Dynamic Effects of Trade

Benny Kleinman
Stanford University and NBER
Ernest Liu
Princeton University and NBER
Stephen J. Redding
Stanford University, NBER and CEPR

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A classic insight from international economics is that trade generates aggregate welfare gains but creates winners and losers within countries. For those countries with high expenditure shares on domestically produced goods, such as the United States, these static welfare gains from trade are relatively modest. A review in this journal by Costinot and Rodríguez-Clare (2018) suggests that these static welfare gains range from 2 to 8 percent of real income per year for the United States, depending on assumptions about the sensitivity of trade flows to trade costs.

However, when making comparisons of the aggregate gains from trade to its income distributional consequences, these static welfare gains almost certainly underestimate the total gains from trade, because trade can also lead to dynamic changes in an economy, including capital accumulation, learning by doing and innovation. The magnitude of these dynamic effects of trade depends critically on whether the opening of trade permanently affects the economy's growth rate (as in models of "endogenous growth") or only affects the economy's growth rate along the transition path to steady-state (as in models of "semi-endogenous growth"). Small permanent effects on growth rates compound over time to lead to large differences in levels of income.

Benny Kleinman is Assistant Professor of Economics, Stanford University, Stanford, California. Ernest Liu is Associate Professor of Economics, Princeton University, Princeton, New Jersey. Stephen J. Redding is Kleinheinz Family Professor of International Studies, Stanford University. Kleinman is a Faculty Research Fellow and Liu and Redding are Research Associates, National Bureau of Economic Research, Cambridge, Massachusetts. Their email addresses are bennyk@stanford.edu, ernestliu@princeton.edu, and reddings@stanford.edu.

After beginning with a brief review of the conventional consensus about the quantitative magnitude of the static welfare gains from trade, we turn to four aspects of dynamic trade models: dynamic welfare gains from capital accumulation; learning by doing as a source of endogenous technological change; intentional investments in innovation as another source of endogenous technological change; and how the selection of heterogeneous firms within markets affects innovation, technology adoption, and the diffusion of ideas. We focus on the dynamic effects of international flows of goods rather than those of capital and ideas. But we also discuss how openness in capital markets and international knowledge spillovers shape these dynamic effects of trade in goods. While there is broad agreement about the economic relevance of these dynamic welfare effects of trade, there is much less consensus about their quantitative magnitude than for the conventional static welfare gains from trade.

Many dynamic trade models are characterized by externalities and market failures. For example, models of endogenous technological change often feature monopoly profits for successful innovators and externalities from knowledge spillovers. As a result, the market equilibrium in these models need not be efficient. Therefore, small changes in trade costs that reallocate resources across alternative uses can have first-order effects on welfare. This insight helps to explain why the dynamic welfare gains from trade can be large relative to the static welfare gains from trade, because the reallocation of resources induced by trade can move the economy closer to an efficient allocation. But this insight also implies that protectionist trade and industrial policies can be welfare improving in some circumstances, if they counteract existing distortions. At the end of the paper, we discuss some potential insights from dynamic models for trade and industrial policy.

1 The Gains from Trade in Static Models

The last two decades have seen the development of a reasonable degree of consensus about the quantitative magnitude of static gains from trade. Quantitative trade models are sufficiently rich to capture key features of the data, such as the presence of many asymmetric countries and a realistic geography of bilateral trade costs. Despite this richness, these models remain tractable and amenable to a theoretical analysis of their properties, including the existence and uniqueness of the equilibrium, and the comparative statics of the global economy in response to shocks. In addition, because these quantitative trade models can rationalize the observed data on bilateral trade and income as an equilibrium outcome, they can be used to undertake counterfactuals for empirically-relevant changes in trade policies from this initial equilibrium.

1.1 Constant Elasticity Trade Models

Researchers have developed a class of static models that feature a "gravity equation" for trade, in which bilateral trade declines with higher bilateral trade costs at a constant elasticity and also depends on the size of the importing and exporting economies.

This class of models makes a number of assumptions, including for example balanced trade and a single factor of production. Under these assumptions, Arkolakis et al. (2012) (henceforth ACR) show that the change in welfare in response to a change in trade costs can be summarized by two sufficient statistics. The first is the constant trade elasticity (θ), which can be estimated using the gravity equation and data on bilateral trade and trade costs. The second is the domestic trade share (the share of a country's expenditure on its own goods, S_{nn}) before and after the change in trade costs. Given these sufficient statistics, the change in welfare ($\mathbb{W}_n$) for country n as a result of the change in trade costs can be expressed as the so-called ACR formula:

$$\frac{\mathbb{W}'_n}{\mathbb{W}_n} = \left(\frac{S_{nn}}{S'_{nn}}\right)^{\frac{1}{\theta}}, \qquad \text{(static gains from trade)}$$

where we denote the value of a variable before the change in trade costs without a prime (e.g., x) and its value afterwards with a prime (e.g., x').

Reductions in trade costs lower the domestic trade share ($S'_{nn} < S_{nn}$) by making foreign goods more attractive relative to domestic goods, which raises a country's welfare ($\mathbb{W}'_n > \mathbb{W}_n$). The less substitutable are domestic goods for foreign goods (the lower θ), the larger the welfare gain from a given reduction in the cost of foreign goods and a given movement in domestic expenditure shares. The intuition is that reductions in trade costs correspond to an improvement in the "technology" for obtaining goods consumed on world markets in exchange for goods produced. The welfare gain from this expansion in consumption possibilities is larger when domestic goods are less good substitutes for foreign goods.

This sufficient statistics formula holds for changes in trade costs that involve real resources (e.g., transportation costs, such as containerization). In contrast, for changes in trade taxes that raise revenue (e.g., import tariffs), the changes in revenue from these trade taxes must be taken into account. If a country is large enough to affect prices on world markets, a lower tariff raises import demand and bids up the price of imported goods. This increase in import prices relative to export prices reduces the quantity of imports that can be obtained for a given quantity of exports (the "terms of trade"). This deterioration in the terms of trade contributes negatively towards welfare, and appears as part of government revenue, which equals the difference between domestic and world prices multiplied by the quantity of imports.

This welfare formula above can be used for *ex post* evaluation of actual changes in trade costs

and *ex ante* evaluation of counterfactual changes in trade costs. For *ex post* evaluation, the domestic trade shares (S_{nn} and S'_{nn}) are observed (assuming that all else is equal), and the trade elasticity (θ) can be estimated, thereby allowing the welfare formula to be directly evaluated. For *ex ante* evaluation, a researcher does not in general observe the counterfactual domestic trade share (S'_{nn}). Instead, she must solve the general equilibrium conditions of this class of constant elasticity trade models for the counterfactual domestic trade share (S'_{nn}). An important exception is when the counterfactual change in trade costs is prohibitive and takes the economy to autarky. In this case, the counterfactual domestic trade share is necessarily one ($S'_{nn} = 1$), which allows the change in welfare to be directly computed from the observed open-economy domestic trade share ($0 < S_{nn} < 1$) and the trade elasticity (θ). As an illustrative example, roughly based on the United States, if the open-economy domestic trade share is 85 percent of expenditure, and the trade elasticity is 4, then the welfare cost of autarky would be 4.1 percent.

1.2 Quantitative Results

Empirical implementations of this sufficient statistics approach find relatively modest static welfare gains for large countries with high open-economy domestic trade shares. For the United States, Costinot and Rodríguez-Clare (2018) report a range of estimates from 2 to 8 percent of real income. Nevertheless, these static welfare gains can be substantial for small countries with lower open-economy domestic trade shares. For example, for a small open economy such as Belgium, estimates can range up to around 50 percent of GDP, as discussed in Costinot and Rodríguez-Clare (2014); see also Costinot and Rodríguez-Clare (2018) and Caliendo and Parro (2022).

In evaluating these predictions of quantitative trade models, it is challenging to find real-world examples of countries moving from autarky to open trade against which to compare these theoretical predictions.[1] But research has considered two natural experiments from history that approximate these conditions. The first is Japan's opening to trade in the mid-19th century following the arrival of US Commodore Matthew Perry in Tokyo Bay in 1853, forcing Japan to accept US exports under threat of military force. Using data from this episode, Bernhofen and Brown (2005) estimate an upper bound to the welfare gains from the opening of Japan to trade of 8 to 9 percent. A second example is the United States in the early 19th century, when Congress imposed a nearly complete embargo on international trade at the request of President Thomas Jefferson in 1807. Using evidence from this incident, Irwin (2005) estimates a welfare cost from closing trade of 5 percent of gross national product. Although modern economies have changed in many ways since the 19th century, the evidence from these natural experiments aligns in broad magnitude with the predictions of this class of quantitative trade models.

[1] Jaravel and Sager (2026) compare the observed price effects of international trade to the predicted changes in consumption price indexes in quantitative trade models.

A good deal of consensus has been achieved about the quantitative magnitude of these static welfare gains from trade. Nevertheless, this degree of consensus should not be overstated. Estimates of the trade elasticity (θ) range widely from 2 to 12, which substantially affects the magnitude of the implied welfare gains from trade in the sufficient statistics formula above. Although for simplicity we have focused here on the constant elasticity case, the trade elasticity can also be modeled as variable, as in Melitz and Redding (2015) and Adão et al. (2026).

Even in static settings, it is well understood that the welfare gains from trade can be magnified by heterogeneity across industries and input-output linkages. If there are many industries, with low trade elasticities in some industries and low substitutability across industries, the static welfare gains from trade can become substantially larger than implied by single-sector models (as in Ossa 2016). For example, if oil is a critical input for modern economies, and a country does not have its own natural endowments of oil, there are large welfare gains from importing oil.

Additionally, if these multiple industries are connected by input-output networks, international trade costs are incurred not only when final goods are shipped abroad, but also each time an intermediate input crosses a national border. Therefore, the more times that parts and components cross international borders as part of a global value chain, the larger the welfare gains from reductions in international trade costs (for discussion, see Yi 2003 and Caliendo and Parro 2015). Despite these caveats, the degree of consensus over the quantitative magnitude of the static welfare gains from trade is far larger than for the dynamic welfare gains from trade discussed in the ensuing sections.

2 Capital Accumulation

A natural source of dynamic effects of international trade is physical capital accumulation. The canonical framework for thinking about capital accumulation and growth is the neoclassical growth model of Ramsey (1928), Solow (1956) and Swan (1956).

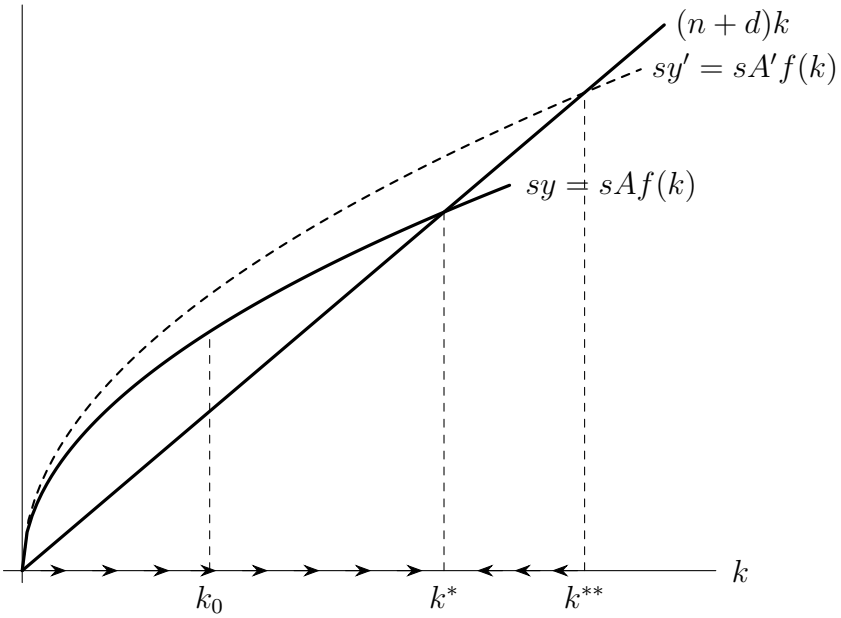
2.1 Closed-economy Neoclassical Growth Model

In the textbook version of this model, goods and capital markets are both closed. Each country produces output of a single final good (Y) using labor (L) and capital (K) with the following production technology: $Y = AF(K, L)$, where A denotes total factor productivity (TFP), and $F(\cdot)$ is characterized by constant returns to scale in capital and labor together and diminishing marginal returns in capital alone. If these diminishing marginal returns are powerful enough, such that capital's marginal product converges to zero for a large enough capital stock, long-run growth cannot be sustained by capital accumulation alone. Instead, each country converges to a steady-state level

of the capital-labor ratio and income per capita.

In Figure 1, we illustrate the determination of this steady-state capital-labor ratio in the closed-economy neoclassical growth model. We denote the capital-labor ratio by $k = K/L$ and output per capita by $y = Y/L = Af(k)$. We assume a constant saving rate (s) out of income, a constant rate of depreciation of capital (d), and a constant exogenous rate of population growth (n).[2] The assumption of a constant saving rate implies that the increase in the economy's stock of capital per person as a result of saving can be shown by the solid savings curve $sy = sAf(k)$, which has a decreasing slope because of diminishing marginal returns to capital. The assumption of constant rates of population growth and depreciation implies that the decrease in the economy's stock of capital per person as a result of population growth and depreciation can be shown by the solid straight line $(n + d)k$.

Figure 1: The Neoclassical Growth Model



Note: Determination of the steady-state capital-labor ratio in the closed-economy neoclassical growth model; $k = K/L$ denotes capital (K) per person (L); $y = Y/L = Af(k)$ corresponds to output (Y) per person (L); s is the constant saving rate; d is the constant depreciation rate; and n is the constant exogenous rate of population growth.

For low initial levels of the capital-labor ratio (such as k_0), the marginal product of capital is high, and the increase in the capital stock per person from saving exceeds the decline in the capital stock per person from population growth and depreciation, thereby leading to capital deepening (a rise in the capital-labor ratio), as shown by the arrows on the horizontal axis. For high initial levels of the capital-labor ratio, the converse is true, which leads to "capital shallowing" (a fall

[2] In the original Solow-Swan model, the saving rate is constant by assumption. In the Ramsey neoclassical growth model, this constant saving rate can be microfounded by the assumption that capital and labor are separately owned (by capitalists and workers) and intertemporal preferences are logarithmic, as in Kleinman et al. (2023).

in the capital-labor ratio), as again shown by the arrows on the horizontal axis. The steady-state capital-labor ratio (k^*) is where the increase in the capital stock per person from saving is exactly equal to the fall in the capital stock per person from population growth and depreciation at the intersection of the two solid lines.

An increase in productivity from A to A' directly raises output for a given capital-labor ratio, which shifts up the savings curve from sy to sy'. The resulting increase in savings per person for each capital-labor ratio also induces additional capital accumulation, which indirectly raises output, with the steady-state capital-labor ratio increasing from k^* to k^{**}.

2.2 Opening up the Neoclassical Growth Model

We next consider the implications of opening this closed economy to international trade in goods, maintaining for now the assumption of closed capital markets.[3] We assume that each economy has a single non-traded final good, which is produced using traded intermediate inputs from each country. Each country's intermediate input is produced using capital and labor according to a constant returns to scale Cobb-Douglas production technology. Intermediate inputs are horizontally differentiated between countries, such that the French good is differentiated from the German good, and so on for all of the other countries.

Trade in these intermediate inputs is subject to "iceberg" transport costs, whereby a fraction of each unit of a country's good is absorbed in transport costs ("melts") when it is shipped between countries. If there is a constant elasticity of substitution between the differentiated goods produced by each country, then static production and trade are the same as in the class of quantitative trade models with a constant trade elasticity discussed in the previous section.

The key difference from a static trade model is that each economy's capital stock is now endogenous and influenced by international trade. The opening of trade in goods reduces the consumption price index for the non-traded final good in each country through the conventional static gains from trade. Because the non-traded final good is also used for investment, this reduction in the consumption price index reduces the cost of investment relative to the return to capital (the rental rate), and thereby raises the return to saving. Therefore, the opening of trade both directly raises welfare for a given capital-labor ratio (through the conventional static gains) and indirectly raises welfare (through induced capital accumulation). In this respect, the opening to trade has a similar effect as the increase in productivity in Figure 1.

In this dynamic framework, Kleinman et al. (2024) show that the sufficient statistics for the

[3] For models along these lines, see for example Baldwin and Forslid (1999), Anderson et al. (2015), Alvarez (2017), Brooks and Pujolas (2018), Mutreja et al. (2018), Ravikumar et al. (2019), and Baqaee and Malmberg (2025).

impact of opening the closed economy on steady-state welfare are:

$$\frac{\mathbb{W}_n^{O*}}{\mathbb{W}_n^{A*}} = \left(\frac{1}{S_{nn}^{O*}}\right)^{\frac{1}{\mu\theta}}, \qquad \text{(dynamic gains with capital)}$$

where the superscripts O and A denote the open and closed economies, respectively; we use an asterisk to denote a steady-state value; and μ is the share of labor in production costs for each country's intermediate inputs.

The labor share term makes the denominator of the exponent smaller (because the labor share (μ) is by definition less than one, such that $\mu\theta < \theta$), and thus makes the overall gains from trade larger than in the formula for the static gains from trade in the previous section. In the illustrative numerical example roughly based on US parameters, if we assume a domestic trade share of 0.85, a trade elasticity of 4, and a labor share of 0.6, then the gains from opening to trade would be 7 percent — which is substantially higher than the 4.1 percent gain from using these parameters in the earlier static gains from trade equation. Using data for 44 countries, Kleinman et al. (2024) find that this magnification of the gains in steady-state welfare through capital accumulation is as large as the conventional static welfare gains from trade for many countries. Kleinman and Yerushalmi (2026) find an even larger magnification of the static gains from trade once investment in non-rival assets is incorporated in addition to capital accumulation.

In terms of Figure 1, the increase in the return to saving shifts the sy curve upwards to sy', analogous to the upward shift from the improvement in domestic productivity from A to A'. The resulting increase in savings per person for each capital-labor ratio raises the steady-state capital stock to k^{**} and leads to a period of capital accumulation and economic growth along the transition path to the new steady-state.

Although the steady-state welfare gains from trade are magnified by capital accumulation, note that it takes time for these steady-state welfare gains to be realized, because capital accumulation occurs gradually along the transition path to steady-state. Because agents in these models are typically assumed to discount the future, this discounting dampens the increase in the welfare gains from trade as a result of the induced capital accumulation.

Although research on capital accumulation has focused on the impact of trade in goods, Kleinman et al. (2024) develop a model with open goods and capital markets. The capital holdings of different countries are assumed to be imperfect substitutes for one another, because of idiosyncratic shocks to the productivity of these capital holdings. This assumption of imperfect substitutability enables the model to explain a number of features of trade and capital holdings data, including gross capital holdings that are greater than net capital holdings, and gravity equations for goods trade and capital holdings (consistent with the evidence in Obstfeld and Rogoff 2000). Under this assumption, the opening of capital markets raises the return to saving, because coun-

tries gain access to new investment opportunities abroad, and domestic investments are imperfect substitutes for these foreign investments. This increase in the return to saving induces additional capital accumulation beyond that implied by the opening of goods markets. For most countries the sum of the static and dynamic gains from trade in goods exceeds this dynamic gain from open capital markets. But for some small economies with open capital markets (such as the Netherlands and Norway), the capital accumulation induced by open capital markets can make up more than half of the overall welfare gains from opening the closed economy.

With open capital markets, a country's wealth differs from its domestic capital stock, and a country's gross domestic product (GDP) is distinct from its gross national product (GNP). Whereas GDP captures the income paid to factors of production used in a country (regardless of their country of ownership), GNP captures the income received by factors of production owned by a country (regardless of the country in which they are used in production). Welfare depends on wealth accumulation and GNP rather than on capital accumulation and GDP. For small open economies, the difference between real GNP and real GDP can be several percentage points. When countries hold wealth as capital overseas, changes in the relative prices of capital across countries generate valuation effects, as in Gourinchas and Rey (2007).

Finally, Fitzgerald (2025) considers a setting with three-dimensional trade: across countries at a point in time, over time (through consumption-savings decisions), and across states of nature (through international risk sharing). Although this framework abstracts from capital accumulation, these 3-D gains from trade are at least two thirds larger than the conventional static gains from trade for developing countries with volatile productivities.

2.3 Trade, Growth and Income Convergence

Capital accumulation can influence the impact of international trade in goods in other ways. Acemoglu and Ventura (2002) consider a setting with a final goods production technology that has constant (instead of diminishing) returns to capital. Countries are assumed to produce horizontally differentiated goods under frictionless trade and to differ in the productivity of capital. In a closed economy, these differences in capital productivities lead to different rental rates, which results in different rates of capital accumulation and a divergence of the cross-country income distribution over time.

In contrast, in the open economy, a faster rate of capital accumulation in a given country leads to an increase in the relative supply of its good. Because the goods of different countries are imperfect substitutes, this increase in relative supply leads to a fall in the relative price of that country's good (a deterioration in the terms of trade), and a convergence in rental rates, rates of capital accumulation, and income growth across countries. Therefore, this endogenous change in the terms of

trade on world markets results in a stable world income distribution in the open economy, despite the differences in countries' productivities of capital. The magnitude of this equilibrium cross-country income dispersion depends on the forces that shape the terms-of-trade effects: openness to international trade and the degree of substitutability between countries' goods.

While we have so far focused on settings in which countries produce differentiated goods, Ventura (1997) embeds capital accumulation into a version of the Heckscher-Ohlin trade model, in which goods are homogeneous across countries. In this model, the world economy consists of two countries that differ in factor "abundance," defined as their initial relative supplies of capital and labor. There are two production sectors that differ in the factor intensity with which they use these two factors of production. Production technologies in each sector are assumed to be constant returns to scale in capital and labor, with diminishing marginal returns to capital alone.

In this model with a closed economy, capital accumulation leads to a decline in the return to capital, because of diminishing marginal returns to capital. Therefore, economic growth gradually slows along the transition path to steady-state, with each country having a steady-state capital-labor ratio in each sector. In contrast, for a small open economy trading at constant world prices, the predictions are starkly different. For this type of economy, the return to capital is pinned down by world prices independently of the economy's own factor supplies (by way of the famous factor price equalization or factor price insensitivity theorem). Therefore, a small open economy can continue to accumulate capital and enjoy rapid economic growth, without experiencing a fall in the return to capital. This theoretical prediction provides an explanation for apparent economic growth "miracles," in the form of the rapid growth of small open economies such as South Korea in the decades after the Second World War.

3 Learning by Doing

Although capital accumulation is a natural force for magnifying the static welfare gains from trade, the neoclassical growth model has two limitations for thinking about dynamic effects of trade. First, it treats production technology as exogenous. But improvements in TFP are an important source of output growth, especially in advanced economies close to the technological frontier, such as the United States (the classic citation is Solow 1957). Second, if diminishing marginal returns to capital are powerful enough, long-run growth ceases, as each country converges to its steady-state income per capita. We now turn to consider models of endogenous technological change, in which trade can have dynamic welfare effects through a change in a country's long-run growth rate. Since long-run growth rates compound over time, even small differences in these long-run growth rates can have large impacts on relative levels of income per capita.

3.1 Learning by Doing and Endogenous Technological Change

Learning by doing refers to the phenomenon whereby productivity improves with cumulative production of a good and is typically assumed to occur as an externality of production. In some respects, learning by doing operates in a similar way to static external economies of scale, as discussed in Thompson (2012). However, a key difference is that learning by doing affects growth rates rather than levels of income per capita.

Perhaps the most famous evidence of the empirical relevance of learning by doing comes from the production of "Liberty Ships" in the United States during the Second World War. For each individual shipyard, Searle (1945) plotted man-hours per vessel against the number of vessels completed to date in that yard, and found that man-hours per ship fell by 12 to 24 percent with each doubling of cumulative output. Estimating a production function that includes cumulative output as a separate explanatory variable, Rapping (1965) obtained a similar conclusion that a doubling of cumulative output led to a productivity improvement of 11 to 29 percent. More contemporary examples of industries where learning by doing is believed to be important include semiconductors, solar panels and electric vehicles (for example, Irwin and Klenow 1994, Miller 2022).

The implications of learning by doing for the dynamic effects of trade depend crucially on the level at which this learning by doing occurs: whether it is specific to a firm, an industry within a country, across industries within a country, within an industry across countries, or across countries and industries. Typically, learning by doing is assumed to extend beyond the boundaries of the firm through knowledge spillovers. Under this assumption, an individual firm does not fully internalize the benefits from learning by doing, because it takes into account the effect of its output on its own productivity, but not the effect on other firms' productivities. Empirical research typically finds that knowledge spillovers are indeed larger within than between countries (for discussion, see Jaffe et al. 1993, Eaton and Kortum 1999).

3.2 Learning by Doing and Comparative Advantage

With national knowledge spillovers, there is a two-way interaction between trade and learning by doing, with causality running in both directions. On the one hand, trade affects learning by doing, because it leads countries to specialize across industries according to their relative productivities (comparative advantage), which affects learning by doing. On the other hand, learning by doing feeds back to influence international trade, because it changes relative productivities across countries and industries, which shapes patterns of specialization. This two-way interaction provides microfoundations for "hysteresis" or "path dependence," whereby temporary shocks to specialization affect learning by doing and hence have permanent effects on comparative advantage and international trade, as in Krugman (1987) and Lucas (1988).

3.3 Trade, Learning by Doing and Growth

The presence of an externality in the form of knowledge spillovers implies that the market equilibrium in models of learning by doing is inefficient. As a result, the opening of international trade can either raise or reduce a country's welfare, as shown in Young (1991). Consider a world of two countries (D for "developed" and E for "emerging"), each of which has a single factor of production, labor, which can produce any of a continuum of goods with varying degrees of technological sophistication s. Goods are horizontally differentiated from one another, such that consumer preferences exhibit a love of variety across goods. All goods are produced with a constant returns to scale production technology under conditions of perfect competition.

More sophisticated goods have potential for learning by doing over time: that is, they begin with higher actual labor requirements when first introduced (lower actual productivity when first introduced), and then evolve toward lower potential labor requirements (higher potential productivity). Unit labor requirements for each good fall with cumulative production across all goods. But this learning by doing is bounded, in the sense that there is a lower bound to the potential labor requirements for each good. Since learning by doing spills over across goods, old goods are eventually discarded in favor of new and more advanced goods as in Stokey (1988).

Assume for simplicity that there are no international spillovers of knowledge. Each country is characterized by a level of technological sophistication at a given point in time, which corresponds to the most sophisticated good for which learning by doing has been exhausted. For all goods less sophisticated than this level, labor requirements are constant over time. For all goods more sophisticated than this level, there is scope for further learning by doing. Labor requirements for these more sophisticated goods fall at a rate determined by cumulative production across all goods for which the potential for learning by doing has not yet been exhausted.

Now consider the opening of trade between these two countries, which are identical except for their labor supplies and levels of technological sophistication. We assume that the level of technological sophistication is higher in the developed than in the emerging country. As a result, specialization according to comparative advantage leads the developed country to reallocate resources towards more-sophisticated goods, where learning by doing can still occur. In contrast, the emerging country reallocates resources towards less-sophisticated goods, where the scope for learning by doing has been exhausted. Nevertheless, the ranges of goods produced by the two countries can overlap, such that the emerging country still produces some goods where there remains the potential for learning by doing.

This specialization according to comparative advantage affects rates of economic growth in the two countries. In the developed country, the reallocation of resources towards goods with more potential for learning by doing implies that the rate of output growth in the open economy is at least as large as in the closed economy. In contrast, in the emerging country, the reallocation of

resources towards goods with less potential for learning by doing implies that the rate of output growth in the open economy is less than or equal to that in the closed economy.

The evolution of the technological gap between the two countries depends on the amount of labor allocated to the production of goods for which there remains potential for learning by doing, which depends not only on comparative advantage, but also on the relative population of the two countries. If the initial technological gap is large enough, and the population of the emerging country is small enough relative to that of the developed country, the initially developed country remains the technological leader for all time. In this case, the developed country necessarily experiences dynamic welfare gains from trade. Although output growth in the emerging country is lower in the open economy than in the closed economy, this reduction in output growth does not necessarily translate into a reduction in consumption growth, because the emerging country experiences a terms of trade gain from the developed country's productivity growth in goods where there remains the potential for learning by doing. Nonetheless, it is possible for consumption growth to fall in the emerging country, in which case it experiences dynamic welfare losses from trade. Whether trade raises or reduces overall welfare in the emerging country depends on whether the conventional static welfare gains from trade are larger or smaller than these dynamic welfare losses from trade.

In contrast, if the initial technological gap between the two countries is small enough, and the population of the emerging country is large enough relative to that of the developed country (e.g., China and India as large emerging countries), the technological gap between the countries can fall over time, because the rate of learning by doing increases with employment size. In this case, income per capita in the emerging country rises relative to that in the developed country, until eventually the roles of developed and emerging country are reversed. Over time, the country that initially starts out as developed can end up experiencing a reduction in its rate of output growth. Therefore, learning by doing also can rationalize the rapid structural transformation and catchup in East Asian miracle countries, such as South Korea, as emphasized in Lucas (1993).

Most existing empirical evidence on learning by doing is from microeconometric studies of individual countries and industries (such as the Liberty ships discussed above). Evidence on the macroeconomic implications of learning by doing is more limited, with conflicting findings. Using South Korea's Heavy and Chemical Industry (HCI) Drive in the 1970s, Choi and Levchenko (2025) estimate an elasticity of productivity with respect to past output of 0.48, and argue that this industrial policy raised South Korea's real income by 3 to 4 percent. In contrast, Atkin et al. (2025) develop a model of a ladder of development, in which countries differ in capability, goods differ in their complexity, and capability growth depends on specialization patterns in a way that allows for learning by doing. The median country is found to experience modest dynamic welfare losses from trade, which reduce its welfare gains from trade by 2.5 percent.

4 Endogenous Innovation and Growth

Learning by doing is a serendipitous by-product of cumulative production. However, firms devote considerable resources to intentional investments in innovation, including expenditure on research and development, motivated by expectations of future profits from successful innovation, as emphasized by Schmookler (1966).

4.1 Expanding Product Variety and Improving Product Quality

An early wave of research on "endogenous growth" developed models in which the economy's long-run rate of growth is endogenously determined by intentional investments in new ideas. In variety-based models, endogenous innovation takes the form of an expansion in product variety (as in Romer 1990 and Rivera-Batiz and Romer 1991). In quality-ladder models, it takes the form of increments in product quality or improvements in productivity (as in Aghion and Howitt 1992, Grossman and Helpman 1991b and Grossman and Helpman 1991a).

Both approaches emphasize that ideas have public good characteristics: in particular, they are "non-rival," but "partially excludable" through the use of intellectual property rights. These properties of innovative ideas generate externalities and market failures. In quality-ladder models, technologies are vertically differentiated, such that each innovation displaces the existing state-of-the-art technology. Growth becomes a process of "creative destruction," as emphasized in Schumpeter (1942), and hence these frameworks are often referred to as Schumpeterian models (Aghion and Howitt 1997; Aghion et al. 2014; and Aghion 2026).

4.2 Trade and Endogenous Innovation

Both variety-based and quality-ladder models of endogenous innovation highlight a number of channels for dynamic effects of trade. First, international trade increases product market competition, because domestic firms are exposed to foreign competitors. In conventional Schumpeterian models, this greater product market competition reduces the monopoly profits from innovation, which lowers incentives to invest in innovation. However, existing empirical evidence paints a more complicated picture. Nickell (1996) finds that greater product market competition raises firm productivity growth. Aghion et al. (2005) estimate an inverted U-shaped relationship between innovation (as measured by patents) and product market competition, which implies that more competition at first increases and then later reduces rates of innovation.[4]

[4]Existing evidence using the China trade shock as an exogenous shock to competition yields ambiguous conclusions. While Bloom et al. (2016) find a positive effect, Autor et al. (2020) find a negative effect.

Extended Schumpeterian models highlight a number of channels through which these positive effects of product market competition can occur. In models of "neck and neck" competition between firms, greater competition can increase incentives to innovate to "escape competition," as in Aghion et al. (2001). In settings where successive vintages of technologies coexist and are gradually improved through subsequent development, greater competition can speed up innovation by reallocating resources towards the latest vintages, as in Aghion and Howitt (1996). In the presence of a principal-agent problem between managers and firm owners, greater competition can enhance innovation by reducing the amount of slack that a manager can afford while keeping the firm alive, as in Aghion et al. (1999).

Second, models of endogenous innovation often feature scale effects, because upfront investments in innovation correspond to a fixed cost, whereas the monopoly profits from successful innovation increase with market size. Therefore, international trade can enhance incentives to innovate by raising the profits from successful innovation as a result of greater market size. Whether these market size effects are realized depends on the research technology, market structure and preferences. Rivera-Batiz and Romer (1991) distinguish between a "knowledge-based" research technology (which uses only ideas as inputs) and a "lab equipment" research technology (which uses ideas and goods as inputs). In variety-based growth models with a knowledge-based research technology, monopolistic competition, and constant elasticity of substitution preferences, the expansion in market size for domestic varieties is exactly offset by greater product market competition from foreign varieties, leaving profits per firm and the rate of innovation unchanged (Grossman and Helpman 1991a; Rivera-Batiz and Romer 1991). In contrast, in variety-based growth models with a lab-equipment research technology, the reduction in the goods price index from a larger total number of varieties (domestic plus foreign) in the open economy lowers the cost of inputs into research and raises the rate of innovation, even under monopolistic competition and constant elasticity of substitution preferences (Rivera-Batiz and Romer 1991).

Third, the opening of a closed economy allows for international knowledge spillovers. In both product variety and product quality models of innovation, each generation of researchers builds on the existing stock of knowledge. In the open economy, researchers in each country can build on a larger stock of ideas than in the closed economy, which raises the productivity of research, and in this way can raise the long-run growth rate (Grossman and Helpman 1991a; Rivera-Batiz and Romer 1991). International trade in goods also can reduce duplication in research, by ensuring that countries specialize in distinct varieties of goods, or can act as a conduit for international knowledge spillovers, as in the classic example of the reverse engineering of products (for example, Coe and Helpman 1995).

Fourth, the opening of international trade leads to specialization across sectors according to comparative advantage. If sectors differ in rates of innovation, this specialization affects aggregate

output growth through a change in sectoral composition, as in Grossman and Helpman (1991a), echoing findings for learning by doing above. In the absence of international knowledge spillovers, comparative-advantage-based models of endogenous innovation also can exhibit hysteresis and path dependence, because temporary shocks can affect the accumulation of national knowledge stocks, and hence have permanent effects on specialization and trade.

4.3 Endogenous Versus Semi-Endogenous Growth

Early "knowledge-based" models of endogenous innovation assumed an elasticity of the productivity of research workers with respect to the existing stock of knowledge of one, with the result that the change in knowledge is proportional to the existing stock of knowledge. This specification gives rise to endogenous long-run growth. Therefore, policies that raise employment in the research sector permanently raise the economy's long-run growth rate.

In contrast to this theoretical prediction, recent decades have witnessed an increased share of resources devoted to the research sector without a corresponding increase in the economy's rate of long-run growth (Jones 1995b; Bloom et al. 2020). A classic example is Moore's Law, where the number of researchers required today to achieve a doubling of computer chip density is more than 18 times larger than the number required in the early 1970s.

To rationalize this empirical evidence, Jones (1995a) develops a semi-endogenous growth model, in which the elasticity of the productivity of research workers with respect to the existing stock of knowledge is less than one. Policies that change the share of resources devoted to the research sector (including potentially trade liberalization) affect economic growth along the transition path to steady-state and the steady-state level of income per capita. But these policies have no effect on the economy's long-run growth rate of income, which is instead determined by exogenous population growth. Kortum (1997) develops a quantitative semi-endogenous growth model that is successful in matching observed trends in research, patenting, and productivity.

5 Producer Heterogeneity and Technology Diffusion

The research on endogenous technological change in the previous two sections assumed a representative firm, at least within a given sector and country. More recent research has examined the dynamic effects of trade in models of heterogeneous firms with endogenous distributions of productivity across firms. In these frameworks, trade liberalization changes the sets of firms producing in each country and serving each market, which in turn affects firms' incentives to adopt new technologies and the diffusion of technologies across firms. For a review of the wider literature on firm heterogeneity and international trade, useful starting points are Bernard et al. (2007)

and Melitz and Redding (2014).

5.1 The Canonical Model of Firm Heterogeneity

The canonical framework for modelling firm heterogeneity is the Melitz (2003) model of heterogeneous firms in differentiated product markets. In this framework, a competitive fringe of potential firms can enter an industry by paying an upfront fixed entry cost, which is thereafter sunk. Potential entrants face uncertainty about their productivity in the industry. Once the sunk entry cost is paid, a firm draws its productivity from a fixed distribution. In this formulation, the fixed entry cost can be viewed as an investment in research and development, and the productivity draw can be interpreted as an innovation. Profits are increasing in firm productivity and there is a fixed production cost. Therefore, firms drawing a productivity level below some lower threshold (the "zero-profit productivity cutoff") would be unable to cover the fixed production cost and would make negative profits if they chose to produce, and hence exit the industry. Firms face additional fixed and variable costs of exporting. Therefore, of the active firms within the industry, only those that draw a productivity above a higher threshold (the "export productivity cutoff") find it profitable to export in equilibrium. Whatever the productivity draw, firms also face a constant exogenous probability of death as a result of *force majeure* events.

Trade liberalization increases profits that existing exporters can earn in foreign markets, and in this way reduces the productivity cutoff above which firms export, thereby inducing entry into exporting. In contrast, the profitability of low-productivity firms that only serve the domestic market declines, because of increased product market competition from high-productivity foreign firms, and increased labor-market competition with high-productivity domestic firms. This reduction in domestic market profits induces some low productivity firms who were previously marginal to exit the industry. As low-productivity firms exit, and as output and employment are reallocated towards higher-productivity firms, average industry productivity rises.

5.2 Firm Heterogeneity and Endogenous Growth

In Melitz (2003), a firm's productivity remains fixed after it is drawn upon entry. However, Atkeson and Burstein (2010) extend the model to cover the situation in which firm investments in innovation lead to endogenous changes in firm productivity over time. In this case, trade liberalization affects welfare through a rich range of mechanisms, including firm exit, exporting, and process innovation. Despite these multiple mechanisms, the aggregate effect of trade liberalization on welfare is disciplined by the "free entry condition" that equates the expected value of firm entry to the sunk entry cost. Other things equal, a reduction in barriers to international trade raises the profits associated with firm entry. In equilibrium, in order to satisfy the free-entry condition, this increase

in expected profits must be offset by an increase in the real wage and a change in aggregate output, both of which are determined by aggregate productivity. To a first-order approximation, the required change in aggregate productivity is independent of the details of whether it is achieved through firm entry, exporting or process innovation. A key implication of this insight is that expanding the range of mechanisms through which firms can respond to trade liberalization does not necessarily affect the overall magnitude of the aggregate welfare gains from trade.

Whether incorporating additional mechanisms affects the overall size of the aggregate welfare gains from trade depends on the extent to which the market equilibrium is efficient. Suppose that the market is not efficient because of knowledge spillovers across firms, and suppose further that entering firms learn from incumbents (Sampson 2016). Because only firms with a sufficiently high productivity draw find it profitable to produce, the incumbent distribution is a truncation of the entry distribution, which implies that each generation of entering firms learns from an incumbent distribution that is shifting progressively to the right, thereby resulting in endogenous long-run growth. Calibrating the model to U.S. data, dynamic selection approximately triples the overall welfare gains from trade compared to static heterogeneous firm economies.

Instead of assuming that entrants learn from incumbents, Perla et al. (2021) allow the distribution of productivity across incumbents to evolve endogenously over time, such that each incumbent firm experiences stochastic productivity shocks and chooses whether to incur a fixed cost to adopt new technologies already in use by other firms in their home country. Opening to trade increases the spread of profits between the most and least productive firms, because of a combination of increased export opportunities and foreign competition. This increased dispersion in profits raises the incentive to upgrade technology and hence accelerates the pace of endogenous growth. The resulting framework is able to account for a range of features of micro data on firm dynamics, including the transition probabilities of surviving establishments between quantiles of the employment-size distribution. Calibrating the model to match moments of these micro data, the overall welfare gains from trade taking into account this acceleration of technology adoption are an order of magnitude larger than the conventional static welfare gains.

5.3 Producer Heterogeneity and Idea Diffusion

Other research has explored the determinants of idea diffusion between heterogeneous producers. Buera and Oberfield (2020) assume that new ideas arrive to potential producers of a good randomly. These new ideas build on insights from others, but there is randomness in the adaptation of these insights. Therefore, the productivity of each idea has a random original component, which is combined with a random insight drawn from the distribution of ideas across other producers. This specification captures the notion that interactions with more productive individuals typically

lead to more useful insights, but allows for randomness in the adaptation of knowledge from elsewhere to one's own specific context. The arrival of these new ideas leads to a gradual outward shift in the productivity distribution and endogenous long-run growth. For the preferred calibration of the model, the overall welfare gains from trade and the fraction of productivity growth explained by trade in goods are more than twice as large as in the special case without idea diffusion.

5.4 Firm Heterogeneity and Creative Destruction

The variety-based and quality-ladder models of growth discussed earlier offer starkly different perspectives on the extent to which growth involves creative destruction. In the variety-based models, innovation takes the form of the creation of new varieties. In the quality-ladder model, the incumbent supplier of the state-of-the-art technology is entirely displaced by innovation from a new entrant. In between these two extremes, innovation can encompass the creation of new varieties by either entrants or incumbents, improvements in quality or productivity for existing varieties within incumbent firms, or creative destruction when a firm improves on and takes over a variety supplied by another firm, as analyzed in Klette and Kortum (2004) and Garcia-Macia et al. (2019).

Using micro data from the Longitudinal Business Database (LBD) in the United States, Garcia-Macia et al. (2019) provide empirical evidence on the relative importance of these different forms of innovation. The role of each type of innovation is inferred using the model from observed job creation and job destruction by incumbents and entrants in the LBD. Most growth is found to originate from incumbents rather than from new entrants, because most entering firms are small. Most growth also occurs through quality or productivity improvements within existing varieties rather than from an expansion in the number of varieties. Creative destruction accounts for around 25 percent of growth, with the remainder mostly accounted for by quality or productivity improvements for existing varieties within incumbent firms.

When creative destruction involves innovators in one country taking over the market for an existing product in another country, it leads to changes in patterns of trade in goods, as analyzed in Hsieh et al. (2023). When innovators can build on the technology of sellers (including imports), international trade has dynamic effects on domestic welfare by facilitating the international flow of ideas. For the United States, the overall welfare gains from opening the closed economy incorporating this role for trade in goods in idea diffusion are more than double the conventional static welfare gains from trade.

5.5 Sufficient Statistics for Dynamic Gains

The existing estimates of the dynamic gains from trade in the previous sections are based on calibrating specific quantitative general equilibrium models, where the assumptions and predictions

of these models differ across studies. To place the dynamic and static gains from trade on a more equal footing, more progress is needed in developing a small number of sufficient statistics for the dynamic gains from trade that hold across an entire class of models.

To make progress in this direction, Boehm et al. (2023) consider a class of dynamic trade models, in which the stock of firms serving each market or customer capital in each market evolves gradually over time. Within this class of models, the gains in steady-state welfare from opening the closed economy to trade can be expressed in terms of the steady-state domestic trade share in a similar form to equation (dynamic gains with capital). But the exponent on the steady-state trade share now depends on the long-run elasticity of trade with respect to trade costs and a parameter that governs the relationship between the stock of firms and sales per firm.

One challenge in implementing this formula is the need to estimate the parameter regulating the relationship between the stock of firms and sales per firm. But Boehm et al. (2023) show that this parameter can be recovered by combining estimates of the short-run and long-run elasticities of trade with respect to tariffs as a measure of trade costs.[5] Conditional on the same long-run tariff elasticity, the gains in steady-state welfare from opening the closed economy to trade are larger than implied by the ACR formula. The reason is that the gradual adjustment in the stock of firms or customer capital in response to the opening of trade acts as a magnification force in a similar way to capital accumulation in equation (dynamic gains with capital).

6 Implications for Trade and Industrial Policy

The externalities and market failures in dynamic trade models provide a potential rationale for activist trade and industrial policies. Recent years have seen a resurgence of interest in such policies, including the bipartisan US CHIPS and Science Act of 2022. China's industrial policies potentially could be justified in these terms (for example, Liu 2019, Barwick et al. 2025). The debate over these industrial policies was a subject of the Fall 2024 special issue of this journal, including Juhász and Lane (2024), Barwick et al. (2024), and Bown and Wang (2024). For our purposes, the key point is that trade and industrial policies presuppose a dynamic framework: The hope is that short-term and temporary costs of either industrial subsidies or forgone short-term gains from trade will bolster domestic industries and lead in time to larger dynamic gains from trade that will more than offset the short-term costs. This set of ideas has a long history in economics dating back at least to Mill (1848) and is referred to as the "infant industry" argument.

[5] For empirical evidence that trade elasticities are smaller in absolute value in the short-run than in the long-run, see for example Ruhl (2008), Anderson and Yotov (2020), and Boehm et al. (2023).

6.1 Prerequisites for Successful Industrial Policy

Despite the resurgence of interest in activist trade and industrial policies, the evidence in support of their success is scarce relative to the level of interest from policy makers. The finding that temporary protection can enable an industry to subsequently become economically viable is not sufficient to establish that this policy is welfare-improving. Instead, the sufficient condition for success is that the policy raises lifetime welfare, which requires that the net present value of the stream of initial welfare losses and future welfare gains is greater than or equal to zero. Furthermore, any policy intervention should be targeted as close as possible to the source of the market failure. If the market failure is knowledge spillovers, a production subsidy or R&D tax credit will typically dominate a tariff. If the market failure is the inability of firms to borrow to finance initial losses, policy interventions should be targeted to alleviate these credit market imperfections.

6.2 Strategic Trade and Industrial Policy

These arguments for trade and industrial policy interventions connect with an earlier literature on strategic trade policy, which emphasized imperfect competition as the source of market failure: for starting points, see Krugman (1994) and Brander (1995). If there are supernormal profits within an industry — airplane production was a common example — then activist trade and industrial policies may seek to shift profits from foreign to domestic firms. However, the resulting policy prescriptions can be highly sensitive to the details of the strategic interaction between firms. For example, if firms compete in foreign export markets in quantities under Cournot competition, an export subsidy can shift profits from foreign to domestic firms. In contrast, if these firms compete in prices under Bertrand competition, an export tax is the appropriate policy to shift profits from foreign to domestic firms. Knowing the details of strategic interaction between firms within industries imposes strong informational requirements on policy makers.

Additionally, arguments for policy intervention based on imperfect competition typically focus on a single industry in partial equilibrium, and often require substantial qualification in general equilibrium. For example, if several industries employ the same factor of production that is in limited supply for the economy as a whole, protection of one industry based on strategic considerations acts as anti-protection for other industries using that same factor of production. Finally, the impact of one country introducing an industrial policy can be offset by the introduction of retaliatory industrial policies of its trade partners.

6.3 Industrial Policy and Endogenous Technological Change

Dynamic trade models instead emphasize externalities, such as knowledge spillovers from learning by doing and innovation, as the rationales for trade and industrial policies. This rationale ex-

plicitly takes into account reallocations across industries in general equilibrium. Perhaps surprisingly, one country's policy interventions, by offsetting the misallocation in the market equilibrium, can even raise the welfare of all countries (Redding 1999).

When industries are connected by an input-output network, arguments for activist trade and industrial policies become considerably more complicated, because market imperfections in one industry propagate to other industries through the production network. Liu (2019) provides an analytical characterization of industrial policy when economic sectors form a production network. Starting from a decentralized, no-intervention economy, policies can be guided by a measure of "distortion centrality" that takes into account all distortionary effects of market imperfections through the production network. In hierarchical production networks, in which sectors follow a pecking order so that upstream sectors supply a disproportionate fraction of output to other sectors, distortion centrality reduces to a measure of the upstreamness of the sector. Therefore, this analysis provides a microfoundation for policy interventions targeting upstream sectors, as observed empirically in China and South Korea.

Evidence on the potential quantitative magnitude of the welfare gains from activist trade and industrial policies is provided by Bartelme et al. (2025), using a multi-sector quantitative trade model with static external economies of scale within sectors and countries. Using data on 61 countries, the paper estimates sizable external economies of scale for all two-digit manufacturing industries, with an average elasticity of productivity with respect to scale of 0.21. But even in this model, with sizable external economies of scale, the welfare gains from an optimal industrial policy are found to be relatively modest. The reason is relatively low elasticities of substitution across sectors and relatively high trade costs between countries. Together, these two forces imply relatively little reallocation across sectors in response to the optimal industrial policy.

7 Conclusion

A growing research literature has investigated the dynamic effects of international trade through factor accumulation and technological change. A common finding is that the dynamic effects of trade lead to overall welfare gains that can more than double the static welfare gains in conventional trade models. But these findings are based on specific quantitative general equilibrium models that differ in their assumptions. More research is needed to place these dynamic gains on the same footing as their static counterparts, with a small number of sufficient statistics that discipline their quantitative magnitude across a large class of models.

In addition, a focus on dynamic gains from trade emphasizes that trade is more than just producing in one country and selling in another. Openness to trade affects behaviors like investment in capital and in research and development, learning by doing, participation in the diffusion of

ideas, entry and exit, the type and degree of specialization, patenting behavior, and other dimensions. A dynamic perspective on gains from trade is necessary to understand both how trade affects national economies and growth prospects, as well as the world income distribution.

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