneous fixed costs and on trade-related knowledge spillovers. Again, a move from autarky to trade generates pro-growth and anti-growth tensions. The former is related to the presence of knowledge spillovers whose higher intensity increases the productivity of R&D workers and accelerates growth. The latter is associated with the introduction of foreign market entry fixed costs that absorb resources from R&D and dampen the pro-growth effect of trade. Assumptions $\theta = \zeta_x$ and $f_e + f_d \geq f_x$ guarantee that the beneficial effects of knowledge spillovers exceed the resource cost generated by higher instantaneous fixed costs. Thus a move from autarky to trade increases long-run growth.

We now investigate the nature of the ambiguity associated with *further* exposure to trade on growth captured by a reduction in trade costs τ or a reduction in fixed export costs f_x. We maintain the assumption that quality levels are drawn from the Pareto distribution and analyze the following two special cases.

Case 2: $f_x = f_d = f; \theta = \zeta_x$. This case highlights the pro-growth effects of a marginal reduction in variable trade costs τ, under the assumption that each firm faces identical domestic and foreign market entry costs and the assumption that the intensity of trade-related knowledge spillovers equals the endogenous share of traded varieties. Eq. (28) implies that $\lambda_x = \tau\lambda_d$. Inserting this expression in $\tilde{\lambda}_i / \lambda_i = (1+\kappa)/\kappa$ yields $\tilde{\lambda}_x = \tau\tilde{\lambda}_d$. Furthermore, Eqs. (14) and (37) generate $\zeta_x = \tau^{-\kappa}$. This means that a reduction in variable trade costs increases the intensity of trade-related knowledge spillovers. In addition, the average global quality $\tilde{\lambda}$ is given by

$$\tilde{\lambda} = \tilde{\lambda}_d = (1+\kappa)\lambda_d/\kappa.$$

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[21] This result still holds even if we assume that θ is proportional to the trade volume (normalized by the total output) as in Unel (2010). To see this, notice that $\theta = (\text{Import} + \text{Export})/\text{Output} = 2R_x/R = 2\zeta_x/(1+\zeta_x) > \zeta_x$, where R_x is the revenue obtained from the sales in foreign market.

Eq. (30) implies that

$$(1+\tau^{-\kappa})H(\lambda_d,1) = f_e/f \Longrightarrow \lambda_d^{\kappa}(\lambda_d-1) = \frac{(1+\tau^{-\kappa})f}{(1+\kappa)f_e}. \tag{39}$$

Inspection of Eq. (39) implies that a reduction in trade cost τ increases the domestic cutoff quality level λ_d.

The analysis so far indicates that a marginal reduction in variable trade costs increases the intensity of knowledge spillovers and the average global quality level. Both effects are beneficial to long-run growth: the former increases directly the productivity of R&D researchers engaged in discovering new varieties; and the latter shifts resources from manufacturing to R&D activities. The expected instantaneous fixed cost is given by

$$\overline{f} = f_e\lambda_d^{\kappa}+f(1+\tau^{-\kappa}) = f(1+\tau^{-\kappa})\left[1+\frac{1}{(1+\kappa)(\lambda_d-1)}\right], \tag{40}$$

where the second equality follows from (39). Substituting $\theta = \zeta_x$ together with $\tilde{\lambda} = (1+\kappa)\lambda_d/\kappa$ and $\overline{f}$ from (40) into (34) yields

$$\gamma = \frac{1+\zeta_x}{\overline{f}}-\frac{\rho-n}{\tilde{\lambda}-1} = \frac{1}{f\left[1+\frac{1}{(\kappa+1)(\lambda_d-1)}\right]}-\frac{\rho-n}{\frac{\kappa}{1+\kappa}\lambda_d-1},$$

where λ_d is determined by (39). Thus, trade liberalization, measured by a reduction in variable trade costs τ, accelerates long-run growth. Observe also that, in this case, an R&D subsidy that lowers the fixed costs of variety creation f_e increases the domestic cutoff quality level and accelerates long-run economic growth. Consequently when firms face identical (or very similar) domestic market and foreign market entry costs, lower variable trade costs and R&D subsidies stimulate long-run growth.

Case 3: $f_d = 0$. The assumption that firms do not face any domestic market entry costs allows us to explore the growth effects of a reduction in foreign market entry costs f_x. We maintain the assumption that the intensity of trade-related knowledge spillovers is exogenous and modeled by parameter θ. The zero-profit condition (11) implies that the domestic quality cutoff level is equal to unity ($\lambda_d = 1$), and therefore the average domestic quality level is given by $\tilde{\lambda}_d = (1+\kappa)/\kappa$. Thus both λ_d and $\tilde{\lambda}_d$ are independent of foreign market entry costs f_x. The export cutoff quality level is still given by Eq. (27). The expected instantaneous costs equal $\overline{f} = f_e+\zeta_x f_x$ and the share of traded varieties is $\zeta_x = \lambda_x^{-\kappa}$. Using (27) in the free-entry condition (17) yields

$$\frac{1+\tau\lambda_x^{-1-\kappa}}{1-\tau\lambda_x^{-1}} = \frac{(1+\kappa)f_e}{f_x}, \tag{41}$$

which determines the unique equilibrium value of the export quality cutoff level λ_x. Differentiating this equation with respect to f_x and τ yields that further exposure to trade decreases the export cutoff level λ_x, i.e., $d\lambda_x/df_x > 0$ and $d\lambda_x/d\tau > 0$.

The assumption that the quality levels are drawn from a Pareto distribution implies that $\zeta_x = \lambda_x^{-\kappa}$. Thus a reduction in f_x increases the share of traded varieties.[22] What about the effect of f_x on $\overline{f}$? Differentiating $\overline{f} = f_e+\zeta_x f_x = f_e+\lambda_x^{-\kappa}f_x$ with respect to f_x yields

$$\frac{d\overline{f}}{df_x} = \lambda_x^{-\kappa}(1-\kappa\varepsilon), \quad \varepsilon \equiv \frac{f_x}{\lambda_x}\frac{d\lambda_x}{df_x} = \frac{f_x(\tau^{-1}\lambda_x+\lambda_x^{-\kappa})}{(1+\kappa)(f_e+f_x\lambda_x^{-\kappa})}, \tag{42}$$

where ε is the elasticity of the export quality cutoff level with respect to the fixed cost f_x and $d\lambda_x/df_x > 0$ is obtained from (41). Note that $\varepsilon > 0$ because $d\lambda_x/df_x > 0$.

In addition to the change in expected instantaneous fixed costs, a decline in f_x changes the average global quality level $\tilde{\lambda}$. The latter is given by

$$\tilde{\lambda} = \frac{1+\kappa}{\kappa}\left[\frac{1+\lambda_x^{-\kappa}}{1+\tau\lambda_x^{-1-\kappa}}\right].$$

Differentiating this equation with respect to f_x yields the following expression:

$$\frac{1}{\tilde{\lambda}}\frac{d\tilde{\lambda}}{df_x} = \lambda_x^{-1-\kappa}\left[\frac{(1+\kappa)\tau\lambda_x^{-1}+\tau\lambda_x^{-1-\kappa}-\kappa}{(1+\lambda_x^{-\kappa})(1+\tau\lambda_x^{-1-\kappa})}\right]\frac{d\lambda_x}{df_x}. \tag{43}$$

A decline in foreign market entry costs affects long-run growth through its impact on the expected instantaneous fixed costs, which is captured by (42), and its effect on the average global quality level, which is captured by (43). Sufficiently high values of trade costs and low values of the right-hand-side of (41) imply a high value of the export cutoff quality level and $\kappa\varepsilon > 1$. Thus, a reduction in fixed export costs increases the expected instantaneous costs, i.e., $d\overline{f}/df_x < 0$. In addition, using (41) ensures that the numerator of the expression in the bracket of (43) is positive when $f_e > f_x$. Since $d\lambda_x/df_x > 0$, it follows that a reduction in f_x decreases the average quality $\tilde{\lambda}$, and hence shifts resources from R&D activities to manufacturing of final goods. Consequently, trade liberalization that takes the form of a marginal reduction in foreign market entry costs decreases global long-run growth.

Starting at an initial high-level of protection, a reduction in fixed export costs causes a large decline in the export cutoff quality level. This in turn increases the level of expected instantaneous fixed costs of variety creation and reduces the average

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[22] The qualitative results in this section remain mostly the same, if instead one considers a reduction in trade costs τ. For the sake of brevity, we do not report this straightforward exercise here, but the results are available upon request.

global quality level. Both effects reduce long-run growth: the former reduces the productivity of R&D workers and the latter shifts resources from R&D investment to manufacturing of varieties. Of course, as in the previous case, the assumption that the intensity of trade-related spillovers is endogenous and increases with trade liberalization measures introduces a pro-growth effect that, in principle, can reverse this result.

Finally, consider the very special case where in addition to $f_d = 0$, each firm faces identical R&D and foreign market entry costs, i.e., $f_e = f_x = f$. In this case, a simultaneous reduction in both components of instantaneous fixed costs accelerates long-run growth. To see this, observe that Eq. (41) implies that λ_x (and therefore ζ_x and $\tilde{\lambda}$) are independent of f. Therefore, a reduction in f reduces the level of expected instantaneous fixed costs $\overline{f} = f_e + \zeta_x f_x = f(1 + \lambda_x^{-\kappa})$ without affecting the average global quality level. Lower instantaneous fixed costs deliver higher long-run growth.

3.2. Related studies

The result that exposure to trade has an ambiguous effect on long-run growth is similar to that in Baldwin and Robert-Nicoud (2008) and Unel (2010). However, there are two important differences between our result and theirs. First, long-run growth in their model is subject to the scale-effects critique of Jones (1995a). Second, in their model the ambiguous relationship between trade liberalization and growth stems solely from the effect of trade on the intensity of trade-related spillovers. In the absence of the latter (i.e., if $\theta = 0$), these models predict that trade openness unambiguously reduces long-run growth. In contrast, our model highlights that, even in the absence of technology diffusion through trade, exposure to trade has an ambiguous effect on long-run growth. This indeterminacy is generated by the presence of limit-price strategies, Cobb–Douglas preferences, and an endogenous distribution of quality levels and markups.

The ambiguous long-run growth effect of trade liberalization is absent from the semi-endogenous growth model with heterogeneous firms proposed by Gustafsson and Segerstrom (2010), where long-run growth depends positively only on the rate of population growth and a parameter measuring the intensity of intertemporal knowledge spillovers. Trade liberalization does not affect long-run productivity growth in their model. In the short run, the growth effects of trade liberalization depend on the size of intertemporal knowledge spillovers. When the size of these spillovers is weak (strong) trade liberalization promotes (retards) productivity growth and steady-state welfare. Our model predicts that a higher rate of population growth promotes long-run growth as in Gustafsson and Segerstrom (2010): an increase in the rate of population growth lowers the effective discount rate $\rho - n$, reduces per-capita consumption expenditure and shifts resources from manufacturing towards R&D investment. However, unlike Gustafsson and Segerstrom (2010), our model allows us to analyze the long-run effects of trade openness on economic growth. Trade liberalization has an ambiguous effect on long-run growth which depends on a variety of channels (as opposed to only the size of intertemporal knowledge spillovers) that are not present in their model. Ceteris paribus, our model predicts a positive relationship between long-run growth and the size of intertemporal knowledge spillovers.

Finally, our results complement those in Haruyama and Zhao (2008) who develop first generation and semi-endogenous quality ladders growth models with heterogeneous firms. In their model endogenous growth is based on continual quality improvements (as opposed to variety expansion) and productivity heterogeneity. Firms employ limit-price strategies that generate endogenous markups as in our model. They find that trade liberalization increases average markups and the share of labor used in R&D. According to their R&D specification that delivers endogenous growth, trade liberalization unambiguously raises long-run growth. However, when the model is modified to remove the scale-effect property, they find that the rate of technical progress is independent of trade liberalization—the long-run growth rate in their semi endogenous growth model is driven by the rate of population growth as in Gustafsson and Segerstrom (2010). In contrast, the present paper present a fully endogenous growth model in which the trade openness can raise or reduce the global quality level and the instantaneous fixed R&D cost. This in turn delivers an ambiguous effect on the long-run growth rate.

4. Welfare analysis

We now analyze the welfare properties of the model. We would like to address two important questions. First, what is the dynamic effect of trade liberalization on consumer welfare? Second, is the market resource allocation socially optimal? Following the relevant literature, we measure welfare by the instantaneous utility function of the representative consumer. Since $p(\lambda) = \lambda$, Eq. (3) implies that the corresponding per-capita demand is given by $\lambda q(\lambda)/L = E/M_c$. Inserting this expression into the utility function defined by Eq. (2) and performing the integration yields

$$\ln u = M_c \ln(E). \tag{44}$$

Observe that utility of a typical consumer depends positively on the mass of varieties consumed M_c and on the per-capita expenditure E.[23] Since in the steady-state equilibrium E_t is time-invariant, Eq. (44) implies that the instantaneous utility $\ln u$ grows at the endogenous growth rate γ. This, combined with Propositions 2, yields the following results.

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[23] We can now derive a sufficient condition which guarantees that the consumer consumes all available varieties. In principle, each consumer chooses $q(\omega)$ and M to maximize (2) subject to the budget constraint. The first order condition with respect to M yields $\ln[M_c \lambda(M)q(M)/L] \geq 0$, which holds with equality if $M < M_c$. Using $p(M) = \lambda(M)$ and (3) in this condition yields $\ln E \geq 0$. Thus to ensure that $M = M_c$, we must have that $E > 1$. Using $v_d(\lambda_d)/\overline{v} = \pi(\lambda_d)/\overline{\pi} = f_d/\overline{f}$ implies that $(1 + \zeta_x)f_d/(1 - \lambda_d^{-1}) = \overline{f}/(1 - \tilde{\lambda}^{-1})$. Substituting this into (33) yields $E = [(\rho - n)(1 + \zeta_x)f_d]/[(1 + \theta)(1 - \lambda_d^{-1})]$. Since $\lambda_d \in$

Proposition 3. *A reduction in variable trade costs ($\tau\downarrow$) or foreign market entry costs ($f_x\downarrow$) has an ambiguous effect on long-run welfare growth, whereas an increase in the intensity of trade-related knowledge spillovers raises long-run welfare growth.*

Given that long-run welfare growth rate is given by γ, the conditions that we derived in Section 3.1 also resolve the ambiguous effect of trade liberalization on long-run welfare *growth*. Substituting $M_c = (1+\zeta_x)M_d = (1+\zeta_x)M_0 e^{\gamma t}$ into (44), and then using the final expression in the intertemporal utility function (1) yields the life-time welfare of the representative household:

$$W = \left[\frac{(1+\zeta_x)M_0}{\rho-n-\gamma}\right]\ln E = \left[\frac{(1+\zeta_x)M_0}{\rho-n-\gamma}\right]\ln\left[\frac{(\rho-n)\overline{f}}{(1+\theta)(1-\tilde{\lambda}^{-1})}\right],$$

where the second equality follow from (33). Note that there is a tension between the term in the first bracket and the per-capita expenditure E: pro-growth trade liberalization measures have a negative impact on the per-capita expenditure E. The overall welfare effect is ambiguous.

However, our quantitative analysis, which is based on the special cases discussed in Section 3.1, suggests that further exposure to trade through a reduction in trade costs τ is welfare improving. Fig. 1a shows the effects of a reduction in trade costs τ on welfare W under the restriction $f_d=f_x=f$, which corresponds to Case 2.[24]

Fig. 1b shows the effects of a reduction in trade costs τ on welfare W under the condition $f_d=0$, which corresponds to Case 3. This figure illustrates the results under three different specifications: $f_x=0.1f_e$, $f_x=0.9f_e$, and $f_x=1.1f_e$.[25] There are three novel remarks associated with Fig. 1b. First, under each specification, a reduction in trade costs τ is welfare improving. Second, the relationship between welfare W and foreign market entry costs f_x is not monotonic. Finally, for any given τ, a reduction in f_x is welfare improving if f_x is close to f_e. Therefore, although in principle trade liberalization has an ambiguous effect of steady-state global welfare, the conditions under which the trade-growth ambiguity is resolved imply that trade liberalization is welfare improving.

We finish the welfare analysis by establishing that the market cutoff quality level, per-capita expenditure, and growth rate are socially suboptimal. For the sake of brevity, we only consider the closed economy case. In this case, number of products consumed will be the same as the number of products produced, i.e., $M_c=M_d=M$. The planner maximizes the following intertemporal utility function

$$U = \int_0^\infty e^{-(\rho-n)t}M(t)\ln[E(t)]\,dt, \tag{45}$$

subject to the resource constraint which reflects the full-employment of labor condition. Before going further, it is important to emphasize that we must have $\ln[E(t)] > 0$ (or $E > 1$); otherwise, consuming all available products will not be an optimal decision.

The full employment condition (25) implies that total labor used in the R&D process is given by $L_e = L - \tilde{\lambda}_d^{-1}EL$, where $\tilde{\lambda} = \tilde{\lambda}_d$. Inserting this into (19) delivers

$$\dot{M} = (1-\tilde{\lambda}_d^{-1}E)M/\overline{f}, \tag{46}$$

where $\overline{f} \equiv f_e/[1-G(\lambda_d)]+f_d$.

In the steady-state equilibrium, E and λ_p are time-invariant and the socially optimum values E^S and λ_d^S satisfy the following system of equations (see Appendix for details):

$$f_d H(\lambda_d,E) = f_e, \tag{47}$$

$$1-\tilde{\lambda}_d^{-1}E(1-\ln E) = (\rho-n)\overline{f}, \tag{48}$$

where $H(\lambda_d,E)$ is defined by (31) and the requirement that the denominator $1-\lambda_d^{-1}E$ in $H(\lambda_d,E)$ must be positive implies that $\lambda_d > E$. Furthermore, $H(\lambda_d,E)$ decreases in λ_d and increases in E.[26]

Eqs. (47) and (48) define two curves in (λ_d,E) space (not shown for brevity of exposition). The slope of the curve defined by (47) is positive, while the slope of (48) is indeterminate.[27] Consequently, these curves may intersect each other more than once, and hence, might give rise to multiple socially optimum cutoff quality levels.

(*footnote continued*)

(1,k) with $k=1/(1-f_d/f_x)$, it follows that $E > [(\rho-n)(1+\zeta_x)f_d]/[(1+\theta)(1-k^{-1})] = (\rho-n)(1+\zeta_x)f_x/(1+\theta)$. Finally, using $\theta \in [0,1]$ and $\zeta_x \in [0,1]$ implies that $E > (\rho-n)(1+\zeta_x)f_x/(1+\theta) > (\rho-n)f_x/2$. Thus, $f_x > 2/(\rho-n)$ ensures that $E > 1$.

To derive the sufficiency condition when $f_x=0$, we directly use $E = [(\rho-n)(1+\zeta_x)f_d]/[(1+\theta)(1-\lambda_d^{-1})]$. Since $\theta \in [0,1], \zeta_x \in [0,1]$, and $\lambda_d > 1$, it follows that $E > (\rho-n)f_d/2$. In this case, $f_d > 2/(\rho-n)$ guarantees that $E > 1$. Thus, the principle of non-satiation holds under the sufficient condition $Max(f_d,f_x) > 2/(\rho-n)$.

[24] In plotting this graph, following Dinopoulos and Segerstrom (2007), we assume that $\rho = 0.07$ and $n=0.014$ so that $\rho-n = 0.056$; and $\theta = \zeta_x$ as in Baldwin and Robert-Nicoud (2008). We further set $M_0=1$, $k=3$, $f_e=10$, and $f_d=1$ (results are robust to alternative parameter values).

[25] In this exercise, we set $\theta = \zeta_x, f_e = 20$, and $k=4$.

[26] $\partial H/\partial E = [1-G(\lambda_d)](\lambda_d^{-1}-\tilde{\lambda}_d^{-1})/(1-\lambda_d^{-1}E)^2 > 0$.

[27] Totally differentiating (47) yields $dE/d\lambda_d = \{1+[1-G(\lambda_d)f_d/f_e]\}(E/\lambda_d)^2 > 0$. On the other hand, totally differentiating (48) yields $dE/d\lambda_d = \mu(\lambda_d)\tilde{\lambda}_d\{(\rho-n)f_e/[1-G(\lambda_d)]-(\lambda_d^{-1}-\tilde{\lambda}_d^{-1})E(1-\ln E)\}/\ln E$. Notice that for $\ln E \geq 1$, the slope is positive.
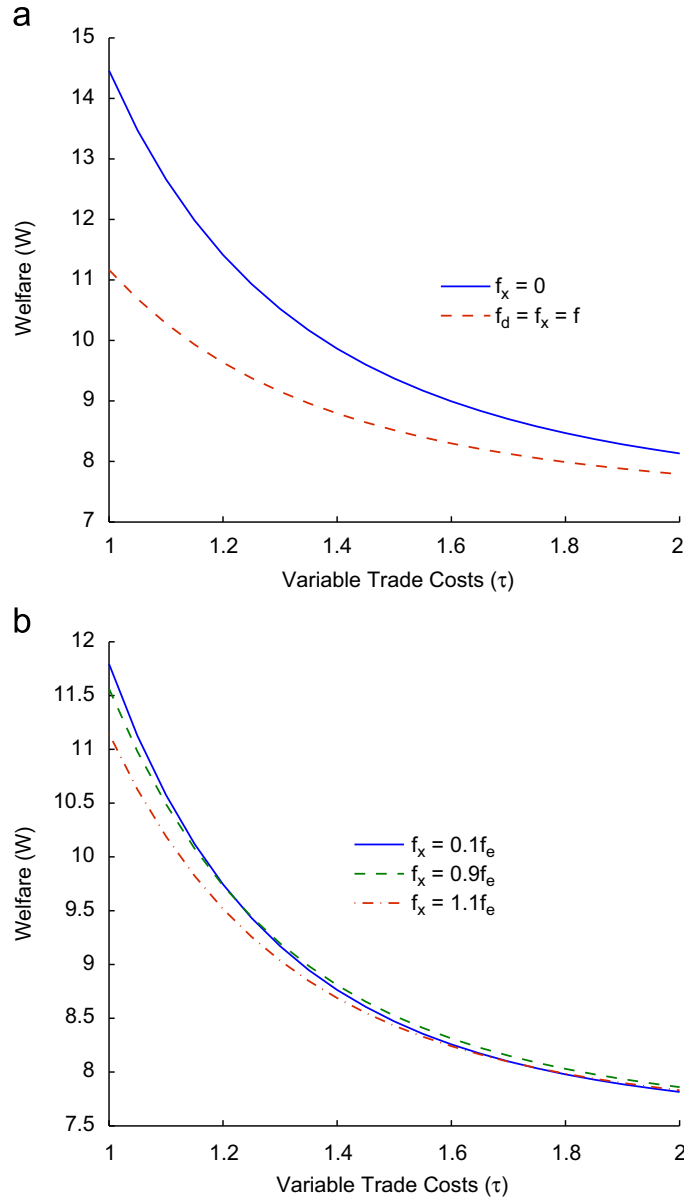
Fig. 1. Effects of trade liberalization on welfare. (a) $f_d = f_x = f$. (b) $f_d = 0$.

How does the socially optimum solution compare to the market equilibrium? To facilitate the comparisons of the efficient and market equilibria, rewrite the conditions that determine the market values of E^A and λ_d^A:

$$f_d H(\lambda_d, 1) = f_e, \tag{49}$$

$$(1 - \tilde{\lambda}_d^{-1})E = (\rho - n)\bar{f}, \tag{50}$$

where (50) is obtained from the closed-equilibrium versions of (32).[28] Observe that (50) and (48) will be identical, if E in (50) is equal to one. In this case, the efficient and market cutoff levels will be the same, i.e., the market cutoff level is socially optimal. However, as discussed above, in the optimal solution E^S must be greater than 1. Furthermore, since $H(\lambda_d, E)$ increases in E, it follows that $\lambda_d^S > \lambda_d^A$, i.e., the efficient cutoff level is greater than the market cutoff level. Because λ_d^S differs from λ_d^A, E^S generally differs from E^A.

Once the efficient per-capita expenditure and production cutoff level are determined, one can obtain the socially optimum growth rate by substituting the efficient solution in (46):

$$\gamma^S = \frac{1}{\bar{f}^S} - \frac{(\tilde{\lambda}_d^S)^{-1} E^S}{\bar{f}^S}, \tag{51}$$

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[28] From the free-entry innovation condition (17), we have $\Pi/(\rho - n) = M_d \bar{f}\phi$. Substituting (32) and setting $M_c = M_d$ and $\theta = 0$ yields (50).

where $\bar{f}^S = f_e/[1-G(\lambda_d^S)]+f_d$. A comparison of (51) with (35) reveals that generally the socially optimal growth rate differs from the market growth rate.

Proposition 4. *The laissez-faire cutoff quality level λ_p^A, per-capita expenditure E, and growth rate γ^A are socially sub-optimal.*

5. Conclusions

This paper developed a fully endogenous growth model with firm-specific quality heterogeneity and an endogenous distribution of markups. The model was used to analyze the determinants of long-run global growth and welfare. In doing so, it complements recent studies of τ growth with firm-specific productivity heterogeneity. The effects of trade liberalization on long-run growth work through a variety of mechanisms that shape the incentives to innovate. An increase in the size of international knowledge spillovers unambiguously raises the rate of long-run growth by increasing the productivity of R&D workers. However, a reduction in trade costs, or a reduction in foreign market entry costs generates pro-growth and anti-growth forces. The former force stems from an increase in the average global quality level which reduces the fraction of labor devoted to manufacturing and increases the fraction of labor engaged in R&D. The latter force arises from the possibility that R&D can become more risky and therefore generate higher expected instantaneous fixed costs that retard the productivity of R&D researchers.

Despite the ambiguity between trade and long-run growth, an increase in the exogenous intensity of international knowledge spillovers or an increase in the rate of population growth accelerate long-run growth. In an effort to explore the nature of the indeterminacy between trade and growth we identified three special cases. Each case is based on sufficient conditions on the model parameters that resolve the growth-trade ambiguity and deliver a definite pro-growth or anti-growth effect of trade liberalization. In addition, simulation analysis indicates that the conditions that resolve the trade-growth ambiguity imply that trade liberalization policies improve the steady-state welfare. Furthermore, the conditions under which lower trade costs promote growth, imply that an R&D subsidy promotes long-run growth as well.

Appendix A. Properties of $H(\lambda_i, \alpha)$ function

According to Eq. (28), when the production cutoff quality level attains its minimum level (i.e., $\lambda_d = 1$), the export cutoff quality level equals the per-unit trade costs (i.e., $\lambda_x = \tau$), whereas as λ_d approaches its supremum (i.e., $\lambda_d \to k$), λ_x approaches infinity (i.e., $\lambda_x \to \infty$). The following conditions characterize the limiting behavior of $H(\lambda_d, 1)$ and $H(\lambda_x, \tau)$:

$$\lim_{\lambda_d \to 1} H(\lambda_d, 1) = \infty, \quad \lim_{\lambda_x \to \tau} H(\lambda_x, \tau) = \infty, \tag{52}$$

$$\lim_{\lambda_d \to k} H(\lambda_d, 1) > 0, \quad \lim_{\lambda_x \to \infty} H(\lambda_x, \tau) = 0. \tag{53}$$

To prove the claims in (52), first note that $H(\lambda_i, \alpha)$ can be written as

$$H(\lambda_i, \alpha) = \frac{\int_{\lambda_i}^{\infty}[1-\alpha\lambda^{-1}]g(\lambda)\,d\lambda}{1-\alpha\lambda_i^{-1}} - [1-G(\lambda_i)].$$

The numerator of the first term on the right-hand-side is always positive as long as $g(\cdot)$ is continuous at λ_i. Taking the limits of both sides as $\lambda_d \to 1$ and $\lambda_x \to \tau$ immediately yields the claims in (52). In addition, the above equation implies that $\lim_{\lambda_x \to \infty} H(\lambda_x, \tau) = 0$ as $\lambda_x \to \infty$. The first claim in (53) immediately follows from $H(k,1) = [1-G(k)](k^{-1}-\tilde{k}^{-1})/(1-k^{-1}) > 0$ since $k^{-1} > \tilde{k}^{-1}$, where $\tilde{k} \equiv [1/(1-G(k))\int_k^{\infty}\lambda^{-1}g(\lambda)\,d\lambda]^{-1}$.

Thus, the left-hand-side of (30) is always positive and defines a negatively sloped curve starting at infinity as $\lambda_d \to 1$ and reaching the value $H(k,1)$ as $\lambda_d \to k$. Given that the right-hand-side of (30) is equal to f_e/f_d, the existence of a unique cutoff quality level $\lambda_d > 1$ is guaranteed for a sufficiently high value of f_e/f_d. The sufficiency condition $H(k,1) < f_e/f_d$ ensures the existence of the unique equilibrium.

Appendix B. Analysis of the planner's problem

The corresponding Hamiltonian is given by

$$\mathcal{H}(E, \lambda_d, M) = e^{-(\rho-n)t}M\ln E + \psi\left[\frac{1-\tilde{\lambda}_d^{-1}E}{\bar{f}}\right]M,$$

where ψ is a time-varying Lagrange multiplier. In this problem, E and λ_d are control variables, while M is a state variable. The necessary conditions are given by

$$\frac{\partial \mathcal{H}}{\partial E} = 0 \Longrightarrow e^{-(\rho-n)t}\overline{f} = \psi \tilde{\lambda}_d^{-1} E, \tag{54}$$

$$\frac{\partial \mathcal{H}}{\partial \lambda_d} = 0 \Longrightarrow [1 - G(\lambda_d)]\left[\frac{1 - \tilde{\lambda}_d^{-1} E}{1 - \lambda_d^{-1} E} - 1\right] = \frac{f_e}{f_d}, \tag{55}$$

$$\frac{\partial \mathcal{H}}{\partial M} + \dot{\psi} = 0 \Longrightarrow \frac{e^{-(\rho-n)t}\ln E}{\psi} + \frac{1 - \tilde{\lambda}_d^{-1} E}{\overline{f}} = -\frac{\dot{\psi}}{\psi}, \tag{56}$$

$$\lim_{t \to \infty} \psi(t) M(t) = 0. \tag{57}$$

The last condition represents the transversality condition.

Again, we shall only consider the steady-state equilibrium. Notice that $1 - \tilde{\lambda}_p^{-1} E$ represent the fraction of labor used in the R&D process and in the steady-state equilibrium, this must be constant. Moreover, since $\dot{M}/M$ is constant in the steady-state, the constraint implies that $\overline{f}$ also must be constant. This further implies that λ_p must be constant. Finally, combining this with the constancy of $1 - \tilde{\lambda}_p^{-1} E$ ensures that E is constant.

Notice that (55) is the same as (47). Since λ_d and E are time-invariant, (54) implies that ψ grows at rate $n - \rho$. Moreover, solving (54) for ψ and substituting it into (56) implies (48) in the main text.

References

Aw, B.Y., Sukkyun, C., Mark, J.R., 2000. Productivity and turnover in the export market: micro evidence from the Republic of Korea and Taiwan (China). The World Bank Economic Review 14, 65–90.

Baldwin, R.E., Robert-Nicoud, F., 2008. Trade and growth with heterogeneous firms. Journal of International Economics 74, 21–34.

Bernard, A.B., Jensen, J.B., 1999. Exceptional exporter performance: cause, effect, or both. Journal of International Economics 47, 1–25.

Bernard, A.B., Jensen, J.B., 2004. Exporting and productivity in the USA. Oxford Review of Economic Policy 20, 343–357.

Clerides, S.K., Lach, S., Tybout, J.R., 1998. Is learning by exporting important? Micro-dynamic evidence from Columbia, Mexico, and Morocco. Quarterly Journal of Economics 113, 903–947.

Coe, D.T., Helpman, E., 1995. International R&D spillovers. European Economic Review 39, 859–887.

Dinopoulos, E., Unel, B., 2009. A simple model of quality heterogeneity and international trade. Working Paper, University of Florida.

Dinopoulos, E., Segerstrom, P., 1999. A schumpeterian model of protection and relative wages. American Economic Review 89, 450–472.

Dinopoulos, E., Segerstrom, P., 2007. North-south trade and economic growth. Mimeo, Stockholm School of Economics.

Dinopoulos, E., Thompson, P., 1998. Schumpeterian growth without scale effect. Journal of Economic Growth 3, 313–335.

Dixit, A.K., Stiglitz, J.E., 1977. Monopolistic competition and optimum product diversity. American Economic Review 67, 297–308.

Grossman, G.M., Helpman, E., 1991. Innovation and growth in the global economy.

Gustafsson, P., Segerstrom, P., 2010. Trade liberalization and productivity growth. Review of International Economics 18, 207–228.

Ha, J., Howitt, P., 2007. Accounting for trends in productivity and R&D: a schumpeterian critique of semi-endogenous growth theory. Journal of Money, Credit, and Banking 33, 733–774.

Hallak, J.C., 2006. Product quality and the direction of trade. Journal of International Economics 68, 238–265.

Harrison, A., 1994. Productivity, imperfect competition, and trade reform: theory and evidence. Journal of International Economics 36, 53–73.

Haruyama, T., Zhao, L., 2008. Trade and firm heterogeneity in a quality-ladders model of growth. Mimeo, Kobe University.

Howitt, P., 1999. Steady endogenous growth with population and R&D inputs growing. Journal of Political Economy 107, 715–730.

Hummels, D., Skiba, A., 2004. Shipping the good apples out? An empirical confirmation of the Alchian–Allen conjecture. Journal of Political Economy 112, 1384–1402.

Hummels, D., Klenow, P.J., 2005. The variety and quality of a nation's exports. American Economic Review 95, 704–723.

Jones, C.I., 1995a. Times series tests of endogenous growth models. Quarterly Journal of Economics 110, 495–525.

Jones, C.I., 1995b. R&D based models of economic growth. Journal of Political Economy 103, 759–784.

Keller, W., 2004. International technology diffusion. Journal of Economic Literature 42, 755–782.

Lucas, R.E., 1988. On the mechanics of economic development. Journal of Monetary Economics 22, 3–42.

Melitz, M.J., 2003. The impact of trade on intra-industry reallocations and aggregate industry productivity. Econometrica 71, 1695–1725.

Rivera-Batiz, L.A., Romer, P.M., 1991. Economic integration and endogenous growth. Quarterly Journal of Economics 106, 531–555.

Roberts, M.J., Tybout, J.R., 1997. The decision to export in Colombia: an empirical model of entry with sunk costs. American Economic Review 87, 545–564.

Romer, P.M., 1990. Endogenous technical change. Journal of Political Economy 98, 71–102.

Romer, P.M., 1994. New goods, old theory, and the welfare costs of trade restrictions. Journal of Development Economics 43, 5–38.

Schott, P.K., 2004. Across-product versus within product specialization in international trade. Quarterly Journal of Economics 119, 647–678.

Segerstrom, P., 1998. Endogenous growth without scale effects. American Economic Review 88, 1290–1310.

Segerstrom, P., Anant, T.C.A., Dinopoulos, E., 1990. A schumpeterian model of the product life cycle. American Economic Review 80, 1077–1092.

Unel, B., 2010. Technology diffusion through trade with heterogeneous firms. Review of International Economics 18, 465–481.

Young, A., 1998. Growth without scale effects. Journal of Political Economy 106, 41–63.