Globalization and the Ladder of Development: Pushed to the Top or Held at the Bottom?*

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Abstract

We study the relationship between international trade and development in a model where countries differ in their capability, goods differ in their complexity, and capability growth is a function of a country's pattern of specialization. Theoretically, we show that it is possible for international trade to increase capability growth in all countries and, in turn, to push all countries up the development ladder. This occurs if (i) shifting employment towards more complex sectors raises capability growth and if (ii) foreign competition is tougher in less complex sectors for all countries. Empirically, we provide causal evidence consistent with (i) using the entry of countries into the World Trade Organization as an instrumental variable for other countries' patterns of specialization. The opposite of (ii), however, holds in the data. Through the lens of our model, these two empirical observations imply dynamic welfare losses from trade that are pervasive, albeit small for the median country. The same economic forces also suggest that the emergence of China has held back capability growth for a number of African countries who are pushed away from their most-complex sectors, which China exports, and into their least-complex sectors, which China imports.

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1 Introduction

A popular metaphor among development policymakers and practitioners is that countries sit at different rungs of a *ladder*, each associated with a different set of economic activities a country can perform. As countries develop, they become more *capable*, move up the ladder, and start to produce and export more *complex* goods. The goal of this paper is to offer a first formalization of these ideas and use it as a starting point to revisit the relationship between globalization and development.

An enticing feature of the ladder metaphor is the possibility of a two-way relationship between international trade and development. On the one hand, development may cause countries to acquire a comparative advantage in more complex goods and, in turn, tilt their exports towards these goods. This is the classical Ricardian perspective. According to this view, international specialization is Pareto efficient and laissez-faire policy is optimal. On the other hand, specialization in more complex goods may cause countries to grow faster, as a result of greater opportunities for knowledge accumulation and technological spillovers in those sectors. This is the view adopted by influential industrial policy scholars. It suggests that industrial policies subsidizing more complex sectors at the expense of others could be welfare improving, as discussed by Hausman et al. (2007), Hidalgo et al. (2007), and Lin and Chang (2009), among others. It also opens up the possibility that the emergence of large countries like China in the world economy may push some countries to the top of the ladder, while holding others at the bottom.

To formalize the ladder metaphor, Section 2 introduces a dynamic Ricardian model of international trade with many countries, that differ in terms of their capability, and many sectors, that differ in terms of their complexity. We define a "ladder economy" as one that satisfies two critical features. First, at a given point in time, some goods, the most complex ones, are produced by fewer countries, the most capable ones. Second, over time, capability growth increases when employment is shifted towards more complex sectors, a form of learning-by-doing that atomistic firms do not internalize. Under these two assumptions, we show that opening up to international trade must raise capability and real incomes around the world. This occurs because tougher competition lower down the ladder tends to push all countries to specialize in their more complex sectors and, in turn, to stimulate capability growth. Perhaps surprisingly, dynamic gains from trade at the top of the ladder do not occur at the expense of countries at the bottom and so these gains are pervasive rather than zero-sum.

The flip-side of this stark prediction, however, is that in alternative economies, where either more complex goods are produced by more countries or where specialization in these sectors slows down capability growth, opening up to trade must lead to pervasive dynamic losses instead, as we also show in the context of an "inverted ladder economy." According to our formalization of the ladder metaphor, the key question for signing the impact of trade on development is: Are capability-enhancing goods also the goods facing softer foreign competition? If the answer is yes, then trade openness is a force that tends to push all countries up the development ladder. If the answer is no, it tends to hold them all at the bottom.

To make progress on this question empirically and evaluate the importance of these considerations in practice, Section 3 introduces a quantitative version of our stylized ladder economy. We depart from it in two ways. First, we relax the assumption of a strict hierarchical structure in which only the most capable countries produce the most complex goods. Instead we only require that more capable countries be more likely, everything else equal, to produce and export more complex goods. This assumption is in the spirit of previous work by Hausman et al. (2007) and Hausman et al. (2013). It implies that more complex goods may or may not face softer competition, depending on whether they happen to be produced by fewer or more countries. Second, we specify the law of motion for capability as an auto-regressive process of order one whose mean value is a function of the average complexity of a country's output mix. This implies that shifting employment towards more complex goods may or may not stimulate capability growth, depending on whether this function is increasing or decreasing.

Section 4 presents our measures of complexity and capability. We use disaggregated trade data from the United Nations Comtrade Database to measure the complexity of hundreds of manufacturing goods, defined as an SITC 4-digit product, and the capability of 146 countries from 1962 to 2014. As noted above, to bring the ladder metaphor to the data we assume that the probability that a given country exports a good to a given destination increases with the product of that country's capability and that good's complexity. Accordingly, if a country is known to be more capable than another, say the United States versus Bangladesh, then one can identify more complex goods as those that are relatively more likely to be exported by the United States. Conversely, if a good is known to be more complex than another, say medicines versus underwear, then one can identify more capable countries as those that are relatively more likely to export medicines. Our estimates of complexity and capability are a fixed point consistent with both types of observation.

Our measures of complexity and capability reveal reasonable patterns, and are consistent with prior work. Throughout this period, rich countries, like the United States and Western Europe, are revealed to be among the most capable in the world, whereas poor countries, like much of Africa, remain at the bottom. East Asian countries like Korea and Thailand experience periods of rapid catch-up in capability while much of Latin America sees relative declines. Across goods, Medicines, Chemicals, and Cars are consistently revealed to be among the most complex, whereas Men's Underwear, Wood Panels, and Plastic Ornaments are among the least complex.

Section 5 focuses on the law of motion for capability and the estimation of dynamic spillovers. Do increases in the complexity of a country's industry mix raise its capability growth? The key empirical challenge to estimate these dynamic spillovers is the possibility that shocks to a country's capability growth are correlated with its industry mix. To deal with these issues, we require instrumental variables correlated with a country's sectoral employment but uncorrelated with unobserved determinants of its capability. The entry of other countries into the World Trade Organization (WTO) provides such variation. It allows us to construct time- and country-varying shifters of average complexity that rely on first-order approximations to the changes in a country's sectoral employment caused by WTO entrants enjoying lower trade costs with common trading partners. Intuitively, when a country like China enters the WTO, this reduces the sales of other countries' competing products in third markets. If these products that compete with China are more complex than other goods a country produces, as is the case for a less-capable country like Bangladesh, China's WTO entry reduces the average complexity of its product mix. If the competing products are less complex, as is the case for Italy, its product mix becomes more complex.

Our baseline IV estimates point to dynamic economies of scale in more complex sectors that are positive and statistically significant. Exogenous employment shifts towards more complex sectors tend to raise capability. Consistent with our ladder economy, the same exogenous shifts in sectoral employment are also associated with significant increases in real GDP per capita.

Do these positive spillovers, in turn, imply pervasive dynamic gains from trade? The counterfactual analysis of Section 6 offers a resounding no. After calibrating our quantitative model to match observed trade flows as well as our estimates of dynamic spillovers, we conclude that almost every country in our sample would experience *higher* capability under a counterfactual autarkic equilibrium. For the median country, these dynamic considerations lower the welfare gains from trade by 2.5%, though a few developing countries experience much larger welfare losses. The reason behind these pervasive losses is that in sharp contrast to the assumptions of the ladder economy, but in line with those of an inverted ladder economy, sectors that we have identified as more complex in Section 4 tend to face *more* foreign competition, not less.

The same conclusion—pervasive dynamic losses from trade—continues to hold when we consider alternatives measures of complexity and capability that are based on the assumption that more capable countries are those that tend to produce more goods, whereas more complex goods are those that tend to be produced by fewer countries. By construction, goods deemed more complex under this definition face softer foreign competition. Using the same IV strategy, however, we now estimate negative dynamic spillovers. As a result, capability-enhancing goods remain those facing tougher foreign competition. We also obtain similar results when we enrich our model to allow for heterogeneous substitutability between goods from different countries, which generates differences in the intensity of foreign competition across sectors; when we add input-output linkages, which break the mechanical relationship between cheaper foreign goods in a given sector and lower domestic employment in that same sector; and when we introduce sector-specific external economies of scale, which creates additional sources of domestic distortions.

The previous findings focus on whether, when a country opens up to trade, it tends to be pushed up the capability ladder or pulled down. A related but distinct question, more closely related to the reduced form of our IV, is what happens when other countries, such as China, join the world economy. In Section 7, we use our quantitative model as a springboard to explore this issue by constructing a counterfactual trade equilibrium without China from 1992 onward. Our results imply that while most countries benefited from trade with China, these gains occurred mainly through static considerations. In terms of its dynamic consequences, the rise of China actually pulled the majority of countries down, with particularly large losses for a number of African countries who are pushed away from their most-complex sectors, which China exports, and into their least-complex sectors, which China imports.

Related Literature

On the theory side, the static part of our model, with its emphasis on the interaction between a single country characteristic, capability, and a single good characteristic, complexity, is reminiscent of Krugman's (1986) technology gap model, Ricardian models of trade and institutions, like Matsuyama (2005), Levchenko (2007), Costinot (2009), and Melitz and Cunat (2012), and the recent work on quality and capability by Sutton and Trefler (2016) and Schetter (2020).[1] The ladder economy is a strict generalization of Krugman (1979). Like Krugman (1979), our model emphasizes differences in comparative advantage across countries that take place at the extensive margin, a key feature of the ladder metaphor motivating our analysis.[2] But unlike Krugman (1979), our model allows for more than two countries and imperfect substitutability between goods from different

[1] A similar focus on a ladder of countries can be found in Matsuyama (2004; 2013) where productivity differences between countries arise endogenously through symmetry breaking under free trade.

[2] Extensive margin considerations also feature prominently in de Carvalho Chamon and Kremer (2006) who study the impact of cross-country differences in population growth on development in a Ricardian model of trade with three goods—traditional, low-tech modern, and high-tech modern—where only developed countries can produce high-tech modern goods.

countries. The first generalization allows us to distinguish what happens at the top and the bottom of the ladder from what happens in most countries in the middle. The second generalization makes foreign costs decrease in the number of foreign countries that can produce a good, which gives all countries a comparative advantage in more complex goods relative to the rest of the world.

The dynamic part of our model, with its emphasis on external economies of scale, is related to earlier work by Krugman (1987), Boldrin and Scheinkman (1988), as well as Grossman and Helpman (1990), Young (1991) and Stokey (1991) who also allow inter-industry spillovers. A recurrent theme of this earlier literature on the dynamic effects of trade, as reviewed for instance by Grossman and Helpman (1995), is that there are good sectors, with opportunities for learning, and bad sectors, without them. For countries with a static comparative advantage in the former sectors, free trade therefore slows down productivity growth, opening up the possibility of welfare losses from trade liberalization. Our ladder economy maintains a similar good-sector-bad-sector dichotomy, but focuses on extensive margin considerations (in a many-country world) instead of intensive margin considerations (in a two-country world). This seemingly small change of perspective has important welfare implications. More complex sectors, i.e. the good ones, remain those that industrial policy should target, as we formally show. But in a ladder economy, dynamic gains from trade do not have to be zero-sum: all countries that are not at the bottom of the ladder experience strictly positive dynamic gains (since they face strictly more competition for their least complex goods), whereas the poorest country sitting at the bottom experiences neither dynamic losses nor gains (since it faces the same competition from the rest of the world in all sectors in which it is able to produce).

The previous feature is related to recent work by Perla, Tonetti and Waugh (2021), Sampson (2016), and Buera and Oberfield (2020). They focus on economies where firms of heterogeneous productivity can learn from each other. Since opening up to trade reallocates production towards larger, more productive firms, from which other firms have more learn, it also raises aggregate productivity. Hence, we share the same general feature that trade may lead to a reallocation of economic activities that is potentially growth-enhancing in all countries, though the empirical content and policy implications are very different. Rather than dynamic spillovers from large to small firms, we stress spillovers from more complex sectors to other sectors that operate by advancing a country's technological frontier—a mechanism closer to the earlier work of Young (1991), Stokey (1991) and Hausman et al. (2007) and one for which we offer direct empirical evidence.

On the empirical side, we view our estimates of complexity and capability as a bridge between the original, descriptive work of Hidalgo and Hausman (2009) and Hausman et al. (2013) and recent, structural work on comparative advantage by Costinot, Donaldson and Komunjer (2012), Levchenko and Zhang (2016), and Hanson, Lind and Muendler (2016). In the spirit of Hausman et al. (2013), we focus on the extensive margin of trade, that is, whether or not a country exports a particular good, as a way to identify capability and complexity.[3] But like Costinot, Donaldson and Komunjer (2012), Levchenko and Zhang (2016), and Hanson, Lind and Muendler (2016), we use a difference-in-difference strategy that controls for exporter-importer and importer-industry fixed effects. This allows us to separate capability and complexity from bilateral trading frictions and demand differences across countries.

Our estimation of dynamic spillovers is related to the influential work of Hausman et al. (2007) and the general debate about whether what countries export matters, as discussed, for instance, in Lederman and Maloney (2012) and Jarreau and Poncet (2012). Our instrumental variable strategy, based on the differential effects of new WTO members on countries with different industry mixes, aims to provide credible causal evidence that trade indeed matters for the pattern of development, rather than development mattering for the pattern of trade. Our evidence complements the recent work of Bartelme et al. (2019) who study the heterogeneous impact of sectoral foreign demand shocks on real income as well as recent papers such as Bloom et al. (2016) and Autor et al. (2017) that focus on the differential impact of Chinese imports on direct measures of innovation across sectors.

2 The Ladder Metaphor: A First Formalization

The goal of this section is to offer a first formalization of the ladder metaphor and study its implications for the causal relationship between trade and development.

2.1 A Ladder Economy

We consider an economy with many countries, indexed by i, and a continuum of goods or sectors, indexed by k. The total measure of goods is one. Time is continuous and indexed by $t \geq 0$. Labor is the only factor of production. We let $L_{i,t}$ denote the labor supply in country i at date t.

Preferences. In each country, there is a representative agent whose aggregate consumption $C_{i,t}$ derives from consuming varieties from different countries in different sectors,

$$C_{i,t} = (\int (C_{i,t}^k)^{(\epsilon-1)/\epsilon} dk)^{\epsilon/(\epsilon-1)}, \tag{1}$$

$$C_{i,t}^k = (\sum_j (c_{ji,t}^k)^{(\sigma-1)/\sigma})^{\sigma/(\sigma-1)}, \tag{2}$$

[3]See also Hummels and Klenow (2005) for the relative importance of the extensive margin of trade in explaining differences in GDP per capita.

where $\epsilon > 1$ is the elasticity of substitution between goods from different sectors, $\sigma > 1$ is the elasticity of substitution between varieties from different countries within a given sector, and $\sigma > \epsilon$ so that there is more substitutability within than between sectors. This implies that if a country i faces more foreign competition in a sector, that is lower foreign prices, then total expenditure on country i's variety in that sector decreases.

Technology. All production functions are linear,

$$q^k_{ij,t} = A^k_{ij,t} \ell^k_{ij,t}, \tag{3}$$

where $A^k_{ij,t} \geq 0$ denotes the productivity of firms producing good k for country j in country i at date t, inclusive of any transport cost, and $\ell^k_{ij,t} \geq 0$ denotes their employment. Countries differ in terms of their *capability*, $N_{i,t}$, whereas goods differ in terms of their *complexity*, n^k_t. For future reference, we let $F_t(n) = \int_{0 \leq n^k_t \leq n} dk$ denote the share of goods with complexity below a given complexity level n at date t.

At a given point in time, the most complex goods can only be produced by the most capable countries,

$$A^k_{ij,t} = \begin{cases} A_{ij,t} & \text{if } n^k_t \leq N_{i,t}, \\ 0 & \text{otherwise.} \end{cases} \tag{4}$$

Equation (4) allows for arbitrary trading frictions—since $A^k_{ij,t}$ may vary across origins, destinations, and over time—but we require $A^k_{ij,t}$ to be independent of k for all goods below a country's capability. Hence, comparative advantage is a purely extensive-margin affair, in the sense that if two countries i_1 and i_2 are both able to produce two goods k_1 and k_2, then $A^{k_1}_{i_1 j,t} / A^{k_1}_{i_2 j,t} = A^{k_2}_{i_1 j,t} / A^{k_2}_{i_2 j,t}$.

Over time, the evolution of a country's capability depends on its pattern of specialization. Specifically, we assume that changes in a country's capability are determined by its present capability, $N_{i,t}$, and the cumulative distribution of employment across sectors of different complexity, $F^{\ell}_{i,t}$,

$$\dot{N}_{i,t} = H_{i,t}(N_{i,t}, F^{\ell}_{i,t}), \tag{5}$$

$$F^{\ell}_{i,t}(n) = \frac{\int_{0 \leq n^k_t \leq n} \sum_j \ell^k_{ij,t} dk}{\int \sum_j \ell^k_{ij,t} dk}, \tag{6}$$

where $F^{\ell}_{i,t}(n)$ denotes the share of workers from country i employed at date t in sectors with complexity less than n. We leave the impact of present capability $N_{i,t}$ unrestricted, but require $H_{i,t}$ to be increasing in $F^{\ell}_{i,t}$ in the sense that if $F^{\ell}_{i,t}$ first-order stochastically dominates another employment distribution $F^{\ell'}_{i,t}$, then $H_{i,t}(N_{i,t}, F^{\ell}_{i,t}) \geq H_{i,t}(N_{i,t}, F^{\ell'}_{i,t})$. Put simply, complex sectors are good sectors in the sense that shifting employment towards more complex sectors causes higher capability growth. We view this general idea as being commonly associated, and often intertwined, with the ladder metaphor.

In the rest of this paper, we refer to an economy in which equations (4)–(6) hold and $H_{i,t}$ is an increasing function of $F^{\ell}_{i,t}$ as a *ladder economy*.

Market Structure. We focus on a sequence of static competitive equilibria with free trade in goods and financial autarky. At each date t, consumers maximize their utility subject to budget constraints; firms maximize profits taking both prices and capability levels as given; and goods and labor markets clear. These static equilibrium conditions determine wages, good prices, consumption, and employment as a function of current countries' capabilities. Employment shares across countries and sectors then determine countries' future capabilities. We report these equilibrium conditions in Appendix A.1.[4]

2.2 Trade and Development Redux

To evaluate the causal impact of trade on development in a ladder economy, we propose to compare the time paths of capabilities $\{N_{i,t}\}$ and aggregate consumption $\{C_{i,t}\}$ in the original equilibrium with productivity levels $\{A^k_{ij,t}\}$ to their time paths in a counterfactual autarky equilibrium with productivity levels $\{(A^k_{ij,t})'\}$ such that

$$(A^k_{ij,t})' = \begin{cases} A_{ij,t} & \text{if } n^k_t \leq N_{i,t} \text{ and } i = j, \\ 0 & \text{otherwise.} \end{cases} \tag{7}$$

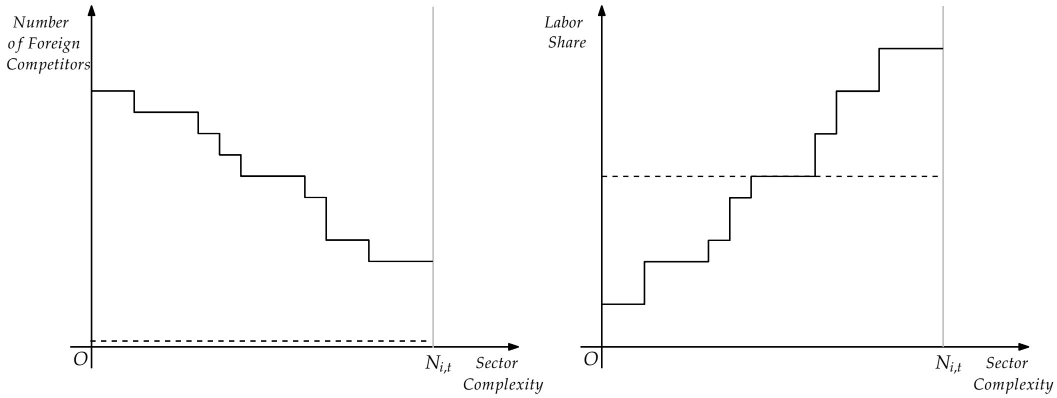
All other structural parameters, including the function $H_{i,t}(\cdot,\cdot)$ that determines the law of motion of a country's capability, are held fixed in the two equilibria.

In the counterfactual autarky equilibrium, all goods produced in a given country i have the same prices, $w_i / A_{ii,t}$; consumers there demand them in the same proportions; and employment shares are equal across sectors. As a result, the autarky employment distribution $(F^{\ell}_{i,t})'$ is equal to F_t in all countries. In the original trade equilibrium, this is not so. As shown in Appendix A.2, country i's employment in a sector k with complexity $n^k_t \leq N_{i,t}$ is equal to the sum of the labor used to serve all destination countries j,

$$\ell^k_{i,t} = \sum_j \frac{(A_{ij,t})^{\sigma-1}(w_{i,t})^{-\sigma}}{\left(\sum_{l:N_{l,t}\geq n^k_t}(w_{l,t}/A_{lj,t})^{1-\sigma}\right)^{\frac{\epsilon-\sigma}{1-\sigma}}} \frac{w_{j,t}L_{j,t}}{(P_{j,t})^{1-\epsilon}}.$$

As the complexity of goods increases, fewer and fewer countries are able to produce them, i.e., fewer countries l satisfy $N_{l,t} > n^t_k$. Thus, country i faces softer international competition, as illustrated in Figure 1a. Under the assumption that $\sigma > \epsilon > 1$, this increases

[4] For the interested reader, Appendix A.2 discusses sufficient conditions under which a competitive equilibrium exists and is unique. We note that we do not require the economy to be on a balanced growth path. We view this as a strength of our analysis, both for theoretical and empirical purposes, as it allows us to dispense with further restrictions on the time paths of F_t, $\{A_{ij,t}\}$, and $\{H_{i,t}\}$.



(a) Foreign Competition **(b)** Sectoral Employment

Figure 1: Changes in the Pattern of Specialization after Opening Up to Trade

Notes: Figure 1a plots the number of foreign competitors faced by country i against sector complexity n_t^k before (dashed line) and after (solid line) opening up to trade, across all the sectors that country i is able to produce ($n_t^k \leq N_{i,t}$). Figure 1b plots for the same country the share of labor employed in sectors of different complexity, both before (dashed line) and after (solid line) opening up to trade.

the price index in that sector in any destination, $P_{j,t}^k = [\sum_{l:N_{l,t} \geq n_k^t} (w_{l,t}/A_{lj,t})^{1-\sigma}]^{1/(1-\sigma)}$, which further raises sales and employment in country i. For any pair of sectors k_1 and k_2, it follows that employment in the more complex sector is relatively higher under trade than under autarky: $n_t^{k_1} \geq n_t^{k_2}$ implies $\ell_{i,t}^{k_1}/\ell_{i,t}^{k_2} \geq (\ell_{i,t}^{k_1})'/(\ell_{i,t}^{k_2})'$, as can be seen from Figure 1b. Accordingly, going from trade to autarky shifts down the employment distribution, $F_{i,t}^{\ell} \succeq_{fosd} (F_{i,t}^{\ell})'$, and since $H_{i,t}(N_{i,t}, \cdot)$ is increasing, this lowers the growth of capability, at impact, and the level of capability, at all subsequent dates. From a welfare standpoint, these dynamic considerations therefore strengthen the static case for the gains from trade.

We summarize this discussion in the next proposition. The formal proof can be found in Appendix A.3.

Proposition 1. *In a ladder economy, openness to trade raises capability and aggregate consumption at all dates in all countries.*

Like earlier work on the dynamic effects of trade, our ladder economy emphasizes a dichotomy between good sectors, which promote capability growth, and bad sectors, which slow it down. Yet, in contrast to earlier work, our ladder economy does not predict that countries specializing in good sectors under free trade win from these dynamic considerations, whereas countries specializing in bad sectors lose. Here, dynamic gains from trade are not zero-sum. According to Proposition 1, *all* countries enjoy higher capability and higher consumption because of international trade.

Although our ladder economy imposes strong restrictions on the distribution of productivity across countries and sectors—albeit restrictions that we think capture well the ladder metaphor that policymakers and practitioners appeal to—it allows for a general law of motion for capability and, in turn, rich dynamics for the distribution of productivity across countries and sectors. Proposition 1, for instance, can accommodate scale effects, such that variation in the size of sectors, rather than their shares of total employment, matters for capability. This simply corresponds to the special case where $H_{i,t}$ is a function of $L_{i,t}$.

Proposition 1 also allows for the possibility that at an arbitrary point in time, capability growth may be lower under trade than what they would have been under autarky. The proof of Proposition 1 relies on the observation that whenever capability levels coincide in the trade and autarky equilibria, differences in the distribution of employment between the two equilibria imply higher capability changes in the former. Whether or not countries are on a balanced growth path and whatever the equilibrium levels of wages may be, this difference in employment distributions is sufficient to guarantee higher levels of capability under trade at all dates, which further raises aggregate consumption relative to autarky. At worst, capability remains the same in the two equilibria, which is what happens in the country with the lowest capability. For this country, since the number of foreign competitors is the same in all sectors in which it produces, the distribution of employment across sectors remains given by F_t after opening up to trade.

The fact that comparative advantage may only express itself at the extensive margin is critical for this last observation. If we were to allow more capable countries to have a comparative advantage in more complex goods by assuming more generally that $A^k_{ij,t}$ is log-supermodular in $(n^k_t, N_{i,t})$, then the least capable country at the bottom would face tougher competition for its most complex products, exclusively through intensive margin considerations, and there would be winners and losers in line with earlier work on the dynamic effects of trade.[5]

2.3 Discussion

Could *all* countries be held at the bottom instead? According to Proposition 1, all countries are pushed to the top because (i) specialization in more complex sectors is capability-enhancing and (ii) all countries face less foreign competition in their more complex sectors. If one were to reverse either one of these two conditions, while holding the other fixed, the exact same logic would imply dynamic losses in *all* countries. To see this, consider two simple alternatives to the ladder economy, that are equivalent up to a change of variable, and which we will refer to as *inverted ladder economies*. In the first

[5] In the quantitative analysis of Section 6, we will reintroduce such intensive margin considerations along with the extensive margin considerations that are specific to the ladder metaphor.

one, we assume that $H_{i,t}$ is increasing in $F_{i,t}^{\ell}$, but instead of equation (4), we require that

$$A_{ij,t}^{k} = \begin{cases} A_{ij,t} & \text{if } g(n_t^k) \leq N_{i,t}, \\ 0 & \text{otherwise,} \end{cases} \tag{8}$$

with $g(\cdot)$ a strictly decreasing function. Hence, (i) still holds, but (ii) no longer does. In the second economy, we maintain the assumption that labor productivity is given by equation (4), but we now assume that $H_{i,t}$ is decreasing in $F_{i,t}^{\ell}$, so that (ii) holds but (i) does not. Either way, opening up to trade now pushes all countries towards sectors associated with lower capability growth. This leads to the following proposition, whose formal proof is given in Appendix A.4.

Proposition 2. *In an inverted ladder economy, openness to trade lowers capability at all dates in all countries and may lower aggregate consumption at some dates.*

The key issue for the impact of trade on development is whether goods that are capability enhancing also tend to face softer international competition. If the answer is yes, then dynamic gains from trade are pervasive, as predicted by Proposition 1. If the answer is no, dynamic losses are pervasive, as predicted by Proposition 2.

What are the policy implications of the ladder economy? Our ladder economy features external economies of scale. Firms' hiring decisions in different sectors affect a country's employment distribution and, in turn, its capability path, which firms do not internalize. By a standard Pigouvian argument, this calls for employment subsidies that increase with a sector's complexity, as formally shown in Proposition 3 in Appendix A.5. While the same rationale for industrial policy applies to closed and open economies, it should be clear that the social marginal value of changes in sectoral employment, like the magnitude of the optimal subsidies, may be affected by trade, as can also be seen from the proof of Proposition 3.

In the absence of optimal industrial policy, opening up to trade in a ladder economy helps correct the underlying distortion by moving workers from the least to the most complex sectors.[6] This is why, as we saw in Proposition 1, the existence of dynamic economies of scale magnifies the gains from trade. In an inverted ladder economy, distortions are aggravated instead and the gains from trade dampened, as we saw in Proposition 2.[7] Interestingly, regardless of whether we are in a ladder or inverted ladder economy, optimal industrial policy in the rest of the world always tends to reduce the dynamic gains from

[6]The same observation implies that trade taxes can also be used as a second-best instrument to help correct distortions in a country's output mix. Everything else being equal, import tariffs and export subsidies should tend to increase with a sector's complexity.

[7]Proposition 4 in Appendix A.6 offers explicit bounds on the magnitude of these dynamic gains, or losses, as a function of $H_{i,t}$ and a few sufficient statistics.

trade (or increase the dynamic losses). In either case, foreign subsidies that target the good sectors tend to make international competition tougher in those, thereby aggravating domestic distortions. We come back to this observation in our concluding remarks.

3 The Ladder Metaphor: Going from Theory to Data

In the previous section, we have provided sufficient conditions under which opening up to trade in the presence of capability ladders may cause either pervasive dynamic gains or losses. Which of these two polar scenarios is more likely in practice? The end goal of our paper is to make progress on this question and assess whether trade openness is a force that tends to push countries up the capability ladder or instead hold them at the bottom. The model from Section 2, however, is both too stylized and too general to be taken directly to the data. It is too stylized because we do not expect productivity across countries and sectors to satisfy the clear hierarchical structure imposed in equation (4). It is too general because we have yet to impose any parametric restriction on capability's law of motion in equation (5). Here we describe how our empirical and counterfactual analysis depart from the previous assumptions to evaluate the real world relevance of Section 2's predictions regarding the impact of trade on development.

3.1 Capability, Complexity, and Productivity

In the ladder economy, complexity and capability determine the set of goods that a given country can produce at some fixed productivity level $A^k_{ij,t} = A_{ij,t} > 0$, as described in (4). In our subsequent analysis, we propose to generalize this idea by treating $A^k_{ij,t}$ as a random variable whose probability of being non-zero depends on both country i's capability, $N_{i,t}$, and good k's complexity, $n_{k,t}$. In our baseline analysis, we assume that

$$\text{Prob}(A^k_{ij,t} > 0) = \delta_{ij,t} + \gamma^k_{j,t} + N_{i,t} n^k_t, \tag{9}$$

with independence across origins and goods, but not necessarily across destinations. In line with previous work on revealed comparative advantage (e.g. Costinot, Donaldson and Komunjer 2012, Levchenko and Zhang, 2016, and Hanson, Lind and Muendler 2016), the exporter-importer-year specific term $\delta_{ij,t}$ aims to capture bilateral trading frictions, whereas the importer-good-year specific term $\gamma^k_{j,t}$ aims to capture demand differences across countries. This leaves the interaction between capability and complexity $N_{i,t} n^k_t$ as the sole determinant of international specialization at the extensive margin.

Consistent with the ladder metaphor that motivates this paper, equation (9) captures the notion that "complex goods are what capable countries do" in the sense that more complex goods are more likely to be produced and exported by more capable countries. This is also similar in spirit to the existing empirical literature, e.g. Hausman et al. (2007)

and Hausman et al. (2013), that extracts measures of country and product sophistication from export patterns. Compared to equation (4), however, equation (9) implies that we may find that some countries produce certain goods whose complexity is above their capability. Importantly, equation (9) also does not impose that more complex goods are produced by fewer countries. Whether or not that is the case depends not only on the interaction term $N_{i,t}n_t^k$ but also on how $\gamma_{j,t}^k$ varies with good k's complexity. Finally, it is worth noting that conditional on producing and exporting a given good, $A_{ij,t}^k > 0$, we do not impose any restriction on the realization of the productivity draws $A_{ij,t}^k$ in the observed trade equilibrium. Instead, we will set those so that the calibrated economy exactly matches available trade data.[8]

3.2 Law of Motion for Capability

In our subsequent analysis, we assume that time is discrete and let changes in capability occur over a period Δ,

$$N_{i,t+\Delta} - N_{i,t} = H_{i,t}(N_{i,t}, F_{i,t}^{\ell}), \tag{10}$$

In addition, we depart from the general law of motion for capability described in (5) by imposing the following parametric restriction,

$$H_{i,t}(N_{i,t}, F_{i,t}^{\ell}) = \beta S_{i,t} + (\phi - 1) N_{i,t} + \gamma_i + \delta_t + \varepsilon_{i,t}, \tag{11}$$

where $S_{i,t} \equiv \int n dF_{i,t}^{\ell}(n)$ denotes the average complexity of the goods that country i produces. The first parameter, β, is the main coefficient of interest. It measures the magnitude of the dynamic spillovers. If $\beta > 0$, then $H_{i,t}$ is increasing in $S_{i,t}$ and a shift in the distribution of employment that increases the average complexity of country i's industry mix also increases future capability. If $\beta < 0$, the converse is true and increases in average complexity reduce future capability.

The second parameter, ϕ, determines the persistence of shocks. If $\beta > 0$ and $\phi < 1$, then positive and permanent shocks to the average complexity of a country's industry mix lead to an increase in capability changes, in the short-run, and convergence to a new steady state with a higher capability level in the long-run. In the knife-edge case $\phi = 1$, permanent shocks to average complexity have permanent effects on capability changes. Mathematically, ϕ plays a similar role as the returns to scale for ideas in endogenous growth models, for which $\phi = 1$, and semi-endogenous growth models, for which $\phi < 1$.[9]

The third parameter, γ_i, captures all country-specific determinants of capability growth that are constant over the 50-year horizon that we consider, such as geography or the ori-

[8] At the intensive margin, comparative advantage therefore does not have to be driven by the interaction of one-dimensional country and good characteristics.

[9] Jones (1999) and Atkeson and Burstein (2019) offer general discussions. Quantitatively, the magnitude of dynamic gains from trade depends both on β and ϕ, as can be seen from Proposition 4 in Appendix A.6.

gin of country i's legal system. The fourth parameter, δ_t, captures time-specific determinants due to global innovation such as the introduction of the internet. The final term, $\varepsilon_{i,t}$, captures all other idiosyncratic sources of technological innovations and domestic policies that may affect capability growth.[10] In practice, such considerations may also affect the average complexity of a country's industry mix; this is the key endogeneity issue that our IV strategy below seeks to address.

3.3 Other Assumptions

In the next sections, we will use equation (9) to estimate complexity and capability (Section 4) and equations (10) and (11) to estimate dynamic spillovers (Section 5). Before we do so, we briefly preview the other features of the quantitative model used for the counterfactual analysis of Section 6, with the full set of equilibrium conditions laid out in Appendix C.1. On the demand side, we maintain the assumption of nested CES preferences across tradable goods, as described in equations (1) and (2), but add a non-tradable sector that enters preferences in a Cobb-Douglas fashion, with $\theta_{i,t}$ the exogenous share of expenditure on manufacturing goods in country i at date t. We also allow for trade deficits, $D_{i,t}$, in the form of exogenous lump-sum transfers across countries. Finally, we maintain the same market structure as in Section 2. At each date, all markets are perfectly competitive, with free trade in goods and financial autarky.

4 Measuring Capability and Complexity

4.1 Empirical Strategy

To measure capability and complexity, we start from the observation that under CES preferences, trade flows $x^k_{ij,t} \equiv p^k_{ij,t} c^k_{ij,t}$ from country i to country $j \neq i$ in sector k at date t are non-zero if and only if productivity $A^k_{ij,t}$ is non-zero. Equation (9) therefore implies the following linear probability model,

$$\pi^k_{ij,t} = \delta_{ij,t} + \gamma^k_{j,t} + N_{i,t} n^k_t + \epsilon^k_{ij,t}, \tag{12}$$

where $\pi^k_{ij,t}$ is a dummy variable for whether or not $x^k_{ij,t} > 0$ and $\epsilon^k_{ij,t} \equiv \pi^k_{ij,t} - E[\pi^k_{ij,t}]$ is an error term.[11] According to equation (12), measuring capability and complexity boils

[10] Although $L_{i,t}$ does not appear on the right-hand side of the previous specification, it is worth noting that we implicitly allow for some scale effects. Both systematic differences in country size, absorbed in γ_i, and uniform changes in the world population, absorbed in δ_t, may affect capability growth.

[11] We utilize trade data as disaggregated product-level production data are not available for many countries and years. Our focus on the extensive margin both accords with our ladder economy and mirrors the influential work of Hausman et al. (2013). Practically, since most of the variation is on the extensive rather than intensive margin, estimates of $N_{i,t}$ and n^k_t are very similar when replacing $\pi^k_{ij,t}$ with the inverse hyperbolic sine of the quantity exported $x^k_{ij,t}$. We will explore the robustness of our conclusions to starker departures from equation (12) in Section 6.4.

down to estimating the interacted country-year and good-year fixed effects: $N_{i,t}$ and n_t^k.

To understand how we identify the two sets of fixed effects, it is useful to start from the extreme case where there are no error terms: $\epsilon_{ij,t}^k = 0$. In this case, one can take any pair of countries, say the United States (US) and Bangladesh (BG), and compare which of these two countries is more likely to export a given good k relative to another reference good k_0. Equation (12) then implies

$$n_t^k = n_t^{k_0} + \frac{(\pi_{USj,t}^k - \pi_{USj,t}^{k_0}) - (\pi_{BGj,t}^k - \pi_{BGj,t}^{k_0})}{N_{US,t} - N_{BG,t}}.$$

Intuitively, if the United States is known to be more capable than Bangladesh, $N_{US,t} - N_{BG,t} > 0$, then the fact that the United States is more likely to export good k relative to k_0, $(\pi_{USj,t}^k - \pi_{USj,t}^{k_0}) - (\pi_{BGj,t}^k - \pi_{BGj,t}^{k_0}) > 0$, reveals that good k is more complex than k_0. This explains why the double-difference inside the numerator above identifies complexity n_t^k, up to affine transformation.

The same logic applies to the identification of capability. If a good is known to be more complex than another, say medicines (ME) versus men's underwear (UW), then one can identify that country i is more capable than another reference country i_0 if it is more likely to export medicines than underwear. Formally, equation (12) implies

$$N_{i,t} = N_{i_0,t} + \frac{(\pi_{ij,t}^{ME} - \pi_{ij,t}^{UW}) - (\pi_{i_0j,t}^{ME} - \pi_{i_0j,t}^{UW})}{n_t^{ME} - n_t^{UW}},$$

which shows that capability $N_{i,t}$ is also identified, up to affine transformation.

We derive our estimators of capability and complexity by generalizing the previous argument to the case where there are error terms, but those are assumed to be mean zero:

$$\epsilon_{ij,t}^k = \xi_{i,t}^k + u_{ij,t}^k,$$

with $\xi_{i,t}^k$ mean zero and i.i.d across both goods and origins and $u_{ij,t}^k$ mean zero and i.i.d across goods, origins and destinations. Thus, we allow some countries to have unexpected export success in particular goods for which $\xi_{i,t}^k > 0$. By the law of large numbers, we can then construct consistent estimators of capability and complexity by averaging the previous double-differences for different sets of countries and goods.

The full description of our estimation procedure can be found in Appendix B.2. It discusses two additional issues. First, there are potentially many averages that one could take, each leading to consistent estimators, but with potentially different small sample properties. To address this issue, we propose an iterative procedure that guarantees that our estimators of capability and complexity are mutually consistent even in small samples. Specifically, we first estimate good complexity by comparing a good's average exports from G-10 countries to average exports from all countries, with more complex goods more likely to be produced by G-10 countries. Given these complexity measures, we next estimate country capability by comparing a country's average exports of more complex goods to average exports of all goods. In the next step, we use these new capability measures instead of membership of the G-10 to reestimate complexity, which we then use to recover another round of capability measures, etc., until both sets of measures have converged. Reassuringly, the set of capable countries in the first step of our iterative procedure has no effect on our ultimate estimates of capability and complexity except when we go to the extreme and select a random set of countries, as described in Appendix B.2.

Second, our estimators only converge to the true capability and complexity up to affine transformation. To deal with this indeterminacy, we further assume that (i) the lowest and highest complexity levels are time-invariant, $\min_k n_t^k = \underline{n}$ and $\max_k n_t^k = \bar{n}$; and (ii) the lowest complexity level is zero, $\underline{n} = 0$. Condition (i) implies that moving from specializing in the least to the most complex good generates the same-sized spillover in any period, whereas condition (ii) implies that there is no spillover from producing the least complex good. Although these two assumptions are not sufficient to identify the overall levels of complexity and capability, they are sufficient to estimate dynamic spillovers in Section 5 and to quantify the dynamic gains from trade in Section 6. Any remaining indeterminacy about complexity levels only affects the units in which β is measured in equation (11), whereas any remaining indeterminacy about capability levels only affects the value of the time-specific fixed effects in equations (11) and (12), without further consequences for the rest of our analysis.

4.2 Data

Our baseline empirical analysis uses trade data from 1962 to 2014 for 146 countries and 715 4-digit SITC Rev. 2 manufacturing products, which we will treat as the counterpart of a good or sector in our model.

All trade data are from the UN Comtrade database. It contains more than 3 billion records on annual imports and exports by detailed product code going back as far as 1962. We start by extracting all trade transactions between 1962 and 2014 across all countries in the database.[12] Transactions are concorded to the 4-digit SITC rev 2 level by Comtrade and all trade flows are converted into real 2010 US dollars using the US CPI. We then perform a number of data cleaning steps that closely follow Feenstra et al. (2005) (e.g. giving primacy to importer's reports where available, correcting values where UN values are known to be inaccurate, and accounting for re-exports of Chinese goods through Hong

[12] We combine East and West Germany in the years prior to reunification. Several countries report jointly for subsets of years in the database. For this reason, we combine: Belgium and Luxembourg; the islands that formed the Netherlands Antilles; North and South Yemen; and Sudan and South Sudan.

Kong).[13] This procedure gives us the value of trade flows $x^k_{ij,t}$ from country i to $j \neq i$ in good k at date $t = 1962,...,2014$. To ensure that estimates of the linear probability model (12) are picking up genuine exporting relationships as opposed to sample orders or small quantities of re-exports, we set the positive trade flow dummy $\pi^k_{ij,t}$ equal to 1 if the value of exports is greater than \$100,000 in 2010 US dollars and zero otherwise.

Out of the 1067 total products available in the Comtrade database, we restrict our attention to the 715 manufacturing products. These are the sectors where we expect the technological spillovers emphasized in our theory to be relevant. Out of the 233 countries available in the Comtrade database, we keep 146 countries that satisfy two restrictions. First, as we will ultimately be running panel regressions, we eliminate countries with fewer than 40 years of data. Second, to ensure that results are not driven by the world's smallest countries, we eliminate countries whose exports, averaged over any 5 year period, never rise above \$100 million in 2010 prices. The 146 countries included our baseline sample can be found in Appendix Table B.1.[14]

4.3 Estimates of Capability and Complexity

Before using our capability and complexity estimates to uncover the sign and strength of dynamic spillovers in Section 5, we start by describing how capability and complexity vary across countries and sectors. For convenience, and without loss of generality for our later analysis, we normalize the measures in Figure 2 and Table 1 below so that the average of US capability $N_{US,t}$ is equal to one; the average capability across all countries is constant over time; and the maximum complexity is equal to one, as discussed in Appendix B.2.

Estimates of Capability. Figure 2 plots the evolution of the recovered capability estimates, $N_{i,t}$, for a range of similarly-sized countries spanning different level of incomes both today and in the 1960s.[15] The estimates of $N_{i,t}$ resonate well with widespread priors about levels of economic development across countries and over time. Western European countries (e.g. Italy) experienced some catchup with the US in the 1960s and subsequently maintained high levels of capability only a little below the US. Starting from

[13] The dataset produced by Feenstra et al. (2005) has two shortcomings for our purposes. First, it only covers the years 1962-1999. Second, purchasing restrictions meant that for the years 1984-1999 they were only able to use trade flows that exceeded \$100,000 per year and only for 72 reporter countries. Thus we use the Feenstra et al. (2005) dataset from 1962-1983 but construct our own dataset for the years 1984-2014 using the full set of trade flows and reporter countries. We perform robustness exercises replacing the 1984-1999 entries in our dataset with the entries from Feenstra et al. (2005).

[14] The first restriction eliminates 84 countries that are either newly formed, no longer exist, or infrequently report. The second restriction eliminates 33 countries (many of which also have short panels).

[15] Larger countries tend to export more goods than smaller ones and the additional goods tend to be relatively complex. For a cleaner visual comparison we focus on similar-sized countries. As we discuss below, this association is absorbed through the use of country fixed effects in our regression analysis.

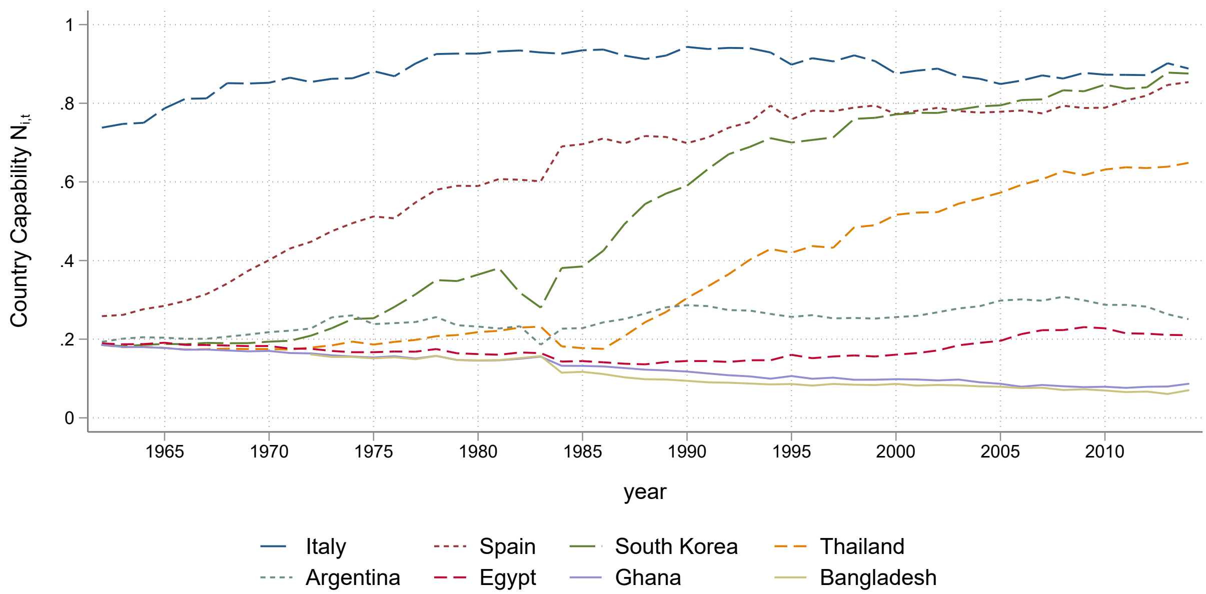


Figure 2: Capability Across Countries ($N_{i,t}$)

Notes: Figure 2 reports the country capability measure $N_{i,t}$ from the linear probability model estimation of equation (12) in a given year t. Capability is normalized so that average capability across all countries is constant over time and the value for the US equals one on average.

somewhat lower initial positions, initially more-backward European countries such as Spain saw their capabilities converge with Western Europe, with particularly rapid convergence in the first 20 years of our sample. Poor African countries such as Ghana had massively lower capability at the start of the period and have, if anything, fallen further behind since. A similar lack of catch up is evident for poor South Asian countries such as Bangladesh. In contrast, the rapid ascent of the East Asian Tigers (e.g. South Korea) in the 1960s through 1990s and the more recent South-East Asian growth miracles such as Thailand show up clearly. The experience of middle-income South American and Middle Eastern countries such as Argentina and Egypt lies somewhere in between these two poles with only limited capability catch up over our 53 year sample.[16]

Estimates of Complexity. We now turn to our baseline estimates of product complexity. Table 1 reports the goods with the 10 highest and 10 lowest values of complexity, averaging across all years from 1962 to 2014. The ranking of those products also fits well

[16]We can also study the relationship between our capability estimates and levels of development more formally by exploring the association with real GDP per capita. To examine the variation across countries within each year, we run a panel regression of log real GDP per capita on both capabilities and year fixed effects. We find a very strong positive relationship, with a coefficient of 2.9 and a standard error of 0.04. If we additionally include country fixed effects, and so are also exploiting variation across time within countries, we still find a strong relationship (coefficient of 1.7, standard error 0.06). Appendix Figures B.2 and B.3 present these relationships visually via binned scatterplots.

Table 1: Complexity Across Goods (n_t^k)

	Goods with highest n^k (Average Value and Rank, 1962-2014)				Goods with lowest n^k (Average Value and Rank, 1962-2014)		
1	Medicaments	0.964	3.7	1	Wool Undergarments	0.068	498.1
2	Chemical Products	0.874	11.2	2	Undergarments of Other Fibres	0.084	494.3
3	Miscellaneous Non-Electrical Machinery Parts	0.880	11.8	3	Men's Underwear	0.100	488.1
4	Miscellaneous Non-Electrical Machines	0.859	12.9	4	Wood Panels	0.097	487.4
5	Cars	0.863	13.8	5	Aircraft Tires	0.090	486.4
6	Miscellaneous Electrical Machinery	0.830	15.9	6	Rotary Converters	0.083	485.0
7	Medical Instruments	0.806	21.9	7	Sheep and Lamb Leather	0.109	476.7
8	Miscellaneous Hand Tools	0.809	23.8	8	Retail Yarn of More Than 85% Synthetic Fiber	0.093	470.4
9	Electric Wire	0.770	24.2	9	Women's Underwear	0.116	465.2
10	Fasteners	0.760	26.8	10	Plastic Ornaments	0.139	463.8

Notes: Table 1 reports the goods with the 10 highest and 10 lowest values of n_t^k from 1962 to 2014 based on each good's average rank (among goods with at least 40 years of data). The third column of each panel displays the average n_t^k, the fourth column the average rank. Complexity n_t^k is estimated year-by-year using the linear probability model described in equation (12). At every date t, complexity is assumed to be 0 for the least complex good and normalized to 1 for the most complex good. The mean of the standard deviation of each good's complexity is 0.09 (median 0.06, 90th percentile 0.23).

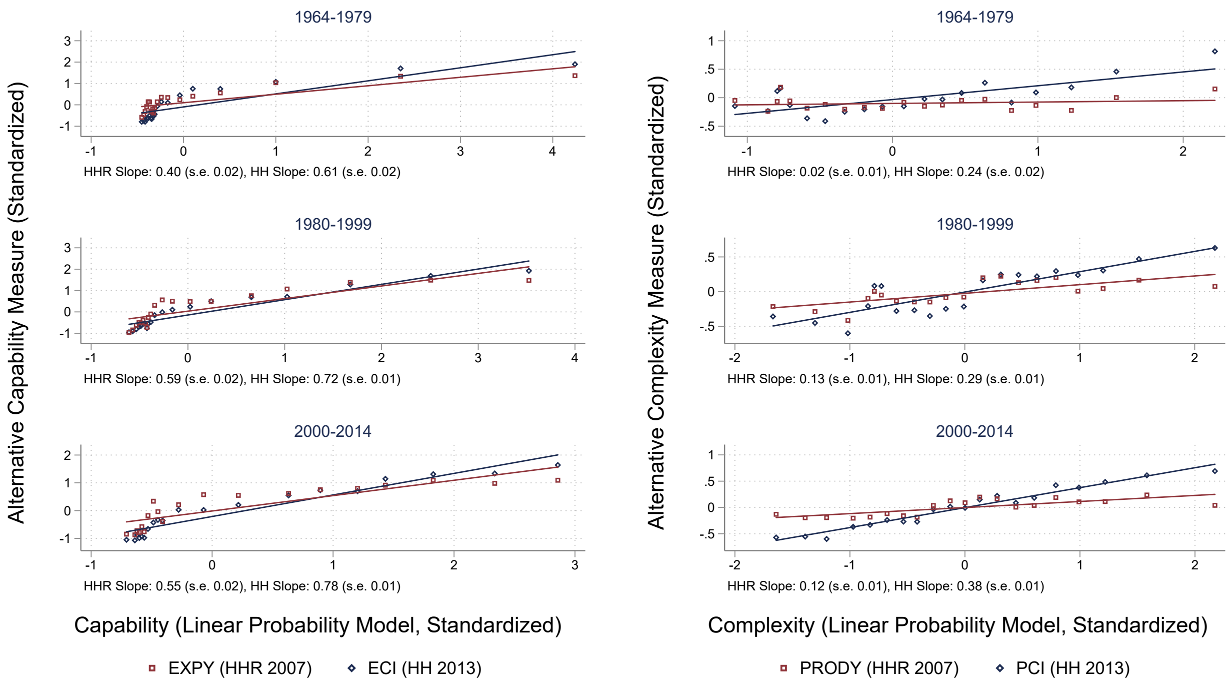
our priors about technological sophistication across sectors, and hence the potential for knowledge spillovers. Medicaments (i.e. medicines), chemicals and cars, for instance, are among the most complex products throughout our sample, whereas men's underwear, wood panels and plastic ornaments are among the least complex ones.

4.4 Comparison to Earlier Work

To conclude, we compare our baseline measures of capability and complexity to the work of Hausman et al. (2007) and Hausman et al. (2013) who also use trade data to construct technological indices of products and countries.

In Hausman et al. (2007), the counterpart to product complexity, $PRODY^k$, is defined as the weighted-sum of GDP per capita, Y_i, with weights equal to Balassa's (1965) measure of revealed comparative advantage in country i and sector k, whereas the counterpart of a country's capability, $EXPY_i$, is equal to the weighted sum of $PRODY^k$, with weights equal to the share of country i's exports in sector k.

In Hausman et al. (2013), the counterparts of capability and complexity, ECI_i and PCI^k, also highlight the extensive margin of trade, starting from the idea that some countries are more "diverse" than others, i.e. produce more goods, whereas some goods are more "ubiquitous" than others, i.e. are produced by more countries, and iterating to further account for whether a good is produced by more diverse countries, whether a country produces many goods that are produced by more diverse countries, and so on. In practice, Hausman et al. (2013) replace the raw matrix of zero trade flows with a matrix whose entries take a value of one if Balassa's (1965) revealed measure of comparative advantage



(a) Capability Measures (N_{it})

(b) Complexity Measures (n_t^k)

Figure 3: Comparison to Existing Measures of Capability and Complexity

Notes: Figure 3 compares our baseline measures of capability $N_{i,t}$ and complexity n_t^k from the linear probability model estimation of equation (12) to the capability and complexity measures in Hausman et al. (2007) (labeled EXPY and PRODY) and Hausman et al. (2013) (labeled ECI and PCI). Each panel plots binscatters of regressions of these two sets of measures on our baseline measures, absorbing year fixed effects and pooling observations by time period. Regression slope and standard error shown under each figure. All measures standardized mean 0 standard deviation 1 in each year.

is greater than one, and zero otherwise; they then compute normalized versions of the product of that rectangular matrix with its transpose as well as the product of the transpose with the matrix; and finally, they define the vectors of complexity and capability as the eigenvectors associated with the second-largest eigenvalues of these two matrices (normalized by the mean and standard deviation of each eigenvector).

Figure 3 reports how our baseline measures (on the x-axis) correlate with the measures of complexity and capability in Hausman et al. (2007) and Hausman et al. (2013) (red diamonds and blue circles) in different decades of our sample.[17] As can be clearly seen from Figures 3a and 3b, the three empirical measures are strongly and positively correlated, both for product complexity and country capability. This derives from the

[17] Figures are binscatters from regressing each of these existing measures on our baseline measure, controlling for year fixed effects. We start in 1964 rather than 1962 as the Hausman et al. (2013) measures are only available from that year forward.

fact that all three are designed to capture the same general idea that complex goods are what capable countries export, and vice versa.[18] A key benefit of our linear probability model, and the reason why we use it instead of these existing measures, is that it directly maps into primitive assumptions about technology, which we will leverage to conduct counterfactual and welfare analysis in Section 6.

5 Estimating Dynamic Spillovers

5.1 Baseline Specification

The next step of our empirical analysis uses the estimates of capability and complexity, $N_{i,t}$ and n_t^k, from Section 4 to estimate the dynamic spillovers parameterized in (10) and (11). Combining these two equations, we obtain

$$N_{i,t+\Delta} - N_{i,t} = \beta S_{i,t} + (\phi - 1) N_{i,t} + \gamma_i + \delta_t + \varepsilon_{i,t}. \tag{13}$$

In our baseline analysis, we set $\Delta = 5$ years. Given the lack of comparable production data at the product level across countries and time periods, we cannot directly measure $S_{i,t} \equiv \int n dF_{i,t}^{\ell}(n)$. Instead we use trade data to proxy country i's distribution of employment $F_{i,t}^{\ell}$ by its distribution of exports $F_{i,t}^{x}$, replacing $S_{i,t}$ by the average complexity of exports $S_{i,t}^{x} \equiv \int n dF_{i,t}^{x}(n) = \sum_k n_{i,t}^k \times (\sum_j x_{ij,t}^k / \sum_k \sum_j x_{ij,t}^k)$ in our baseline specification,

$$N_{i,t+\Delta} = \beta S_{i,t}^{x} + \phi N_{i,t} + \gamma_i + \delta_t + \varepsilon_{i,t}. \tag{14}$$

For future reference, note also that the restriction $F_{i,t}^{\ell} = F_{i,t}^{x}$ implies that country i is able to sell good k domestically, $A_{ii,t}^k > 0$, if and only if it is able to export it to at least one of its trading partners. We will maintain this assumption in our counterfactual analysis.[19]

5.2 Construction of Instrumental Variables

The main endogeneity concern is that shocks to country i's capability, $\varepsilon_{i,t}$, may be correlated with shocks to the average complexity of its industry mix in period t, $S_{i,t}^{x}$. For example, "good" policies implemented in period t, like investment in R&D and education, may simultaneously promote specialization in complex sectors and capability growth,

[18] We have also compared our empirical measures to those of Schetter (2022) who follows the same approach as Hausman et al. (2013), up to the choice of the initial matrix entering their procedures. Specifically, Schetter (2022) starts from a matrix of structural productivity estimates in a multi-sector model à la Costinot et al. (2012) rather than one based on Balassa's (1965) measure. While his capabilities measures are also strongly and positively correlated with ours, his complexity measures are not, with a small positive or negative correlation depending on the time period.

[19] The assumption $F_{i,t}^{\ell} = F_{i,t}^{x}$ is equivalent to assuming that the unobserved sector-level domestic sales, $x_{ii,t}^k$, are proportional to total exports in each sector, $x_{ii,t}^k = \zeta_{i,t} (\sum_{j \neq i} x_{ij,t}^k)$, for some time-and-country specific shifter $\zeta_{i,t}$. In Section 6, we will use data on total gross output in manufacturing to pin down $\zeta_{i,t}$ so that total domestic sales are consistent with both aggregate trade and production data.

leading to upward bias in β. Or, "bad" policies, such as subsidies to more complex sectors associated with rent-seeking industrialists or crony capitalism, may expand complex sectors but reduce capability growth or be accompanied by other polices that do, leading to downward bias in β. We now describe how we construct instrumental variables to deal with this issue.[20]

The general idea behind our IV strategy is to use the entry of countries into the WTO (or its predecessor, the GATT) as an exogenous shifter of other countries' distribution of exports, $F^x_{i,t}$, and, in turn, their average complexity, $S^x_{i,t}$. As country c enters the WTO at date τ, it faces lower tariffs from current WTO members. This tends to increase the demand for labor from country c and lowers the demand for labor from other countries, but differentially so across sectors and countries depending on country c's export mix. This, in turn, leads to differential effects of c's WTO entry on another country i's average complexity $S^x_{i,t}$ depending on whether country i's more complex sectors are those that are more or less exposed to country c—either because c sells a similar set of products, sells to a similar set of countries, or both. Our IV strategy builds on this observation and the assumption that the timing of country c's WTO entry is orthogonal to capability shocks in other countries. Our use of overlapping export bundles is related to the export similarity index of Finger and Kreinin (1979), although we are not aware of work combining such an index with trade shocks to other countries as we do.

We use our model both to guide the functional forms of this IV strategy and to clarify sufficient conditions for excludability. We start by modeling the entry of any given country c into the WTO at some date τ as a uniform and permanent decrease in trade costs of α%. We then derive, up to a first-order approximation, the counterfactual change in the average complexity of other countries that would have been observed at dates $t \geq \tau$, assuming the entry of country c was the only shock occurring from period τ onward and ignoring general equilibrium adjustments in wages.[21] Finally, we sum the previous changes across all events prior to date t, to obtain the following prediction for country i's average complexity at date t: $\hat{S}^x_{i,t} = S^x_{i,1962} - \alpha(\sigma - \epsilon)Z^I_{i,t} - \alpha(\epsilon - 1)(\sigma - \epsilon)Z^{II}_{i,t}$, where $Z^I_{i,t}$ is the change in average complexity caused by the changes in sector-level price indices associated with the WTO entry events and $Z^{II}_{i,t}$ is the change in average complexity caused

[20]Another endogeneity concern is standard in panel models with fixed effects. The lagged dependent variable, $N_{i,t}$, is mechanically correlated with the demeaned error term that accounts for the country fixed effect, $\varepsilon_{i,t} - \sum_{s=1}^{T} \frac{\varepsilon_{is}}{T}$, the so-called Nickell (1981) bias. Our sensitivity analysis in Section 5.4 suggests Nickell-bias worries are limited.

[21]Taking into account those adjustments would require us to already take a stand on the structural parameters of the model. For the purposes of constructing IV, ignoring those adjustments may weaken our first stage, but it does not affect the validity of our exclusion restriction. The same observation applies to the fact that we model WTO entry events as uniform changes in trade costs and ignore any variation across products and destinations.

by the changes in aggregate-level price indices, as described further below.

Building on this result, in the next subsection we will use $Z^I_{i,t}$ and $Z^{II}_{i,t}$ as separate IVs for country i's average complexity at date t. Although $\hat{S}^x_{i,t}$ itself depends on the structural parameters α, ϵ, and σ, conveniently our instruments $Z^I_{i,t}$ and $Z^{II}_{i,t}$ do not. As we formally establish in Appendix B.4, they take the form of shift-share IVs,

$$Z^I_{i,t} = \sum_{c\neq i}\sum_{\tau} s^I_{ic\tau,t} \times 1[\text{country } c \text{ joins the WTO at date } \tau],$$
$$Z^{II}_{i,t} = \sum_{c\neq i}\sum_{\tau} s^{II}_{ic\tau,t} \times 1[\text{country } c \text{ joins the WTO at date } \tau],$$

where the "shifts" are indicator functions that take the value 1 if country c joins the WTO at date τ and the "shares" capture the exposure at date t of country i's average complexity to this WTO entry event via its impact on either sector- or aggregate-level price indices,

$$s^I_{ic\tau,t} \equiv 1[t\geq\tau] \times \sum_k n^k_{\tau-\Delta} \underbrace{\omega^k_{i,\tau-\Delta}\Big(\sum_{j\neq c,i}\rho^k_{ij,\tau-\Delta}\lambda^k_{cj,\tau-\Delta} - \sum_{k'}\omega^{k'}_{i,\tau-\Delta}\sum_{j\neq c,i}\rho^{k'}_{ij,\tau-\Delta}\lambda^{k'}_{cj,\tau-\Delta}\Big)}_{\text{change in } k\text{'s export share predicted by sector-level price changes}}, \tag{15}$$

$$s^{II}_{ic\tau,t} \equiv 1[t\geq\tau] \times \sum_k n^k_{\tau-\Delta} \underbrace{\omega^k_{i,\tau-\Delta}\Big(\sum_{j\neq c,i}\rho^k_{ij,\tau-\Delta}\lambda_{cj,\tau-\Delta} - \sum_{k'}\omega^{k'}_{i,\tau-\Delta}\sum_{j\neq c,i}\rho^{k'}_{ij,\tau-\Delta}\lambda_{cj,\tau-\Delta}\Big)}_{\text{change in } k\text{'s export share predicted by aggregate-level price changes}}. \tag{16}$$

Note that shares are only functions of complexity measures and exports data at $\tau-\Delta$, prior to any given WTO entry event, where $\omega^k_{i,\tau-\Delta} \equiv \sum_{j\neq i} x^k_{ij,\tau-\Delta}/\sum_{k',j\neq i} x^{k'}_{ij,\tau-\Delta}$ is the share of exports in sector k and country i at that date; $\rho^k_{ij,\tau-\Delta} \equiv x^k_{ij,\tau-\Delta}/\sum_{j\neq i} x^k_{ij,\tau-\Delta}$ is the share of exports in country i and sector k associated with destination j; $\lambda^k_{cj,\tau-\Delta} \equiv x^k_{cj,\tau-\Delta}/\sum_{i\neq j} x^k_{ij,\tau-\Delta}$ is the share of expenditures on imports from country c in sector k and destination j; and $\lambda_{cj,\tau-\Delta} \equiv \sum_k x^k_{cj,\tau-\Delta}/\sum_{i\neq j,k} x^k_{ij,\tau-\Delta}$ is the share of expenditure on imports from country c (across all sectors) in country j.[22] Intuitively, $s^I_{ic\tau,t}$ in the first IV captures the complexity-weighted overlap between i and the WTO-entrant c's export mixes across both products and destinations just prior to entry, while $s^{II}_{ic\tau,t}$ in the second IV just focuses on the complexity-weighted overlap between the destinations the two countries sell to.[23] Note also that the dummy variable $1[t\geq\tau]$ in equations (15) and (16) ensures that any

[22] According to our model, $\lambda^k_{cj,\tau-\Delta}$ and $\lambda_{cj,\tau-\Delta}$ should be computed as shares of expenditure on all goods, not just imports. The difference between the two comes from the inclusion or absence of domestic sales in the denominator. For the purposes of constructing IVs—where proxying expenditure shares with import shares weakens the first stage but does not invalidate our instruments—we prefer to rely solely on product-level trade data that is well reported across many countries rather than impute domestic sales from aggregate gross output data (something that is required in our subsequent counterfactual analysis).

[23] While the destination-level variation in $\lambda_{cj,\tau-\Delta}$ is subsumed in the destination-product level variation $\lambda^k_{cj,\tau-\Delta}$, the first order approximation requires that both $Z^I_{i,t}$ and $Z^{II}_{i,t}$ are included when the elasticity of substitution between sectors, ϵ, is not unity. Note also that while we abstract from an explicit treatment of countries' industrial policies, their impact is implicitly accounted by the export shares $\omega^k_{i,\tau-\Delta}$.

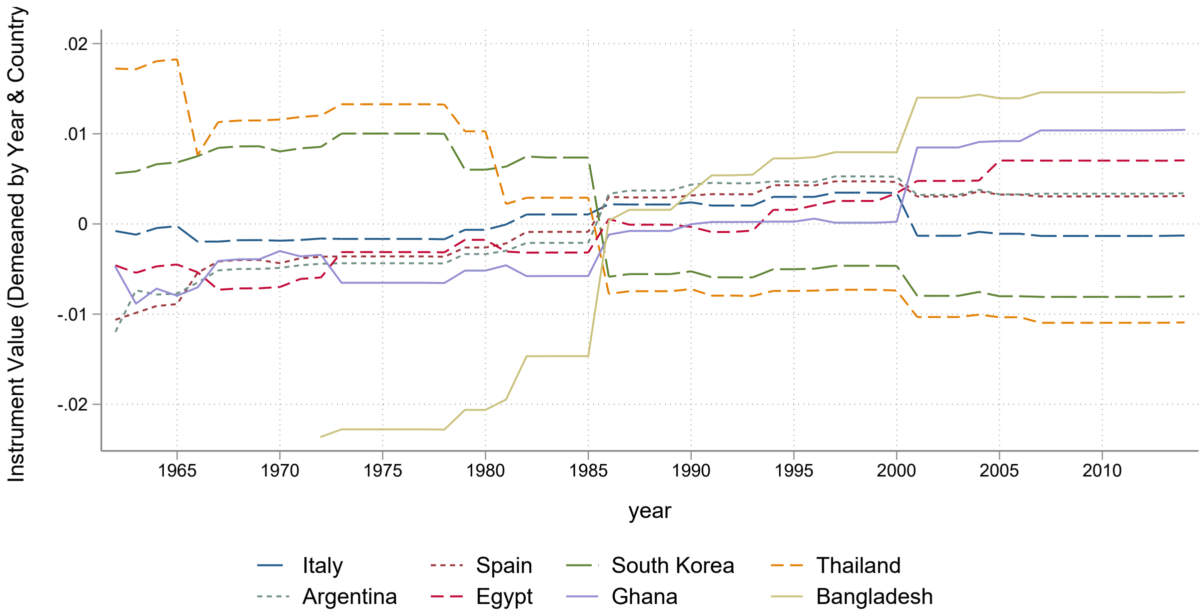


Figure 4: Time Path of $Z^I_{i,t}$

Notes: Figure 4 plots the value of the instrument $Z^I_{i,t}$ over time for a selection of similarly-sized countries. The instrument captures the change in complexity-weighted competition due to sector-level price index changes induced by other countries' entry into the WTO and derives from a first-order approximation of the change in average complexity due to trade cost shocks to WTO entrants, as described in Appendix B.4.

given country i may only be exposed to c's entry in the years $t \geq \tau$ that follow this event.

Following the logic of Borusyak et al. (2022), $Z^I_{i,t}$ and $Z^{II}_{i,t}$ are valid IVs if the shifts corresponding to WTO entry events, $\{1[\text{country } c \text{ joins the WTO at date } \tau]\}$, are mean independent, conditional on the capability shocks $\{\varepsilon_{i,t}\}$ and shares $\{s^I_{ic\tau,t}\}$ and $\{s^{II}_{ic\tau,t}\}$, and any impact of the mean of the shifts is absorbed by the country and year fixed effects, γ_i and δ_t.[24] Thus, we are exploiting the stochastic nature of the timing of WTO entries over our sample period, an identifying assumption we probe further in Section 5.4. Shifts may be serially correlated over time, e.g. after joining at date τ, country c may remain a member in all subsequent dates, and, thus, never enter again. Critically, we also do not need to impose further restrictions on the relationship between $\{\varepsilon_{i,t}\}$, $\{s^I_{ic\tau,t}\}$ and $\{s^{II}_{ic\tau,t}\}$. Hence, capability shocks may affect exports and, in turn, the complexity-weighted overlap in trade patterns between country i and WTO entrants.

In summary, the variation used to identify dynamic spillovers comes from whether new entrants in a particular time period disproportionately affect country i's more or

[24]As an alternative to using fixed effects, Borusyak et al. (2022) suggest to demean the shifts by controlling for the sum of the shares, i.e. $\sum_{c\neq i}\sum_{\tau} s^I_{ic\tau,t}$ and $\sum_{c\neq i}\sum_{\tau} s^{II}_{ic\tau,t}$. This requires, however, all shifts to have the same mean, which we view as implausible in our context. We return to this issue in Section 5.4 where, instead of relying on fixed effects, we explicitly model the dynamics of WTO entry events in order to compute the mean of each of our shifts and recenter our IVs, as in Borusyak and Hull (2020).

less complex products. To illustrate this variation, Figure 4 plots the time path of $Z^I_{i,t}$ for the same subset of countries as in Figure 2.[25] When China enters the WTO in 2001, we see that $Z^I_{i,t}$ jumps up for both Ghana and Bangladesh. This is because, according to our first-order approximation, competition from China in third markets affected products that were relatively complex compared to these two countries' product mix, potentially shifting them towards less complex products (a relationship we will document in our first stage regressions). In contrast, Italy, South Korea and Thailand, experienced a drop in $Z^I_{i,t}$ with China's entry as its relatively less complex sectors experienced greater competition—potentially tilting them towards producing more complex products. To identify whether those sectors are good or bad for capability growth, we can therefore verify whether Ghana and Bangladesh experienced a slowdown relative to other countries post 2000 and whether Italy, South Korea and Thailand experienced an acceleration. We exploit similar patterns in other years, for example 1986 when two other developing countries with large export sectors, Hong Kong and Mexico, entered the GATT.[26]

5.3 Estimates of Dynamic Spillovers

Before presenting our estimates of the sign and size of dynamic spillovers, we first show our first stage regressions for the IV strategy. In Table 2 we regress the average complexity of country i's export mix, $S^x_{i,t}$, on the two instruments described above,

$$S^x_{i,t} = \alpha_1 Z^I_{i,t} + \alpha_2 Z^{II}_{i,t} + \gamma_i + \delta_t + u_{i,t}. \tag{17}$$

As in the second stage regressions, we include year and country fixed effects, γ_i and δ_t respectively. Column 1 presents the first stage regression using only a single instrument $Z^I_{i,t}$, while column 2 presents both instruments. We find very strong negative relationships in either case. When both instruments are included, it is the second instrument that focuses on the overlap between i's export mix and the destinations the WTO entrant sells to that dominates. Interpreted through the lens of our first-order approximation, the negative sign of α_1 points towards an elasticity of substitution between countries within a sector σ that is greater than the elasticity of substitution between sectors ϵ, whereas the negative sign of α_2 suggests the upper-level elasticity ϵ is strictly greater than one.[27]

We now turn to estimating dynamic spillovers, β in equation (14) above. Columns 3–5

[25] For the interested reader, the time path for $Z^{II}_{i,t}$ can also be found in Appendix Figure B.4.

[26] Appendix Table B.1 presents the GATT/WTO accession dates for every country in our 146 country sample. As shown in Appendix Figure B.1, 1986 and 2001 were the two most significant entry years in terms of the share of world trade accounted for by new members prior to their entry.

[27] In theory, one could use the ratio of α_2 and α_1 to identify ϵ. This structural interpretation, however, would require stronger assumptions than those needed for $Z^I_{i,t}$ and $Z^{II}_{i,t}$ to be valid instruments, namely that WTO entries correspond to uniform changes in trade costs, that those are orthogonal to other changes in trade costs, and that general equilibrium responses are small enough to be ignored. In the quantitative exercise of Section 6, we therefore prefer using existing estimates of ϵ from the literature.

Table 2: Changes in Capability and Industrial Structure

	Average Complexity $S^x_{i,t}$		Country Capability $N_{i,t+\Delta}$			
	(1)	(2)	(3)	(4)	(5)	(6)
	FS	FS	OLS	IV ($Z^I_{i,t}$)	IV ($Z^I_{i,t}$, $Z^{II}_{i,t}$)	RF ($Z^I_{i,t}$, $Z^{II}_{i,t}$)
WTO Entrant IV $Z^I_{i,t}$	-0.647***	-0.151				-0.154***
(Product-Destination Level)	(0.214)	(0.224)				(0.0511)
WTO Entrant IV $Z^{II}_{i,t}$		-4.075***				-0.624***
(Destination Level)		(0.779)				(0.219)
Average Complexity $S^x_{i,t}$			0.00902**	0.366**	0.279***	
			(0.00389)	(0.147)	(0.0870)	
Initial Capability $N_{i,t}$			0.934***	0.831***	0.856***	0.932***
			(0.0208)	(0.0477)	(0.0353)	(0.0209)
Country and year FEs	Yes	Yes	Yes	Yes	Yes	Yes
Observations	7,617	7,617	6,872	6,872	6,872	6,872
R-squared	0.586	0.592	0.987	0.622	0.707	0.987
Clusters	1588	1588	1438	1438	1438	1438
CD F-Stat				30.15	37.25	
KP F-Stat				8.538	8.767	

Notes: Columns 1 and 2 of Table 2 report estimates of α_1 and α_2 in equation (17) by regressing the average complexity of country i's export mix in year t, $S^x_{i,t}$, on our two WTO entry instruments, $Z^I_{i,t}$ and $Z^{II}_{i,t}$, as well as country and year fixed effects. Instruments defined in equations (15) and (16) constructed from data on WTO entry events and the complexity-weighted overlap between i and the WTO-entrant's export mixes 5-years prior to entry. Measures of complexity n^k_t calculated using the linear probability model estimation of equation (12). Columns 3–6 report estimates of β and ϕ in equation (14) by regressing capability of country i in $t+5$, $N_{i,t+\Delta}$ with $\Delta = 5$, on the average complexity of i's export mix, $S^x_{i,t}$, initial capability, $N_{i,t}$, and country and year fixed effects, using the baseline measures of complexity n^k_t and capability $N_{i,t}$ from the same linear probability model. Columns 4 and 5 instrument average complexity of country i's export mix, $S^x_{i,t}$, by the two WTO entry instruments $Z^I_{i,t}$ and $Z^{II}_{i,t}$. Column 6 reports the reduced form regression corresponding to column 5. Standard errors clustered at the 5-year-period-country level.

of Table 2 present the regressions of country capability on the average complexity of the export mix in the previous period.[28] Column 3 shows the ordinary least squares regressions while columns 4 and 5 present the IV regressions using the WTO-entry instruments. Following the first stage discussion above, column 4 reports results using only the single instrument $Z^{I}_{i,t}$ that captures export-mix overlap with WTO entrants across both destinations and products, while our preferred column 5 allows these two dimensions to have different effects on the average complexity of i's export mix by using both $Z^{I}_{i,t}$ and $Z^{II}_{i,t}$ as instruments.

Both of our IV specifications show positive and significant coefficient estimates on the average complexity of the export mix, i.e. $\beta > 0$. Producing more complex goods raises a country's capability growth. The fact that the OLS estimate is much closer to zero is consistent with endogeneity concerns that bias β downwards, i.e. "bad" policies that retard capability growth at the same time as shifting resources into complex sectors. For example, a corrupt government may damage growth-enhancing institutions while putting in place policies that favor their cronies in industries with greater scope for learning.

Column 6 reports the corresponding reduced form regression. This is of independent interest as it directly reveals a policy-relevant comparative static: does a country's entry into the WTO push more capable countries up the ladder and less capable countries down? Column 6 shows that, indeed, the entry into the WTO of countries that compete with country i relatively more in the sectors and destinations where it sells its most complex goods retards capability growth. For example, in the case of China's WTO entry in 2001, these are countries like Ghana and Bangladesh, as can be seen from Figure 4. Conversely, the entry of countries competing with i's less complex goods raises capability growth. This is what happens, for instance, in Italy, South Korea and Thailand as a result of China's entry, as can also be seen from Figure 4.

5.4 Robustness

The previous finding of positive dynamic spillovers continues to hold across a range of robustness checks. This section focuses on robustness checks designed to alleviate concerns about: threats to the exclusion restriction related to the way we construct either the shifts or the shares entering our IVs; the existence of a mechanical relationship between the average complexity of a country's export mix and its future capability; heterogeneity in production processes and thus spillovers across rich and poor countries; and the relevance of our findings on capability growth for the growth in GDP per capita. Additional robustness analysis dealing with alternative data samples, alternative lag structures, and

[28] Recall that the period length $\Delta = 5$ years, as is common in growth regressions. Given the 5-year lead on $N_{i,t+\Delta}$, observations within 5-year periods are not independent and so we cluster standard errors at the 5-year-period-country level. Appendix B.6 finds similar results using one observation per period.

lagged IVs to address Nickel bias can be found in Appendix B.6.

Table 3 first explores the robustness of our baseline estimates—column 5 of Table 2 which we reproduce in column 1—to concerns that our instruments violate the exclusion restriction. Recall that our original IVs take a shift-share form that exploits the year of entry of other countries into the WTO interacted with the complexity-weighted overlap in trade patterns between country i and the WTO entrants. Our exclusion restriction may fail if WTO entry dummies are not mean independent, conditional on the shares $\{s^{I}_{ic\tau,t}\}$ and $\{s^{II}_{ic\tau,t}\}$. Even if the entry events are as good as random, the exclusion restriction may also be violated if the impact of the mean of these shifts is not absorbed by our country and year fixed effects, a possibility we highlighted in footnote 24.

To address these issues, we follow the logic of Borusyak and Hull (2020) and recenter our original IVs by simulating alternative histories of WTO entry from a data generating process (DGP) that takes into account the fact that wealthier countries tended to join earlier, and did so in fits and starts.[29] We perform 1000 simulations from this DGP and construct new IVs by subtracting from each shift $1[\text{country } c \text{ joins the WTO at date } \tau]$ its mean value across these simulations. Column 2 of Table 3 presents these recentered IV results. Reassuringly for our claim that identification in our baseline is coming from the random timing of WTO entries, the coefficient on average complexity rises only slightly and remains strongly significant.[30]

Next, we restrict our sample to countries who do not enter the WTO during our sample period, either because they were already in the WTO in 1962 or because they were still outside the WTO in 2014. We do so for both the estimation of dynamic spillovers, using equation (14), and for the measurement of capability and complexity, using equation (12). Dropping WTO entrants serves two purposes. First, this strengthens the assumption that WTO entry events are as good as randomly assigned conditional on the shares, since the shares of WTO entrants no longer enter our regressions. Second, this alleviates concerns of a mechanical relationship between predicted changes in countries' average complexity, $S^{x}_{i,t}$, and future capability, $N_{i,t+\Delta}$, perhaps due to the presence of adjustment costs and the fact that we recover capability from the complexity of a country's

[29]Specifically, we fix the number of entrants in each year t to equal the observed number of entrants, E_t. Starting in 1962, we then randomly draw a vector of E_t entrants without replacement from the 104 countries who had not joined prior to 1962 (with 86 of these joining by 2014). In any given year, we let each country's relative probability of entry be determined by the parameters obtained from a linear probability model projecting entry on log GDP per capita and year fixed effects (rescaling predicted values among at-risk countries to sum to 1 before each draw of a new entrant). We note that the leading example in Borusyak and Hull (2020) has a very similar structure to our instrument, constructing exogenous variation in market access by exploiting the randomness of the year of construction of various railway segments after conditioning on the number of regions a line connects.

[30]The coefficient on average complexity changes only slightly because the expected values of our two IVs over many alternative histories of WTO entry vary little within countries across time or within time periods across countries, as can be seen from Appendix Figure B.5.

Table 3: Changes in Capability and Industrial Structure: Robustness Checks

	Country Capability $N_{i,t+\Delta}$						$\ln GDP_{i,t+\Delta}$
	(1) Baseline	(2) Recenter IV	(3) No WTO Entrants	(4) Fixed n_0^k in IV	(5) Poor Countries	(6) Rich Countries	(7)
Average Complexity $S^x_{i,t}$	0.279***	0.311***	0.466**	0.307**	0.214**	0.239**	0.905**
	(0.0870)	(0.105)	(0.200)	(0.153)	(0.0908)	(0.0952)	(0.409)
Initial Capability $N_{i,t}$	0.856***	0.847***	0.746***	0.848***	1.073***	0.780***	
	(0.0353)	(0.0397)	(0.0584)	(0.0499)	(0.0458)	(0.0437)	
lnGDP per capita $GDP_{i,t}$							0.758***
							(0.0327)
Country and Year FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	6,872	6,872	2,806	6,872	2,812	2,801	6,107
R-squared	0.707	0.679	0.545	0.682	0.743	0.670	0.589
Clusters	1438	1438	591	1438	595	586	1269
CD F-Stat	37.25	28.63	11.98	9.552	15.01	55.77	64.98
KP F-Stat	8.767	6.955	4.560	2.571	6.277	7.815	17.11

Notes: Table 3 reports estimates of β and ϕ in equation (14) by regressing capability of country i in $t+5$, $N_{i,t+\Delta}$ with $\Delta=5$, on the average complexity of i's export mix, $S^x_{i,t}$, initial capability, $N_{i,t}$, and country and year fixed effects, using the baseline measures of complexity n_t^k and capability $N_{i,t}$ from the linear probability model estimation of equation (12). All columns use the two-instrument IV strategy to instrument for $S^x_{i,t}$. Column 1 reports our baseline estimates (column 5 of Table 2). Column 2 recenters both IVs by drawing from a DGP for WTO entry 1000 times, as described in footnote 29, and subtracting off the mean value of the 1000 draws for each it pair. Column 3 re-estimates $N_{i,t}$ and n_t^k using only countries who do not enter the WTO during our sample period, 1962–2014, and also excludes these countries from the regression sample (the instrument is still formed by exploiting the many WTO entry events and the export overlap of the non-entrants sample with the WTO entrants). Column 4 constructs the instruments using a fixed value of complexity, the value of n_t^k in the first year product k appears, to weight the export overlap with WTO entrants. Columns 5 and 6 split the sample by poor and rich countries, defined as whether the country-level mean of log real GDP per capita across all years (using RGDPE from the Penn World Tables 9.0) is above or below the sample median for that object. The median split is identical if log real GDP per capita is first demeaned by year before taking country means. Column 7 replaces the dependent variable capability by log GDP per capita (again using RGDPE from the Penn World Tables 9.0). Standard errors clustered at the 5-year-period-country level.

export mix.[31] By dropping WTO entrants, we make sure that each WTO entry event shifts demand uniformly within a given product-destination (under the assumption of nested CES preferences). Accordingly, their impact on exports should be fully absorbed by the product-destination-year fixed effects in our linear probability model, without further consequences for our estimates of capability. Reassuringly, column 3 shows that the estimates of dynamic spillovers for this subsample remain positive and significant, albeit slightly larger in magnitude.

To further alleviate concerns that WTO entry events may not be as good as randomly assigned conditional on the shares, we also consider alternative IVs that keep the shifts unchanged, but interact them with new shares constructed as in equations (15) and (16), except for the fact that complexity measures are fixed at their value in the first year the product appears rather than their (time-varying) pre-entry values at $\tau - \Delta$. As shown in column 4, our estimates change little—shutting down the possibility that the co-determination of complexity and capability in any given period is driving our results.

A distinct concern with the measures of complexity used in our baseline specification is that they may mask enormous differences in the manufacturing techniques used, and thus the opportunities for learning and spillovers, within our 715 4-digit SITC product codes. While it is of course true that the level of sophistication of the typical medicines exported by the US far exceeds those exported by Bangladesh, the same is also likely to be true for underwear. What matters for the propositions derived in Section 2 is that the production of US medicines rather than US underwear generates greater spillovers for the US, and that Bangladeshi medicines rather than Bangladeshi underwear generate greater spillovers for Bangladesh. Columns 5–6 resolve this question empirically by splitting our sample into rich and poor countries (based on the country-level mean of log GDP per capita). We find equally strong dynamic spillovers among both rich and poor countries, suggesting that even if the same goods differ in their complexity across countries, the ranking of high and low spillover goods within countries remains fairly stable.

Finally, one may wonder whether the changes in capability that we document do go hand-in-hand with changes in GDP per capita, as they do in our model. To answer this question, column 7 replaces the capability of country i with the log of its GDP per capita. As with capability, we find that a decrease in the average complexity of a country's export mix (instrumented by shocks coming from WTO entrants) reduces future GDP per capita, conditioning on initial GDP per capita and both country and year fixed effects. This re-

[31] In our model, there is no mechanical relationship between $S^x_{i,t}$, $N_{i,t}$, and $N_{i,t+\Delta}$ because $S^x_{i,t}$ only varies with changes in exports at the intensive margin, whereas $N_{i,t}$ and $N_{i,t+\Delta}$ only depend on changes in exports at the extensive margin. In practice, however, we do code small values of exports as zeroes, potentially conflating these two margins and creating a spurious correlation between $S^x_{i,t}$ and $N_{i,t}$ as well as between $S^x_{i,t}$ and $N_{i,t+\Delta}$ in the presence of adjustment costs.

sult resonates well with the growth regressions in Hausman et al. (2007) among others. It also helps distinguish the predictions of our theory from those of a Ricardian model with uniform external economies of scale (e.g. $A^k_{ij,t} \propto (\ell^k_{i,t})^\beta$ with $\beta > 0$). In such a model, one would also observe that exogenous shifts of employment in a subset of sectors lead to subsequent expansions of those sectors, since their relative productivities increase. However, such cross-sectoral reallocations would have zero first-order effects on real income, and hence GDP per capita, since the economy remains efficient.[32]

6 Pushed to the Top or Held at the Bottom?

In Section 5, we have documented positive dynamic positive spillovers from shifting employment towards more complex sectors. This finding implies pervasive dynamic gains from trade if more complex sectors systematically face softer international competition, as shown in Proposition 1 for a ladder economy, but pervasive dynamic losses if the opposite is true, as shown in Proposition 2 for an inverted ladder economy. We now explore which, if either, of these two theoretical benchmarks is more relevant in practice.

6.1 Baseline Economy

We focus on a baseline economy in which preferences, technology, and market structure satisfy the assumptions from Section 3. In line with the empirical analysis from Section 4, we treat each tradable good in our model as the counterpart of a 4-digit manufacturing product in the data; and following the timing assumptions in Section 5, we focus on 5-year intervals with $t = 1962, 1967, ..., 2012$.

On the demand side, consumers have nested CES preferences over tradables, like in the ladder economy, and Cobb-Douglas preferences between tradables and non-tradables. To calibrate the lower-level preferences over tradables described in equations (1) and (2), we set $\epsilon = 1.36$ in line with the elasticity of substitution between 4-digit sectors in Redding and Weinstein (2018) and $\sigma = 2.7$ in line with the median elasticity of substitution within 4-digit sectors in Broda and Weinstein (2006).[33] To calibrate the upper-level Cobb-Douglas preferences, we set the exogenous share $\theta_{i,t}$ of expenditure on tradable goods in country i at date t to match the share of expenditure on manufacturing goods in the OECD input-output tables whenever available.[34] Consumers may also receive lump-sum

[32] Another distinction between such a model and ours is that it would predict that shifts in employment affect production and exports at the intensive margin, whereas our model predicts changes at the extensive margin, consistent with how we measure capability in Section 4 and, in turn, how we identify dynamic spillovers in this section.

[33] We are not aware of other estimates of the elasticity of substitution between sectors at the 4-digit level. At the 2-digit level, Oberfield and Raval (2014) report estimates of the elasticity of substitution between sectors centered around one. As already mentioned in Section 5.3, our first stage coefficients point towards an elasticity of substitution between sectors ϵ that is greater than one.

[34] From 1968 to 1990, OECD input-output tables only include nine countries and even for those there are

Parameter	Value	Choice Calibration
Panel A: Nested CES Preferences		
σ	2.7	Broda and Weinstein (2006)
ϵ	1.36	Redding and Weinstein (2018)
Panel B: Dynamic Spillovers		
β	0.279	Baseline estimate (Table 2, Column 3)
ϕ	0.856	Baseline estimate (Table 2, Column 3)

Table 4: Baseline Economy

transfers $D_{i,t}$ from other countries, which we set to be equal to the difference between the value of imports and exports of manufacturing goods.

On the supply side, production functions are linear, like in the ladder economy, but we depart from equation (4) and do not impose any a priori restrictions on the productivity of different manufacturing goods. Instead, we set $\{A^k_{ij,t}\}$ so that the baseline economy matches all trade data in year t, as described in Appendix C.2. This implies that comparative advantage may express itself both at the intensive and extensive margins.[35] Finally, we set labor supply $L_{i,t}$ to match the total sales of country i, as also described in that appendix.

We follow a similar approach for dynamic considerations. We assume that the law of motion for capability is an AR1, with persistence ϕ, that depends on the average complexity of a country's output mix, with β controlling the magnitude of dynamic spillovers, as described in equation (14). We use $\beta = 0.288$ and $\phi = 0.855$, as reported in column 5 of Table 2. We then set the capability shocks, $\hat{\varepsilon}_{i,t} \equiv \varepsilon_{i,t} + \gamma_i + \delta_t$, so that conditional on the measure of complexity estimated in Section 4.3, the baseline economy perfectly matches the path of capability $N_{i,t}$ estimated in the same section, $\hat{\varepsilon}_{i,t} = N_{i,t+\Delta} - \beta S^x_{i,t} - \phi N_{i,t}$.[36] Table 4 reports the values of the main structural parameters used in our baseline economy.

missing years. Starting in 1995, the data is available every year for 64 countries. To fill missing observations, we regress the log of expenditure shares on country and time fixed effects, θ_i and θ_t, respectively, and set the missing observations to $\theta_{it} = \theta_i + \theta_t$. Whenever, θ_t is missing, we linearly interpolate over time. Whenever θ_i is missing, we replace with the average values from the other countries.

[35] When specifying nested CES preferences, we have chosen units so that all goods enter symmetrically. It should be clear that this normalization has no implication for our quantitative results. More generally, if $C^k_{i,t} = (\sum_j (B^k_{ji,t} c^k_{ji,t})^{(\sigma-1)/\sigma})^{\sigma/(\sigma-1)}$, then the procedure in Appendix C.2 identifies the product of the supply and demand shocks $\{A^k_{ji,t} B^k_{ji,t}\}$ required to match the trade data, without further consequences for our analysis.

[36] If export data is missing for a country at some intermediate date t, $S^x_{i,t}$ and $N_{i,t}$ are unobserved and we compute $\hat{\varepsilon}_{i,t}$ by setting $S^x_{i,t} = S^x_{i,t-\Delta}$ and $N_{i,t} = N_{i,t-\Delta}$.

6.2 Construction of the Counterfactual Autarkic Equilibrium

To quantify the static and dynamic effects of trade for development, we return to the counterfactual question of Section 2.2: If a country were to go back to autarky from 1962 onwards, what would be the consequences for its capability and welfare?

For each country i and each year t, we construct the counterfactual autarkic equilibrium as follows. In 1962, we start by setting the counterfactual autarkic capability to the value observed in the initial equilibrium, $(N_{i,1962})' = N_{i,1962}$. We then proceed iteratively.

Step 1: Which goods are produced at date t? In any year $t \geq 1962$, given the counterfactual autarkic capability $(N_{i,t})'$ and the observed measures of complexity n_t^k, we first determine the set of goods that country i produces at that date under autarky, i.e. those such that $(A_{ii,t}^k)' > 0$. To do so, we use the linear probability model associated with equation (9). The specifics of our procedure, described in Appendix C.3, deals with three distinct issues. First, our empirical analysis relies on the assumption that a country i is able to produce good k for its domestic market at date t if and only if it is able to export it to at least one foreign market, i.e. $\Pr[A_{ii,t}^k > 0] = 1 - \prod_{i \neq j} \Pr[A_{ij,t}^k = 0]$. We therefore impose the same restriction when computing $\Pr[(A_{ii,t}^k)' > 0]$. Second, the linear probability model that we have estimated may generate probabilities above one or below zero. We therefore truncate them whenever needed. Third, we keep the counterfactual autarkic equilibrium as close as possible to the observed trade equilibrium by requiring that if country i produces good k at date t under trade (i.e., $A_{ij,t}^k > 0$ for some j) and its capability goes up under autarky (i.e., $(N_{i,t})' \geq N_{i,t}$), then country i still produces that good in the autarky counterfactual (i.e., $(A_{ii,t}^k)' > 0$); and conversely, that if a good is not produced under trade (i.e., $A_{ij,t}^k = 0$ for all j) and capability goes down (i.e., $(N_{i,t})' < N_{i,t}$), then country i is still unable to produce that good under autarky (i.e., $(A_{ii,t}^k)' = 0$). Formally, letting $\pi_{i,t}^k$ and $(\pi_{i,t}^k)'$ denote dummy variables that equal one if country i produces good k at date t under trade and autarky, respectively, we set

$$(\pi_{i,t}^k)' = \begin{cases} \pi_{i,t}^k + (1 - \pi_{i,t}^k) d_{i,t}^k & \text{if } (N_{i,t})' \geq N_{i,t}, \\ \pi_{i,t}^k + \pi_{i,t}^k (1 - d_{i,t}^k) & \text{if } N_{i,t}' < N_{i,t}, \end{cases}$$

where $d_{i,t}^k \in \{0,1\}$ is a random Bernoulli variable, independently drawn across all k, whose distribution is chosen so that $(\pi_{i,t}^k)'$ remains consistent with (9).

Step 2: What is the productivity of goods produced at date t? The next step of our procedure draws the counterfactual productivity levels $(A_{ii,t}^k)'$, conditional on $(A_{ii,t}^k)' > 0$. If a good is already produced in the initial equilibrium, we set $(A_{ii,t}^k)' = A_{ii,t}^k$; if it is not, we randomly draw $(A_{ii,t}^k)'$ from a log-normal distribution whose mean is equal to the sum of the country-time and sector-time fixed effects, $A_{i,t}$ and A_t^k, estimated from the following log-linear regression, $\ln A_{ii,t}^k = A_{i,t} + A_t^k + \alpha_{i,t}^k$, and whose standard deviation is equal to the standard deviation of the estimated residuals. Finally, for all destinations $j \neq i$, we set $(A_{ij,t}^k)' = 0$, so that trade is prohibited.

Step 3: What is future capability at date $t+\Delta$? Given the set of autarky productivity draws $(A_{ij,t}^k)'$ and using country i's labor as our numeraire, $(w_{i,t})' = 1$, we can then use the equilibrium conditions given in Appendix C.1 to solve for all autarky prices and quantities at date t in country i: $(p_{ii,t}^k)'$, $(c_{ii,t}^k)'$, and $(l_{ii,t}^k)'$. Once the counterfactual employment distribution $(F_{i,t}^\ell)'$ is known, the counterfactual autarkic capability at date $t+\Delta$ can be computed using

$$(N_{i,t+\Delta})' = \beta \int nd(F_{i,t}^\ell)'(n) + \phi (N_{i,t})' + \hat{\varepsilon}_{i,t}.$$

This expression summarizes how the lack of foreign competition under autarky shapes future capability and, in turn, the set of goods that each country can produce at date $t+\Delta$.

For each country, we simulate the full counterfactual autarkic path 1000 times and take averages over these 1000 simulations.[37]

6.3 Static and Dynamic Consequences of International Trade

For each period $t \geq 1962$, we define the gains from trade for country i at that date as

$$GT_{i,t} = 1 - \frac{(C_{i,t})'}{C_{i,t}},$$

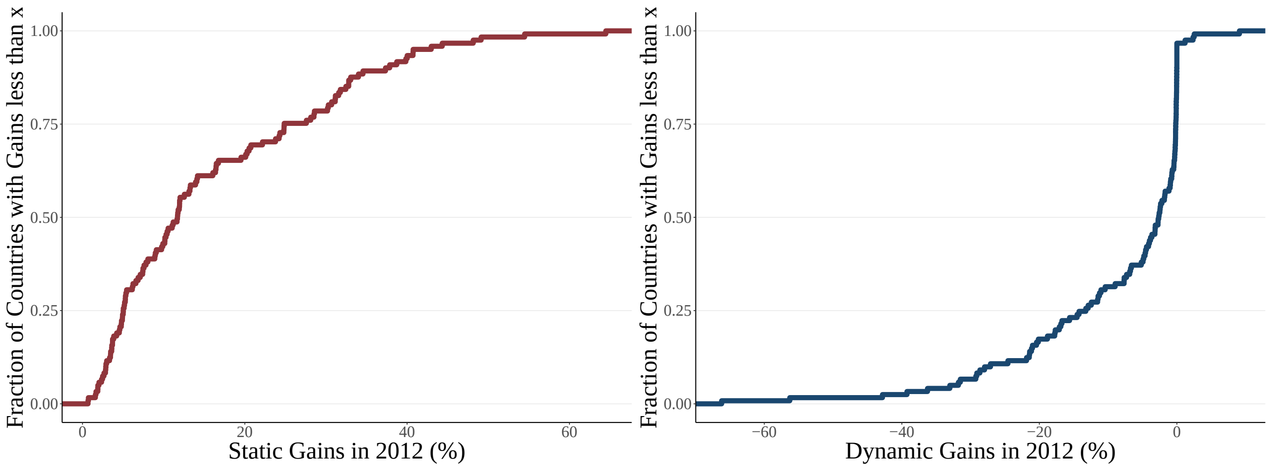
where $C_{i,t}$ and $(C_{i,t})'$ are the aggregate consumption levels in the original trade equilibrium and the counterfactual autarkic equilibrium, respectively.

To decompose the gains from trade into a static and dynamic component, we consider a second counterfactual autarkic equilibrium in which we also set $(A_{ij,t}^k)'' = 0$ for all destinations $j \neq i$, but we now keep capability at the same level as in the original trade equilibrium, $(N_{i,t})'' = N_{i,t}$ for all t. The static gains from trade at date t then correspond to

$$GT_{i,t}^S = 1 - \frac{(C_{i,t})''}{C_{i,t}}, \tag{18}$$

where $(C_{i,t})''$ denotes the aggregate consumption level associated with that second autarkic equilibrium. The dynamic gains from trade, in turn, are defined as the difference

[37]When computing the autarkic equilibrium, we keep fixed the lump-sum transfer received by each country as a share of its own GDP, which guarantees that trade imbalances do not affect the magnitude of the gains from trade. This procedure is equivalent to adjusting the labor endowment of each country under autarky in proportion to the transfer it receives under trade. In a very small number of simulations, a country may be unable to produce at a given date t. In these cases, we infer $(N_{i,t+\Delta})'$ by setting $\int nd(F_{i,t}^\ell)'(n) = \int nd(F_{i,t-\Delta}^\ell)'(n)$.



(a) Distribution of the Static Gains from Trade

(b) Distribution of the Dynamic Gains from Trade

Figure 5: Welfare Consequences of International Trade

Notes: Figure 5a reports the distribution of the static gains from trade, $GT^S_{i,t}$, as described in equation (18), in 2012. Figure 5b reports the distribution of the dynamic gains from trade, $GT^D_{i,t}$, as described in equation (19), for the same countries and year.

between the total gains from trade and the static component,

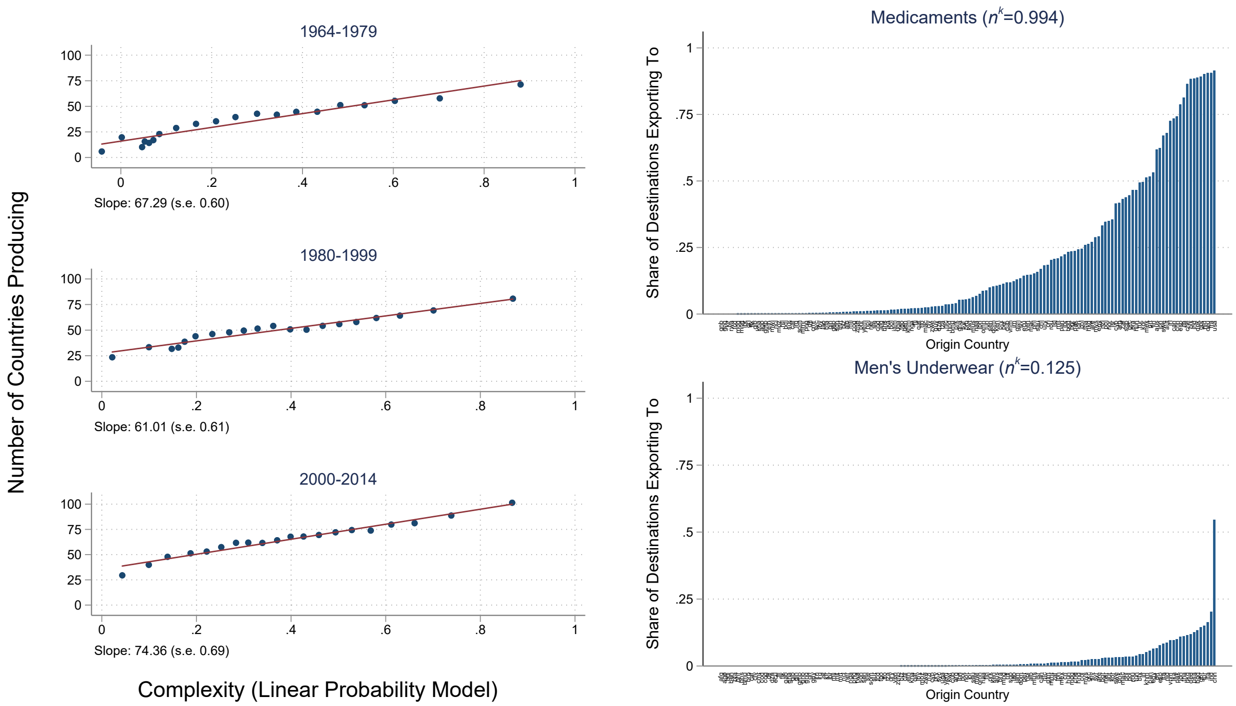
$$GT^D_{i,t} = GT_{i,t} - GT^S_{i,t}. \tag{19}$$

For expositional purposes, we focus on 2012, the end of our last 5-year period.[38] Figure 5 reports the static and dynamic gains from trade across countries. In Figure 5a, we see that the static gains from trade are positive for all countries, as our perfectly competitive model necessarily predicts, and large. The large magnitudes derive both from the low elasticities of substitution used in our calibration—which tends to make domestic and foreign labor services very imperfect substitutes—and from the fact that many countries in our sample have very little domestic production in manufacturing sectors.[39] In contrast, we see in Figure 5b that the dynamic gains from trade are either negative or zero for 96.7% of the countries in our sample. Despite our estimates of positive dynamic spillovers in more complex sectors, we are very far from the qualitative predictions derived in the case of the ladder economy.[40]

[38] Out of the 146 countries included in the empirical analysis of Sections 4 and 5, 26 countries did not report any imports in 2012. Since we cannot measure consumption under trade for these countries, we exclude them in the rest of our counterfactual analysis. The full list of countries included in our counterfactual exercises can be found in Table C.1. Results for other years are qualitatively similar to 2012 with almost all countries experiencing dynamic losses for all years.

[39] As shown by the bounds on the gains from trade derived in Proposition 4 in Appendix A.6, these two considerations shape the size of the static gains from trade in a ladder (or inverted ladder) economy.

[40] Static and dynamic gains are reported separately for each country in Table C.1 of Appendix C.4.1. As can be seen from Figure C.1, static gains from trade tend to offset dynamic losses for all but a very small



(a) Complexity and Number of Exporters

(b) Complexity and Share of Destinations Exported To

Figure 6: Capability-Enhancing Goods Face Tougher Foreign Competition

Notes: Figure 6 plots measures of foreign competition against our measures of product complexity from the linear probability model estimation of equation (12), as described in Section 4.1. Figure 6a plots binscatters of the number of countries exporting on complexity, absorbing year fixed effects and pooling observations by time period. Regression slope and standard error shown under each figure. Figure 6b further explores variation in the share of destinations a country sells to by focusing on one high complexity good (medicaments) and one low complexity good (men's underwear) and plotting a bar graph of the share of destinations sold to over origin countries averaged over the period 2000 to 2014. Titles report average complexity n^k over same period.

Figure 6 explains why. In sharp contrast to the assumptions imposed in Proposition 1 which imply that all countries face less competition in their most complex sectors, but in line with those imposed in the first inverted ladder economy described in Proposition 2, Figure 6a shows that more complex goods tend to be produced by more countries, not fewer. Furthermore, conditional on being exported, more complex goods are exported to more destinations, as illustrated by the comparison between more complex medicaments and less complex men's underwear in Figure 6b. Since more complex sectors face more foreign competition, they shrink relative to other sectors in the trade equilibrium; and since we have identified those sectors as the source of dynamic spillovers, opening up to trade tends to lower capability for most countries. In short, whereas opening up to trade

number of countries in our sample.

in the ladder economy alleviates underemployment in good sectors, opening up to trade in the calibrated economy worsens it.

Quantitatively, the dynamic losses are 8.4% on average, 2.6% for the median country, and most pronounced for the poorest countries, with a correlation between dynamic gains and log GDP per capita in 2012 equal to 0.54 , as illustrated in Appendix Figure C.2.

6.4 Robustness

The same conclusion—pervasive dynamic losses from trade—continues to hold under a variety of departures from our baseline economy.

Alternative Calibration of the Baseline Economy. We first consider the sensitivity of our results to alternative values of Table 4's parameters. As shown in Appendix Figure C.3, the distribution of dynamic gains are close to unchanged when we consider varying the spillover parameter, β, and the persistence parameter, ϕ, by two standard deviations above and below our point estimates in Table 2, column 5. Likewise, our results do not appear to be sensitive to the lower-level elasticity of substitution, σ, though they are sensitive to the value of the upper-level elasticity of substitution, ϵ, with the size of the losses increasing as ϵ approaches 1. We also obtain dynamic gains from trade that are almost identical to those in our baseline economy when we assume that counterfactual autarky productivities are drawn from Pareto or Fréchet distributions rather than log-normal ones, as shown in Appendix Figure C.4.

Alternative Measures of Capability and Complexity. A deeper concern with our previous analysis is that there is some arbitrariness in how we have defined our measures of complexity and capability. This begs the question: would we have reached the same conclusions if we had made very different assumptions about how complexity and capability map into trade flows?

To tackle this issue, we now depart from our original strategy of identifying as more complex the types of goods exported by more capable countries, consistent with the view in Hausman et al. (2007) and Hausman et al. (2013). Instead, we propose to identify sectors as more complex if they face less foreign competition and then check whether or not these sectors generate faster capability growth. More specifically, rather than imposing the linear probability model described in equation (9), we assume that

$$\text{Prob}(A_{ij,t}^{k} > 0) = \frac{e^{(N_{i,t} - n_t^k)}}{1 + e^{(N_{i,t} - n_t^k)}}, \text{ for all } i \neq j,\ k, \text{ and } t, \tag{20}$$

with independence across origins, destinations, and sectors. Consistent with our ladder economy, this standard logistic function implies that the probability of a non-zero productivity draw and hence a non-zero trade flow is increasing with capability and decreasing in complexity. Thus, more capable countries produce more goods and more complex goods are exported by fewer countries, leading to less foreign competition.

It is straightforward to recover estimates of $N_{i,t}$ and n_t^k by fitting a logit model via maximum likelihood where the binary response is whether country i exports good k to country j, and the explanatory variables are sets of country and good fixed effects. We describe these alternative estimates in Appendix B.7. While the recovered capability measures correlate positively with our baseline measures in Section 4, this is not the case for the complexity measures which are negatively correlated, as can be seen from Appendix Figure B.7. This negative correlation is not unique to our baseline complexity measure, with low PCI sectors of Hausman et al. (2013) also facing less competition on average, at least from 1980 onwards, despite the index's original motivation as a measure of ubiquity.

For our purposes, the interesting question, however, is whether using these alternative measures of complexity and capability would affect our conclusions about the consequences of international trade. To address it, we reestimate dynamic spillovers using equation (14) and our two WTO instruments (recalculated using our new measure of n_t^k so that we now exploit shocks due to WTO-entrants' export mixes being relatively more concentrated in the goods i produces but few other countries do). Our results are reported in Appendix B.8. Since baseline and alternative capability measures are positively correlated, whereas baseline and alternative complexity measures are negatively correlated, we now find evidence of negative dynamic spillovers, with a significant $\beta = -0.397$ in our preferred two-instrument specification (Appendix Table B.4, column 5).

More complex sectors now face less foreign competition by construction. But since a more complex product mix now generates negative dynamic spillovers, we are back to an inverted ladder economy and the same qualitative conclusion as in Section 6: pervasive dynamic losses, as illustrated in Appendix Figure C.5. Opening up to trade still moves countries away from the sectors that are capability-enhancing, leading 86% of the countries in our sample to experience dynamic losses. Quantitatively, though, losses tend to be an order of magnitude smaller than in our baseline analysis, with an an average dynamic loss now equal to 0.7% and a median loss of 0.2%.[41].

[41]This reflects capability changes between trade and autarky that are much smaller in the logit case, as can be seen from Appendix Figure C.6. Though our point estimates of β are of similar magnitudes in the linear and logit cases (0.279 and -0.397, respectively), the estimated range of capability is much broader in the logit case. As a result, moving from the 25th to 75th percentile (the IQR) of average complexity $S_{i,t}$ within each year in the linear model results in a change equal to 0.81 IQRs of capability, on average. A similar movement in the logit model changes capability by 0.051 IQRs, in line with the smaller dynamic welfare losses in this case. While we do not attempt to settle which model is more plausible, we note that the R-squared associated with the dynamic spillover regression (14) is higher for the linear model: 0.71 versus 0.35.

Complexity and Foreign Competition. Our baseline analysis rules out any heterogeneity across sectors in the lower-level elasticity of substitution: $\sigma^k = \sigma$. This implies that the number of countries that are able to produce a good determines the extent of foreign competition in that sector. In practice, variation in σ^k may also affect the extent to which foreign competition shifts labor demand across sectors. If sectors that are more complex tend to be those with lower elasticities, then opening up to trade may not move countries away from those sectors, potentially reversing our welfare conclusions.

To assess the importance of these considerations, we return to the baseline economy of Section 6.1 and recompute the counterfactual autarkic equilibria of Section 6.2 under the assumption that σ^k may vary across sectors. We use Broda and Weinstein's (2006) 4-digit estimates for the period 1990-2001. Appendix Figure C.7 shows that this has little effects on our main conclusions. The reason is that elasticities of substitution and complexity are only weakly correlated across sectors, as can be seen from Appendix Figure C.8.

Global Input-Output Linkages. Both in our theoretical and quantitative analysis, we have assumed that when more foreign countries produce in a given sector, this tends to lower employment in that sector. While our reduced-form results about the impact of the entry of other countries in the WTO are overall consistent with that view, the existence of global input-output linkages may, in theory, overturn our conclusions about the dynamic consequences of trade. Intuitively, if countries export intermediate goods, then the fact that more countries export more complex goods may lead to cheaper inputs, and in turn, an expansion of employment in these sectors under trade.[42]

We now formally explore this possibility by introducing input-output linkages as in Caliendo and Parro (2015). Compared to the baseline economy of Section 6.1, we assume that production functions are Cobb-Douglas and require labor as well as composite intermediate goods from multiple 2-digit sectors, which is the level of aggregation at which we observe I-O linkages in the OECD Input-Output Database. To produce composite intermediate goods requires the same CES aggregate of domestic and foreign varieties as in preferences. The formal description of the augmented model, as well as its calibration, can be found in Appendix C.5.4.

Appendix Figure C.9 offers the counterpart of Figure 5 in the presence of input-output linkages. If anything, input-output linkages magnify the dynamic losses documented in the baseline analysis of Section 6: all countries now experience dynamic losses, with the average and median dynamic loss equal to 12.5% and 3%, respectively.

Other External Economies of Scale. The ladder metaphor formalized in Section 2 emphasizes external economies of scale that operate across sectors of different complexity.

[42] If one expects more complex goods to be produced via global supply chains, their introduction may also help explain why more complex goods tend to be exported by more countries.

Shifting employment towards more complex sectors today may lead to higher capability and the creation of new sectors tomorrow, thereby creating a rationale for subsidizing more complex sectors, as discussed in Proposition 3. Another common rationale for industrial policy is the existence of sector-specific external economies of scale, calling for subsidies that target sectors where those are the largest.

To explore whether these considerations may affect our earlier conclusions, we recompute our autarky counterfactuals in a generalized version of our baseline economy that also allows productivity to be a function of 2-digit employment in a given country and industry, as in Bartelme et al. (2021). As described in Appendix C.5.5, we use their estimates to calibrate the elasticity of productivity with respect to size. Appendix Figure C.10 shows that the introduction of this extra source of domestic distortions does not change our final conclusion: dynamic losses from trade continue to be pervasive.

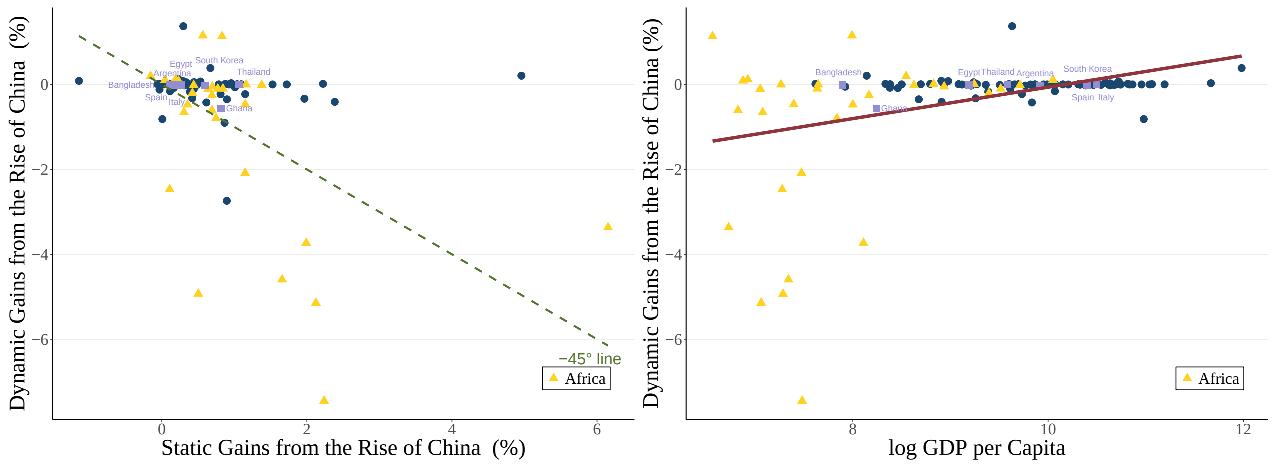
7 The Rise of China: Push or Pull?

In line with Propositions 1 and 2, we have focused so far on the overall impact of international trade by comparing the same country under both trade and autarky. A related, but distinct question, more closely related to the empirical results of Section 5, is whether the entry of other countries in the world economy may affect one country's development path. For instance, if it was not for the emergence of China, and its impact on the patterns of specialization of small open economies like Ghana or Bangladesh, would these countries have developed like South Korea who industrialized in the pre-China era?

7.1 Construction of the Counterfactual Trade Equilibrium Without China

Our model offers a natural springboard to explore such issues. We can do so by comparing the observed trade equilibrium to a counterfactual trade equilibrium without China. Specifically, we use the same procedure as in Section 6.2 to construct the competitive equilibrium of a hypothetical world economy such that starting in 1992, $(A^k_{i\text{China},t})' = (A^k_{\text{China}i,t})' = 0$ for all $i \neq \text{China}$.[43] We say that a country i experiences welfare gains from the rise of China if its welfare is higher at date $t \geq 1992$ in the observed equilibrium than in the counterfactual equilibrium without China. We then decompose the welfare changes associated with this counterfactual scenario into static gains—that measures changes in

[43]Following Autor et al. (2013), we pick the 1990s as the starting date of China's emergence (with 1992 being the first 5-year period in the 1990s). In addition to the above productivity changes, a world economy without China also implies different trade imbalances between countries. To exclude such considerations from our welfare analysis, we first compute an intermediate counterfactual trade equilibrium, with all structural parameters identical to those in the initial equilibrium, except for the exogenous lump-sum transfers received by each country that are set to zero. The impact of China's trade described below corresponds to the comparison between that intermediate counterfactual trade equilibrium, without transfers, and the counterfactual trade equilibrium of interest, without any trade with China.



(a) Dynamic Gains vs. Static Gains

(b) Dynamic Gains vs. GDP per Capita

Figure 7: Welfare Consequences from the Rise of China

Notes: Figure 7a reports the dynamic gains from the rise of China against the associated static gains in 2012, as described in Section 7.1. Figure 7b reports the dynamic gains from the rise of China in 2012 against log GDP per Capita in the same year. The solid line is the line of best fit (slope = 0.37, s.e. = 0.08).

real consumption caused by terms-of-trade effects holding capability fixed—and dynamic gains—that measures changes in real consumption caused by the changes in capability.

7.2 Welfare Consequences from the Rise of China

Figure 7 describes these welfare consequences from the rise of China. For expositional purposes, we again focus on counterfactual results at date $t = 2012$. Since most observations in Figure 7a lie above the -45 degree line, we see that most countries benefit from the rise of China, though the bulk of these gains occur through static considerations.[44] In terms of dynamic consequences, China's rise pulls more countries down than it pushes up. On average, developing countries tend to experience larger losses, as can be seen in Figure 7b. Although losses are close to zero for most countries, they are particularly large for a small number of African countries.

The finding that predominantly African countries suffer substantial losses—and not, for example, similarly-poor South Asian countries—reflects the confluence of three forces. First, and consistent with the time path of our instrument shown in Figure 4, through greater competition in export markets China's rise pushes African countries such as Ghana into less complex sectors slowing their capability growth. The correlation between our destination-level instrument ($Z_{i,t}^{II}$), averaged across years, and the dynamic gains is -0.26. Second, our instrument only focuses on the trade costs faced by China as an exporter. In our counterfactuals, we eliminate both China's exports and imports, allowing China's rise

[44] The counterpart of Figure 5 can be found in Appendix C.6.

to generate dynamic losses by pulling countries into less-complex sectors through its imports. We find that the African countries experiencing the largest losses tend to be those that export their least complex goods to China. The correlation between dynamic gains and the difference in average complexity of exports to China and the rest of the world is 0.24. Finally, these African countries produce very few goods in the original equilibrium—leading small changes in capability and the number of goods being produced to have large welfare consequences in proportional terms.

8 Concluding Remarks

Does international trade push countries up the development ladder? To shed light on this question, we have developed a dynamic trade model in which countries differ in their capability, goods differ in their complexity, and capability growth is a function of the average complexity of the goods that each country produces. Two insights have emerged from our analysis.

First, on the theory side, we have demonstrated that the dynamic gains from trade need not be zero sum, with some countries specializing in "good" sectors that are conducive to growth and others specializing in "bad" sectors that are not. Instead, upon opening up to trade, all countries may move towards their relatively complex sectors that face less foreign competition. And if those sectors create positive dynamic spillovers, all countries may gain.

Second, on the empirical side, we have demonstrated that the conditions required for pervasive dynamic gains do not appear to be satisfied. Using the entry of other countries into the WTO as an exogenous shifter of countries' industry mix, we have provided evidence consistent with the existence of "good" sectors that create positive dynamic spillovers. These sectors, however, tend to be those that face more foreign competition. Through the lens of our model, this implies that rather than pushing countries up the development ladder, opening up to international trade tends to hold many of them back.

It goes without saying, but we will say it anyway: we do not view our results as the final word on the existence (or lack thereof) of dynamic gains from trade. Rather we view our analysis as a first formalization of the standard ladder metaphor and an empirical exploration of its perhaps surprising implications. In practice, there appear to be "good" sectors, but in contrast to the standard ladder metaphor used widely in development policy circles, "good" sectors are those in which more, not less, countries produce and export, a force that pushes towards pervasive dynamic losses from trade. What explains this unexpected correlation between complexity and competition? Does it reflect historical attempts at industrial policy or desires for self sufficiency? These are open questions for future research to tackle.

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Globalization and the Ladder of Development: Pushed to the Top or Held at the Bottom?

David Atkin, Arnaud Costinot, and Masao Fukui

A Online Appendix: Theory

A.1 Definition of Competitive Equilibrium

Static Equilibrium Conditions. Profit maximization by perfectly competitive firms requires the price of a variety of good k produced in country i and sold in country j to be equal to its unit cost,

$$p^k_{ij,t} = w_{i,t} / A^k_{ij,t} \tag{A.1}$$

with $w_{i,t}$ the wage in country i at date t. If country i cannot produce good k at date t, then $A^k_{ij,t} = 0$ and $p^k_{ij,t} = \infty$. Utility maximization requires

$$c^k_{ij,t} = \frac{(p^k_{ij,t})^{-\sigma}}{(P^k_{j,t})^{1-\sigma}} \frac{(P^k_{j,t})^{1-\epsilon} w_{j,t} L_{j,t}}{(P_{j,t})^{1-\epsilon}}, \tag{A.2}$$

where the sector-level price index, $P^k_{j,t}$, and the aggregate price index, $P_{j,t}$, are given by

$$P^k_{j,t} = [\sum_i (p^k_{ij,t})^{1-\sigma}]^{1/(1-\sigma)}, \tag{A.3}$$

$$P_{j,t} = [\int (P^k_{j,t})^{1-\epsilon} dk]^{1/(1-\epsilon)}. \tag{A.4}$$

Good market clearing requires that the demand for any good k from any origin country i in any destination country j equals its supply,

$$c^k_{ij,t} = A^k_{ij,t} \ell^k_{ij,t}, \tag{A.5}$$

whereas labor market clearing requires that the sum of labor demand across all sectors k and destinations j equals the labor supply from each origin country i,

$$\sum_j \int \ell^k_{ij,t} dk = L_{i,t}. \tag{A.6}$$

Dynamic Equilibrium Conditions. For given employment levels $\{\ell^k_{ij,t}\}$, the evolution of capabilities across countries is described by equations (5) and (6), which are reported again below for convenience,

$$\dot{N}_{i,t} = H_{i,t}(N_{i,t}, F^{\ell}_{i,t}), \tag{A.7}$$

$$F^{\ell}_{i,t}(n) = \frac{\int_{0 \le n^k_t \le n} \sum_j \ell^k_{ij,t} dk}{\int \sum_j \ell^k_{ij,t} dk}, \tag{A.8}$$

where $F^{\ell}_{i,t}(n)$ denotes the share of workers from country i employed at date t in sectors with complexity less than n.

Definition of a Competitive Equilibrium. Given a vector of initial capability $\{N_{i,0}\}$ at date 0, a competitive equilibrium corresponds to a path for capabilities, $\{N_{i,t}\}$, wages, $\{w_{i,t}\}$, good prices, $\{p^k_{ij,t}, P^k_{j,t}, P_{j,t}\}$, consumption levels, $\{c^k_{ij,t}\}$, employment levels, $\{\ell^k_{ij,t}\}$, and employment distributions, $\{F^{\ell}_{i,t}\}$, such that equations (A.1)–(A.8) hold for all $t \ge 0$.

A.2 Existence and Uniqueness of a Competitive Equilibrium

By equations (A.1)–(A.6), the equilibrium wages $\{w_{i,t}\}$ solve

$$L_{i,t} = \int_{n \le N_{i,t}} \sum_j \frac{(A_{ij,t})^{\sigma-1}(w_{i,t})^{-\sigma}}{\left(\sum_{l:N_{l,t} \ge n}(w_{l,t}/A_{lj,t})^{1-\sigma}\right)^{\frac{\epsilon-\sigma}{1-\sigma}}} \frac{w_{j,t}L_{j,t}dF_t(n)}{\int_m \left(\sum_{l:N_{l,t} \ge m}(w_{l,t}/A_{lj,t})^{1-\sigma}\right)^{\frac{1-\epsilon}{1-\sigma}} dF_t(m)} \tag{A.9}$$

for each i and t. Below we first establish the existence and uniqueness of $\{w_{i,t}\}$ that solve (A.9). The existence and uniqueness of $\{p^k_{ij,t}\}$, $\{c^k_{ij,t}\}$, and $\{\ell^k_{ij,t}\}$ directly follow from equations A.1-(A.5). We conclude by characterizing the smoothness conditions on F_t and $\{H_{i,t}\}$ required for the existence and uniqueness of $\{N_{i,t}\}$ that solve (5).

Existence and uniqueness of $\{w_{i,t}\}$. Define the excess labor demand function,

$$z_{i,t}(\mathbf{w}_t) \equiv \int_{n \le N_{i,t}} \sum_j \frac{(A_{ij,t})^{\sigma-1}(w_{i,t})^{-\sigma}}{\left(\sum_{l:N_{l,t} \ge n}(w_{l,t}/A_{lj,t})^{1-\sigma}\right)^{\frac{\epsilon-\sigma}{1-\sigma}}} \frac{w_{j,t}L_{j,t}dF_t(n)}{\int_m \left(\sum_{l:N_{l,t} \ge m}(w_{l,t}/A_{lj,t})^{1-\sigma}\right)^{\frac{1-\epsilon}{1-\sigma}} dF_t(m)} - L_{i,t},$$

where $\mathbf{w}_t \equiv \{w_{i,t}\}$, and $\mathbf{z}_t \equiv \{z_{i,t}\}$. Then $z_{i,t}$ is continuous and homogenous of degree zero, $\mathbf{w} \cdot \mathbf{z}(\mathbf{w}) = 0$ for all $\mathbf{w}$, and $\max_i\{z_{i,t}\} \to \infty$ as $w_{l,t} \to 0$ for some l. Therefore assumptions for Proposition 17.C.1 in Mas-Colell et al. (1995) are satisfied. This establishes the existence of $\{w_{i,t}\}$ that solve (A.9).

Next, let us show that $z_{i,t}(\mathbf{w}_t)$ satisfies gross-substitute properties, $\frac{\partial z_{i,t}(\mathbf{w}_t)}{\partial w_{l,t}} > 0$ for $i \neq l$. Let

$$L_{i,t}(\mathbf{w}_t) \equiv \frac{1}{w_{i,t}} \int_{n \le N_{i,t}} \sum_j \lambda^n_{ij,t}(\mathbf{w}_t) \Lambda^n_{j,t}(\mathbf{w}_t) w_{j,t} L_{j,t} dF_t(n),$$

with

$$\lambda^n_{ij,t}(\mathbf{w}_t) \equiv \frac{(w_{i,t}/A_{ij,t})^{1-\sigma}}{\sum_{l:N_{l,t}\geq n}(w_{l,t}/A_{lj,t})^{1-\sigma}},$$
$$\Lambda^n_{j,t}(\mathbf{w}_t) \equiv \frac{\left(\sum_{l:N_{l,t}\geq n}(w_{l,t}/A_{lj,t})^{1-\sigma}\right)^{\frac{1-\epsilon}{1-\sigma}}}{\int_m \left(\sum_{l:N_{l,t}\geq m}(w_{l,t}/A_{lj,t})^{1-\sigma}\right)^{\frac{1-\epsilon}{1-\sigma}} dF_t(m)}.$$

Taking log-derivative for $l \neq i$,

$$\begin{aligned}\frac{\partial \ln L_{i,t}(\mathbf{w}_t)}{\partial \ln w_{l,t}} = \frac{1}{w_{i,t}L_{i,t}} \int_{n\leq \min\{N_{i,t},N_{j,t}\}} \Bigg(& \lambda^n_{il,t}(\mathbf{w}_t)\Lambda^n_{l,t}(\mathbf{w}_t) w_{l,t} L_{l,t} \\ & + \sum_j \lambda^n_{ij,t}(\mathbf{w}_t)\Lambda^n_{j,t}(\mathbf{w}_t) w_{j,t}L_{j,t}\Big[(\sigma-\epsilon)\lambda^n_{lj,t}(\mathbf{w}_t) \\ & + (\epsilon-1)\int_m \lambda^m_{lj,t}(\mathbf{w}_t)\Lambda^m_j(\mathbf{w}_t) dF_t(n')\Big]\Bigg) dF_t(n),\end{aligned}$$

which is strictly positive under the assumptions that $\sigma > \epsilon > 1$. This shows that $L_{i,t}(\mathbf{w}_t)$ is strictly increasing in $w_{k,t}$ for $k \neq i$, implying that $z_{i,t}(\mathbf{w}_t)$ satisfies gross-substitute property. Applying Proposition 17.F.3 in Mas-Colell et al. (1995), the equilibrium wages $\{w_{i,t}\}$ are unique.

Existence and Uniqueness of $\{N_{i,t}\}$. Let $\mathbf{w}_t(\mathbf{N}_t)$ denote the unique equilibrium vector of wages in period t as a function of the capability vector $\mathbf{N}_t \equiv \{N_{i,t}\}$ and let $F^\ell_{i,t}(\cdot;\mathbf{N}_t)$ denote the associated equilibrium distribution of employment across sectors of different complexity,

$$F^\ell_{i,t}(n;\mathbf{N}_t) = \frac{\int_{m\leq n}\sum_j \frac{(A_{ij,t})^{\sigma-1}(w_{i,t})^{-\sigma}}{\left(\sum_{l:N_{l,t}\geq m}(w_{l,t}/A_{lj,t})^{1-\sigma}\right)^{\frac{\epsilon-\sigma}{1-\sigma}}} \frac{w_{j,t}L_{j,t}dF_t(m)}{\int_{m'}\left(\sum_{l:N_{l,t}\geq m'}(w_{l,t}/A_{lj,t})^{1-\sigma}\right)^{\frac{1-\epsilon}{1-\sigma}} dF_t(m')}}{\int_{m\leq N_{i,t}}\sum_j \frac{(A_{ij,t})^{\sigma-1}(w_{i,t})^{-\sigma}}{\left(\sum_{l:N_{l,t}\geq m}(w_{l,t}/A_{lj,t})^{1-\sigma}\right)^{\frac{\epsilon-\sigma}{1-\sigma}}} \frac{w_{j,t}L_{j,t}dF_t(m)}{\int_{m'}\left(\sum_{l:N_{l,t}\geq m'}(w_{l,t}/A_{lj,t})^{1-\sigma}\right)^{\frac{1-\epsilon}{1-\sigma}} dF_t(m')}} \text{ for all } n \leq N_{i,t}. \quad \text{(A.10)}$$

By equations (5) and (6), the equilibrium capability vector $\mathbf{N}_t$ solves the following ODE,

$$\dot{\mathbf{N}} = V(\mathbf{N},t), \tag{A.11}$$

where $V : \mathbb{R}^I \times \mathbb{R} \to \mathbb{R}^I$ is such that for any $i = 1,...,I$,

$$V_i(\mathbf{N},t) \equiv H_{i,t}(N_i, F^\ell_{i,t}(\cdot;\mathbf{N}_t)). \tag{A.12}$$

Existence and uniqueness of $\{N_{i,t}\}$ follow from the conditions of Picard Theorem being satisfied. That is, for any $\mathbf{N}_0 = \{N_{i,0}\}$ and any finite time horizon T, there exists a unique solution $\mathbf{N}_t$ to (A.11) for $t \in [0,T]$ with initial value $\mathbf{N}_0$ provided that F_t, $\{A_{ij,t}\}$, and $\{H_{i,t}\}$ are such that V is Lipschitz-continuous with respect to $\mathbf{N}$ and continuous with respect to t.

A.3 Proof of Proposition 1

We consider a country i that moves from trade to autarky at date 0. We first demonstrate that any date $t \geq 0$, country i's capability must be lower in the autarky equilibrium than what it would have been in the trade equilibrium. We then conclude that at any date $t \geq 0$, country i's aggregate consumption in the autarky equilibrium must be lower as well.

Change in Capability. Let $(N_{i,t})'$ and $N_{i,t}$ denote the capability of country i at date t in the autarky and trade equilibrium, respectively. At date 0, we know that $(N_{i,0})' = N_{i,0}$. To show that $(N_{i,t})' \leq N_{i,t}$ for all $t \geq 0$, it is therefore sufficient to show that if $(N_{i,t_0})' = N_{i,t_0}$ at any date $t_0 \geq 0$, then $\dot{N}_{i,t_0} \geq (\dot{N}_{i,t_0})'$. By equation (5), under the assumption that $H_{i,t}$ is increasing in $F^{\ell}_{i,t}$, this is equivalent to show that if $(N_{i,t_0})' = N_{i,t_0}$, then $F^{\ell}_{i,t} \succeq_{fosd} (F^{\ell}_{i,t})'$.

Take a date t_0 such that $N_{i,t_0} = (N_{i,t_0})' = N_i$. The density of employment in sectors of complexity n in country i at date t_0 in the autarky equilibrium is

$$(f^{\ell}_{i,t_0})'(n) = \begin{cases} f_{t_0}(n) & \text{, for all } n \leq N_i, \\ 0 & \text{otherwise.} \end{cases}$$

The same density in the trade equilibrium is

$$(f^{\ell}_{i,t_0})'(n) = \begin{cases} \dfrac{\sum_j \frac{(A_{ij,t_0})^{\sigma-1}(w_{i,t_0})^{-\sigma}}{(\sum_{l:N_{l,t_0}\geq n}(w_{l,t_0}/A_{lj,t_0})^{1-\sigma})^{\frac{\epsilon-\sigma}{1-\sigma}}} \frac{w_{j,t_0}L_{j,t_0}}{\int (P_{j,t_0}(m))^{1-\epsilon} dF_{t_0}(m)} f_{t_0}(n)}{\int \sum_j \frac{(A_{ij,t_0})^{\sigma-1}(w_{i,t_0})^{-\sigma}}{(\sum_{l:N_{l,t_0}\geq n'}(w_{l,t_0}/A_{lj,t_0})^{1-\sigma})^{\frac{\epsilon-\sigma}{1-\sigma}}} \frac{w_{j,t}L_{j,t_0}}{\int (P_{j,t_0}(m))^{1-\epsilon} dF_{t_0}(m)} dF_{t_0}(n')} & \text{, for all } n \leq N_i, \\ 0 & \text{, otherwise.} \end{cases}$$

Now take $n_1 \leq n_2 \leq N_i$. Since $\sigma > \epsilon > 1$, we must have

$$\Big(\sum_{l:N_{l,t_0}\geq n_2} (w_{l,t_0}/A_{lj,t_0})^{1-\sigma}\Big)^{\frac{\epsilon-\sigma}{1-\sigma}} \leq \Big(\sum_{l:N_{l,t_0}\geq n_1} (w_{l,t_0}/A_{lj,t_0})^{1-\sigma}\Big)^{\frac{\epsilon-\sigma}{1-\sigma}} \text{ for all } j.$$

This implies

$$\frac{f^{\ell}_{i,t_0}(n_2)}{f^{\ell}_{i,t_0}(n_1)} \geq \frac{f_{t_0}(n_2)}{f_{t_0}(n_1)} = \frac{(f^{\ell}_{i,t_0})'(n_2)}{(f^{\ell}_{i,t_0})'(n_1)}.$$

Hence, the distribution of employment under trade, F^{ℓ}_{i,t_0}, dominates the distribution of employment under autarky, $(F^{\ell}_{i,t_0})'$, in terms of the Monotone Likelihood Ratio Property. Thus we must have $F^{\ell}_{i,t_0} \succeq_{fosd} (F^{\ell}_{i,t_0})'$. It follows that $(\dot{N}_{i,t_0})' \leq \dot{N}_{i,t_0}$ and, in turn, that $(N_{i,t})' \leq N_{i,t}$ for all $t \geq 0$.

Change in Aggregate Consumption. Let $(C_{i,t})'$ and $C_{i,t}$ denote aggregate consumption in country i at date t in the autarky and trade equilibrium, respectively, and let $(\bar{C}_{i,t})'$ denote aggregate consumption in country i at date t in a hypothetical autarky equilibrium where capability levels remain fixed at their trade equilibrium values, $N_{i,t}$, at all dates. For fixed capability levels $N_{i,t}$, our economy features a representative agent, perfect competition, and no distortion. Hence, standard arguments (e.g. Samuelson, 1939) imply $(\bar{C}_{i,t})' \leq C_{i,t}$. Since $(N_{i,t})' \leq N_{i,t}$ for all t, we must also have $(C_{i,t})' \leq (\bar{C}_{i,t})'$. Combining the two previous observations, we get $(C_{i,t})' \leq C_{i,t}$ for all $t \geq 0$.

A.4 Proof of Proposition 2

In Section 2.3, we have defined an inverted ladder economy as an economy such that either: (a) $H_{i,t}$ is decreasing in $F^{\ell}_{i,t}$ and labor productivity is given by equation (4) or (b) $H_{i,t}$ is increasing in $F^{\ell}_{i,t}$ and labor productivity is given by

$$A^k_{ij,t} = \begin{cases} A_{ij,t} & \text{if } g(n^k_t) \leq N_{i,t}, \\ 0 & \text{otherwise}, \end{cases} \tag{A.13}$$

with $g(\cdot)$ a strictly decreasing function.

First, note that cases (a) and (b) are formally equivalent, up to a change in variable. Starting from (b), one can set a new complexity measure $\tilde{n}^k_t \equiv g(n^k_t)$. Then equation (4) immediately holds for this new complexity measure. Next, let $\tilde{F}^{\ell}_{i,t}$ denote the cumulative employment distribution associated with the new complexity measure, i.e.,

$$\tilde{F}^{\ell}_{i,t}(n) \equiv \frac{\int_{0 \leq \tilde{n}^k_t \leq n} \sum_j \ell^k_{ij,t} dk}{\int \sum_j \ell^k_{ij,t} dk}.$$

By definition of $\tilde{n}^k_t$, it satisfies

$$F^{\ell}_{i,t}(n) = 1 - \tilde{F}^{\ell}_{i,t}(g(n)), \tag{A.14}$$

which we can describe compactly as $F^{\ell}_{i,t} = G(\tilde{F}^{\ell}_{i,t})$, with the functional $G(\cdot)$ such that equation (A.14) holds for all n. In turn, we get

$$H_{i,t}(N_{i,t}, F^{\ell}_{i,t}) = H_{i,t}(N_{i,t}, G(\tilde{F}^{\ell}_{i,t})) \equiv \tilde{H}_{i,t}(N_{i,t}, \tilde{F}^{\ell}_{i,t}).$$

Note that if two distributions are such that $F^{\ell}_{i,t} \succeq_{fosd} F^{\ell'}_{i,t}$, then $G(F^{\ell'}_{i,t}) \succeq_{fosd} G(F^{\ell}_{i,t})$. Thus starting from (b), $\tilde{H}_{i,t}(N_{i,t}, \cdot)$ is decreasing. This completes the proof of cases (a) and (b) being equivalent, up to a change of variable.

Without loss of generality, let us now focus on case (a). The first part of the proof of Proposition 1 is unchanged and again leads to $F^{\ell}_{i,t_0} \succeq_{fosd} (F^{\ell}_{i,t_0})'$. Under the assumption that $H_{i,t}$ is decreasing in $F^{\ell}_{i,t}$, however, we now conclude that $(\dot{N}_{i,t_0})' \geq \dot{N}_{i,t_0}$ and, in turn, that $(N_{i,t})' \geq N_{i,t}$ for all $t \geq 0$. To show that there may exist some date $t \geq 0$ such that $(C_{i,t})' \leq C_{i,t}$, consider the following example. Suppose that there exists $\hat{t} > 0$ such that $A_{ij,t} = A_{ji,t} = 0$ for all $j \neq i$. Thus at date $\hat{t}$, country i is back to autarky and $C_{i,\hat{t}} = (\bar{C}_{i,\hat{t}})'$. Since $(N_{i,\hat{t}})' \geq N_{i,\hat{t}}$, it follows that $(C_{i,t})' \geq C_{i,\hat{t}}$.

A.5 Optimal Industrial Policy

Proposition 3. *Suppose that country i has access to a full set of trade taxes and employment subsidies. Then, in a ladder economy, optimal employment subsidies are increasing with complexity.*

Proof. It is convenient to start from the problem of a hypothetical planner who can directly choose country i's labor allocation, its vector of exports, and its vector of imports in order to maximize a weighted sum of country i's aggregate consumption at different horizons subject to technological constraints, resource constraints, and trade balance.

Let $\ell_{i,t}(n)$, $c_{ji,t}(n)$, and $c_{ij,t}(n)$ denote country i's employment, imports, and exports at date t in a sector of complexity n. As a function of the previous quantities, country i's aggregate consumption in a sector of complexity n can then be expressed as

$$\tilde{C}_{i,t}(\ell_{i,t}(n),\{c_{ji,t}(n),c_{ij,t}(n)\}_{j\neq i};n)$$
$$\equiv \begin{cases} (A_{ii,t}(l_{i,t}(n)-\sum_{j\neq i}\frac{c_{ij,t}(n)}{A_{ij,t}})^{(\sigma-1)/\sigma}+\sum_{j\neq i}(c_{ji,t}(n))^{(\sigma-1)/\sigma})^{\sigma/(\sigma-1)} & \text{if } n\leq N_{i,t}, \\ (\sum_{j\neq i}(c_{ji,t}(n))^{(\sigma-1)/\sigma})^{\sigma/(\sigma-1)} & \text{otherwise.} \end{cases}$$

In turn, country i's planning problem is given by

$$\max_{\{l_{i,t}(n)\},\{c_{ji,t}(n),c_{ij,t}(n)\}_{j\neq i}}\int \theta_t[\int [\tilde{C}_{i,t}(\ell_{i,t}(n),\{c_{ji,t}(n),c_{ij,t}(n)\}_{j\neq i};n)]^{(\epsilon-1)/\epsilon}dF_t(n)]^{\epsilon/(\epsilon-1)}dt$$

subject to:

$$\dot{N}_{i,t}\leq H_{i,t}(N_{i,t},F^{\ell}_{i,t}), \tag{A.15}$$

$$L_{i,t}\geq \int \ell_{i,t}(n)dF_t(n), \tag{A.16}$$

$$\int \sum_{j\neq i}\tilde{p}_{ji,t}(\{c_{ji,t}(n),c_{ij,t}(n)\}_{j\neq i})c_{ji,t}(n)dF_t(n)\leq \int \sum_{j\neq i}\tilde{p}_{ij,t}(\{c_{ji,t}(n),c_{ij,t}(n)\}_{j\neq i})c_{ij,t}(n)dF(n), \tag{A.17}$$

where $\tilde{p}_{ij,t}(\cdot)$ and $\tilde{p}_{ji,t}(\cdot)$ denote export and import prices that in a competitive equilibrium are a function of country i's export and import quantities.

Now starting from the employment levels $\{l_{i,t}(n)\}$ that solve the planner's problem, consider a variation that reduces employment of sectors with complexity $n\in[n_1,n_1+dn_1]$ by a small amount $\delta\ell/f_t(n_1)>0$ and increases employment of sectors with complexity $n\in[n_2,n_2+dn_2]$ by $\delta\ell/f_t(n_2)>0$, with $n_1\leq n_2$. The necessary first-order condition associated with this variation is

$$\begin{aligned}&[-\theta_t[\int (C_{i,t}(m))^{(\epsilon-1)/\epsilon}dF_t(m)]^{1/(\epsilon-1)}\times(C_{i,t}(n_1))^{(\epsilon-\sigma)/\epsilon(\sigma-1)}\times(c_{ii,t}(n_1))^{-1/\sigma}\\ &+\theta_t[\int (C_{i,t}(m))^{(\epsilon-1)/\epsilon}dF_t(m)]^{1/(\epsilon-1)}\times(C_{i,t}(n_2))^{(\epsilon-\sigma)/\epsilon(\sigma-1)}\times(c_{ii,t}(n_2))^{-1/\sigma}]\\ &=-(\mu_{i,t}/A_{ii,t})(\delta H_{i,t}/\delta\ell),\end{aligned} \tag{A.18}$$

where $c_{ii,t}(n)$ is domestic consumption in a sector of complexity n, $\mu_{i,t}\geq 0$ is the Lagrange multiplier associated with the technological constraint (A.15), and $\delta H_{i,t}$ denotes the change in $H_{i,t}(N_{i,t},F^{\ell}_{i,t})$ associated with that variation. Since the new employment distribution first-order stochastically dominates the original employment one and $H_{i,t}(N_{i,t},\cdot)$ is increasing, we have $\delta H_{i,t}\geq 0$.

Under the assumption that country i has access to a full set of trade taxes and employment subsidies, standard arguments imply that the competitive equilibrium with taxes and subsidies can implement the planner's solution. To characterize the properties of optimal employment subsidies $s_{i,t}(n)$, we can therefore compare the previous first-order condition to those associated with utility and profit maximization in the decentralized equilibrium,

$$\theta_t[\int (C_{i,t}(m))^{(\epsilon-1)/\epsilon} dF_t(m)]^{1/(\epsilon-1)} \times (C_{i,t}(n))^{(\epsilon-\sigma)/\epsilon(\sigma-1)} \times (c_{ii,t}(n))^{-1/\sigma} = \gamma_{i,t} p_{ii,t}(n), \tag{A.19}$$

$$p_{ii,t}(n) = \frac{(1-s_{i,t}(n))w_{i,t}}{A_{ii,t}}, \tag{A.20}$$

where $\gamma_{i,t}$ is the Lagrange multiplier associated with the representative agent's budget constraint in country i and $p_{ii,t}(n)$ is the domestic price of goods with complexity n in country i. Equations (A.18)-(A.20) imply that in order to replicate the planner's solution, subsidies must satisfy

$$s_{i,t}(n_2) - s_{i,t}(n_1) = \frac{\mu_{i,t}}{\gamma_{i,t} w_{i,t}} \times \frac{\delta H_{i,t}}{\delta \ell} \geq 0.$$

It follows that optimal employment subsidies are increasing with complexity. □

A.6 Bounds on the Gains from Trade

In line with the static analysis in Arkolakis, Costinot and Rodríguez-Clare (2012), we assume that the world economy is initially at a steady state, with no technological shocks ($F_t = F$, $A_{ij,t} = A_{ij}$, and $H_{i,t} = H_i$), no population growth ($L_{i,t} = L_i$), and that after moving to autarky, the economy converges to a new steady state, with the transitional dynamics between the two steady states determined by H_i. We can then define the gains from trade (GT) as the (permanent) difference between the income level required to achieve the (lifetime) utility under free trade and the income level required to achieve the (lifetime) utility under autarky, both evaluated at the free trade prices and expressed as a fraction of a country's income level under free trade.

While the exact value of GT depends on the details of the transition from free trade to autarky, the following proposition offers bounds on GT that are robust to alternative transitional dynamics.

Proposition 4. *In a ladder economy, gains from trade in any country i are bounded from below by $\underline{GT}_i$ and above by $\overline{GT}_i$ such that*

$$\underline{GT}_i = 1 - \underbrace{\left[\int e_i(n)(\lambda_{ii}(n))^{\frac{\epsilon-1}{\sigma-1}} dF(n)\right]^{\frac{1}{\epsilon-1}}}_{\text{Static Gains}},$$

$$\overline{GT}_i = 1 - \underbrace{\left[\int e_i(n)(\lambda_{ii}(n))^{\frac{\epsilon-1}{\sigma-1}} dF(n)\right]^{\frac{1}{\epsilon-1}}}_{\text{Static Gains}} \cdot \underbrace{\left[H_i^{-1}(0,F_i^{\ell})/H_i^{-1}(0,F)\right]^{\frac{1}{(1-\epsilon)}}}_{\text{Dynamic Gains}},$$

where $\lambda_{ii}(n)$ is country i's share of expenditure on domestic goods with complexity n in the free trade steady state; $e_i(n)$ is its share of total expenditure on goods with complexity n in that same steady state; F_i^{ℓ}

and F are country i's distribution of employment in the trade and autarkic steady states, respectively; and $H_i^{-1}(0,F^\ell)$ is the capability level N that solves $0 = H_i(N,F^\ell)$. In an inverted ladder economy, gains from trade in any country i are bounded from below by $\overline{GT}_i$ and above by $\underline{GT}_i$ instead.

Proof. First, consider a ladder economy. Let $(N_i)'$ and N_i denote the capability of country i in the autarky and trade steady state, respectively. From the proof of Proposition 1, we already know that $(N_{i,t})' \leq N_i$ for all t. This implies $(C_{i,t})' \leq (\bar{C}_i)'$, where $(\bar{C}_i)'$ denotes aggregate consumption under autarky if country i's capability had remained at its trade steady state value, N_i. We can therefore compute a lower-bound on the cost of autarky, and hence the gains from trade, as

$$\underline{GT}_i = 1 - \frac{(\bar{C}_i)'}{C_i}.$$

Since $(N_{i,0})' = N_i \geq (N_i)'$, we must also have $(N_{i,t})' \geq (N_i)'$ for all t. This implies $(C_{i,t})' \geq (\underline{C}_i)'$, where $(\underline{C}_i)'$ denotes aggregate consumption under autarky if country i's capability had jumped immediately to its autarky steady state value, $(N_i)'$. We can therefore compute an upper-bound as

$$\overline{GT}_i = 1 - \frac{(\underline{C}_i)'}{C_i}.$$

We now describe how to compute $\underline{GT}_i$ and $\overline{GT}_i$ using the same general strategy as in Costinot and Rodríguez-Clare (2013). Consider $\underline{GT}_i$ first. In the trade and autarky equilibria with identical capability N_i, budget balance in every period implies

$$C_i = w_i L_i / P_i, \tag{A.21}$$

$$(\bar{C}_i)' = (\bar{w}_i)' L_i / (\bar{P}_i)'. \tag{A.22}$$

By equation (A.4), we also have

$$\frac{(\bar{P}_i)'}{P_i} = \left[\int_{n \leq N_i} \left(\frac{P_i(n)}{P_i} \right)^{1-\epsilon} \left(\frac{(\bar{P}_i(n))'}{P_i(n)} \right)^{1-\epsilon} dF(n) \right]^{\frac{1}{1-\epsilon}}.$$

Using the fact that $e_i(n) = (P_i(n)/P_i)^{1-\epsilon}$, $(\bar{P}_i(n))' = (\bar{w}_i)'/A_{ii}$ for all $n \leq N_i$, and $\lambda_{ii}(n) = (w_i/(A_{ii}P_i(n)))^{1-\sigma}$ for all $n \leq N_i$ and zero otherwise, this can be rearranged as

$$\frac{(\bar{P}_i)'}{P_i} = \frac{(\bar{w}_i)'}{w_i} \left[\int e_i(n) (\lambda_{ii}(n))^{\frac{\epsilon-1}{\sigma-1}} dF(n) \right]^{\frac{1}{1-\epsilon}}.$$

Combining this expression with equations (A.21) and (A.22), we obtain

$$\underline{GT}_i = 1 - \left[\int_0^{N_i} e_i(n) (\lambda_{ii}(n))^{\frac{\epsilon-1}{\sigma-1}} dF(n) \right]^{\frac{1}{\epsilon-1}}.$$

Next, consider $\overline{GT}_i = 1 - \frac{(\underline{C}_i)'}{C_i}$. As before, budget balance in every period implies

$$(\underline{C}_i)' = (\underline{w}_i)' L_i / (\underline{P}_i)',$$

whereas equations (A.1) and (A.4) imply

$$\frac{(\bar{P}_i)'}{(\underline{P}_i)'} = \frac{(\bar{w}_i)'}{(\underline{w}_i)'} \left(\frac{N_i}{(N_i)'} \right)^{\frac{1}{1-\epsilon}}.$$

Noting that $(\underline{C}_i)'/C_i = ((\underline{C}_i)'/(\bar{C}_i)')((\bar{C}_i)'/C_i)$, we get

$$\overline{GT}_i = 1 - \left[\int_0^{N_i} e_i(n) (\lambda_{ii}(n))^{\frac{\epsilon-1}{\sigma-1}} dF(n) \right]^{\frac{1}{\epsilon-1}} \left[N_i / (N_i)' \right]^{\frac{1}{1-\epsilon}}.$$

In the trade steady state, we know that $0 = H(N_i, F_i^{\ell})$, so that $N_i = H_i^{-1}(0, F_i^{\ell})$. In the autarky steady state, we also know from the proof of Proposition 1 that the employment distribution is equal to F, so that $(N_i)' = H_i^{-1}(0, F)$ with $F_i^{\ell} \succeq_{fosd} F$. Substituting for N_i and $(N_i)'$, we finally obtain

$$\overline{GT}_i = 1 - \left[\int e_i(n) (\lambda_{ii}(n))^{\frac{\epsilon-1}{\sigma-1}} dF(n) \right]^{\frac{1}{\epsilon-1}} \left[H_i^{-1}(0, F_i^{\ell}) / H_i^{-1}(0, F) \right]^{\frac{1}{(1-\epsilon)}}.$$

This concludes our analysis in the case of a ladder economy.

In the case of an inverted ladder economy, Proposition 2 instead implies $(N_{i,t})' \geq N_i$ for all t, which implies $(C_{i,t})' \geq (\bar{C}_i)'$ and, in turn, that $\underline{GT}_i = 1 - (\bar{C}_i)'/C_i$ provides an upper-bound on the cost of autarky, and hence the gains from trade. Conversely, since $(N_{i,0})' = N_i \leq (N_i)'$ in this case, we must also have $(N_{i,t})' \leq (N_i)'$ for all t, which implies implies $(C_{i,t})' \leq (\underline{C}_i)'$ and, in turn, that $\overline{GT}_i = 1 - (\underline{C}_i)'/C_i$ provides a lower-bound on the gains from trade. □

B Online Appendix: Empirics

B.1 Sample of Countries and Accession Dates

Table B.1: Sample of Countries

Country Name	Years in Sample	Max Exports 5-yr Avg ($B)	WTO/GATT Accession	Country Name	Years in Sample	Max Exports 5-yr Avg ($B)	WTO/GATT Accession	Country Name	Years in Sample	Max Exports 5-yr Avg ($B)	WTO/GATT Accession
Afghanistan	53	0.79	2016	Ghana	53	9.67	1957	Nigeria	53	92.07	1960
Albania	53	1.89	2000	Gibraltar	51	0.19	1948	North Korea	53	2.82	
Algeria	53	52.36		Greece	53	20.26	1950	Norway	53	120.49	1948
Angola	53	58.92	1994	Greenland	47	0.80		Oman	53	39.29	2000
Argentina	53	71.72	1967	Guatemala	53	9.71	1991	Pakistan	53	23.09	1948
Australia	53	239.90	1948	Guinea	53	2.14	1994	Panama	53	6.09	1997
Austria	53	143.06	1951	Guinea-Bissau	53	0.25	1994	Papua New Guinea	53	7.19	1994
Bahamas	53	5.18		Guyana	53	1.36	1966	Paraguay	53	5.95	1994
Bahrain	53	6.35	1993	Haiti	53	0.93	1950	Peru	53	37.86	1951
Bangladesh	43	26.49	1972	Honduras	53	7.75	1994	Philippines	53	69.76	1979
Barbados	53	0.66	1967	Hong Kong	53	77.28	1986	Poland	53	160.48	1967
Belgium-Luxembourg	53	316.24	1948	Hungary	53	89.46	1973	Portugal	53	51.93	1962
Belize	50	1.13	1983	Iceland	53	4.69	1968	Qatar	53	94.18	1994
Benin	53	1.03	1996	India	53	216.23	1948	Republic of the Congo	53	10.13	1963
Bermuda	53	0.80	1948	Indonesia	53	184.50	1950	Romania	53	53.89	1971
Bolivia	53	9.16	1990	Iran	53	93.76		Rwanda	52	0.35	1966
Brazil	53	229.93	1948	Iraq	53	72.40		Saint Kitts and Nevis	51	0.40	1994
Bulgaria	53	21.91	1996	Ireland	53	155.60	1967	Saudi Arabia	53	292.65	2005
Burkina Faso	53	1.42	1963	Israel	53	56.88	1962	Senegal	53	1.69	1963
Burma	53	10.98	1948	Italy	53	438.64	1950	Seychelles	46	0.46	2015
Burundi	53	0.24	1965	Jamaica	53	2.63	1963	Sierra Leone	53	1.11	1961
Cambodia	53	8.94	2004	Japan	53	723.21	1955	Singapore	53	167.98	1973
Cameroon	53	4.72	1963	Jordan	53	5.68	2000	Somalia	53	0.49	
Canada	53	413.57	1948	Kenya	53	4.73	1964	South Africa	53	124.20	1948
Central African Republ	53	0.35	1963	Kiribati	53	0.48		South Korea	53	465.30	1967
Chad	53	2.90	1963	Kuwait	53	68.88	1963	Spain	53	246.47	1963
Chile	53	73.65	1949	Laos	53	3.14	2013	Sri Lanka	53	9.49	1948
China	53	2054.70	2001	Lebanon	53	3.19		Sudan	53	9.91	
Colombia	53	51.29	1981	Liberia	53	2.90	2016	Suriname	53	1.99	1978
Costa Rica	53	31.16	1990	Libya	53	41.53		Sweden	53	145.58	1950
Cote d'Ivoire	53	9.32	1963	Macau	52	3.81	1991	Switzerland	53	293.02	1966
Cuba	53	5.03	1948	Madagascar	53	1.81	1963	Syria	53	6.54	
Cyprus	53	3.29	1963	Malawi	52	1.06	1964	Tanzania	53	3.99	1961
Democratic Republic	53	6.92	1997	Malaysia	53	236.31	1957	Thailand	53	207.74	1982
Denmark	53	87.92	1950	Mali	53	1.95	1993	Togo	53	1.70	1964
Djibouti	53	0.18	1994	Malta	53	4.06	1964	Trinidad and Tobago	53	14.37	1962
Dominican Republic	53	7.24	1950	Mauritania	53	2.95	1963	Tunisia	53	15.39	1990
Ecuador	53	23.63	1996	Mauritius	53	2.35	1970	Turkey	53	119.67	1951
Egypt	53	27.35	1970	Mexico	53	345.91	1986	Uganda	53	1.39	1962
El Salvador	53	4.76	1991	Mongolia	53	4.14	1997	United Arab Emirates	49	178.65	1994
Equatorial Guinea	53	10.99		Morocco	53	21.00	1987	United Kingdom	53	399.43	1948
Ethiopia	53	2.15		Mozambique	53	4.08	1992	United States	53	1261.01	1948
Falkland Islands	45	0.19	1948	Nepal	53	0.79	2004	Uruguay	53	9.19	1953
Fiji	53	0.79	1993	Netherland Antilles ar	53	9.03		Venezuela	53	59.20	1990
Finland	53	75.64	1950	Netherlands	53	393.29	1948	Vietnam	53	116.63	2007
France	53	520.74	1948	New Caledonia	53	1.44	1948	Yemen	53	8.17	2014
Gabon	53	9.73	1963	New Zealand	53	35.42	1948	Zambia	53	6.93	1982
Gambia	53	0.25	1965	Nicaragua	53	4.60	1950	Zimbabwe	52	2.47	1948
Germany	53	1228.27	1951	Niger	53	0.72	1963				

Notes: Table reports the 146 countries in our sample alongside the number of years of data, the maximum value of exports over any 5 year period 1962-2014 (in billions of 2010 US dollars), and the year of WTO or GATT accession.

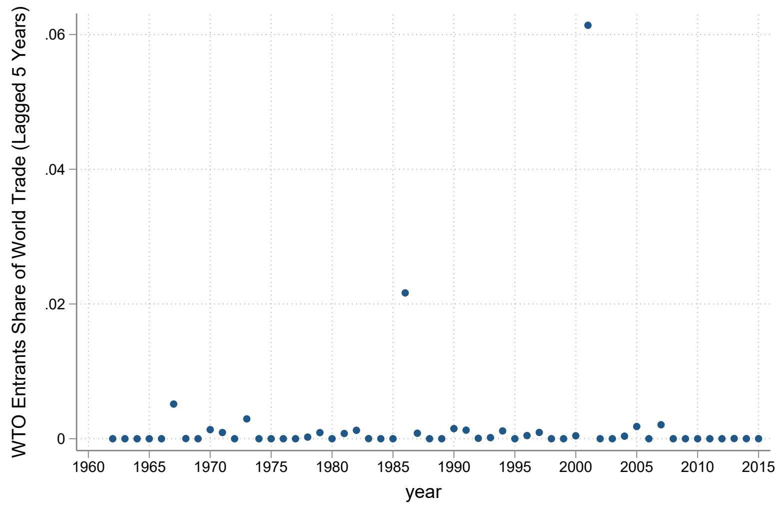


Figure B.1: WTO Entrants Share of World Trade

Notes: Figure B.1 plots, for each year t, the (5-year lagged) share of total exports between our 146 sample countries accounted for by exports from countries that enter into the WTO or GATT in year t.

B.2 Baseline Measures of Capability and Complexity: Construction

This appendix describes how we construct our baseline measures of capability $N_{i,t}$ and complexity n_t^k from the assumption that more capable countries are more likely to export more complex goods. As described in Section 4.1, we posit the following linear probability model:

$$\pi_{ij,t}^k = \delta_{ij,t} + \gamma_{j,t}^k + N_{i,t} n_t^k + \epsilon_{ij,t}^k \tag{B.1}$$

where $\pi_{ij,t}^k$ is a dummy variable that takes the value 1 if positive exports of good k are observed between i and j in period t and $\epsilon_{ij,t}^k$ is a mean-zero error term, independently drawn across origins and sectors, but not necessarily across destinations within the same origin and sector,

$$\epsilon_{ij,t}^k = \xi_{i,t}^k + u_{ij,t}^k,$$

where $\xi_{i,t}^k$ is i.i.d and mean zero across both products and origins and $u_{ij,t}^k$ is i.i.d and mean zero across products, origins and destinations.

To estimate both capability $N_{i,t}$ and complexity n_t^k in any year, we start by taking a double difference, $DD_{ii_0,t}^{kk_0}$, of equation B.1 with respect to a base good k_0 and a base exporter i_0, and average across all j destinations:

$$\begin{aligned} DD_{ii_0,t}^{kk_0} \equiv & \sum_j \frac{1}{J} \left[(\pi_{ij,t}^k - \pi_{i_0j,t}^k) - (\pi_{ij,t}^{k_0} - \pi_{i_0j,t}^{k_0}) \right] \\ & \to_{J\to\infty} (N_{i,t} - N_{i_0,t})(n_t^k - n_t^{k_0}) + (\xi_{i,t}^k - \xi_{i_0,t}^k) - (\xi_{i,t}^{k_0} - \xi_{i_0,t}^{k_0}), \end{aligned} \tag{B.2}$$

where we have applied the law of large numbers across J destination countries to eliminate the

$u_{ij,t}^{k}$ shocks.

Capability Estimator. In order to estimate $N_{i,t}$, up to affine transformation, we first average this difference-in-difference over goods k using the United States (US) as the reference country i_0 to obtain

$$\sum_k \frac{1}{K} DD_{iUS,t}^{kk_0} = \sum_k \frac{1}{K} \sum_j \frac{1}{J} \left[(\pi_{ij,t}^{k} - \pi_{USj,t}^{k}) - (\pi_{ij,t}^{k_0} - \pi_{USj,t}^{k_0}) \right]$$
$$\rightarrow_{J,K\rightarrow\infty} (N_{i,t} - N_{US,t})(\sum_k \frac{1}{K} n_t^k - n_t^{k_0}) - (\xi_{i,t}^{k_0} - \xi_{US,t}^{k_0}),$$

where we have applied the law of large numbers across K sectors to eliminate the $(\xi_{i,t}^{k} - \xi_{i_0,t}^{k})$ shocks. This deals with any potential bias due fact that to the fact that country i may be unusually prone to export any particular good k relative to the United States. To address the bias that i may be unusually productive in making the benchmark good relative to the benchmark country (the $\xi_{i,t}^{k_0} - \xi_{US,t}^{k_0}$ term), we then take a second weighted average over benchmark goods, with the weights $\omega_t^{k_0} \neq \frac{1}{K}$ chosen such that $(\sum_k \frac{1}{K} n_t^k - \sum_{k_0} \omega_t^{k_0} n_t^{k_0}) \neq 0$ and for which the law of large numbers still applies to the weighted average, i.e. $\sum_{k_0} \omega_t^{k_0} (\xi_{i,t}^{k_0} - \xi_{US,t}^{k_0}) \rightarrow_{K\rightarrow\infty} 0$. This implies

$$\hat{N}_{i,t} \equiv \sum_{k_0} \omega_t^{k_0} \sum_k \frac{1}{K} DD_{iUS,t}^{k,k_0} \rightarrow_{J,K\rightarrow\infty} (N_{i,t} - N_{US,t})(\sum_k \frac{1}{K} n_t^k - \sum_k \omega_t^k n_t^k). \tag{B.3}$$

We can therefore use $\hat{N}_{i,t}$ as an estimator of $N_{i,t}$, up to affine transformation,

$$N_{i,t} = a_t \hat{N}_{i,t} + b_t, \tag{B.4}$$

with $a_t \equiv 1/(\sum_k \frac{1}{K} n_t^k - \sum_k \omega_t^k n_t^k)$ and $b_t \equiv N_{US,t}$. We discuss the choice of weights ω_t^k as well as how we deal with a_t and b_t after introducing our estimator of product complexity.

Complexity Estimator. We can follow the same steps to obtain an estimator of complexity n_t^k, up to affine transformation, using medicaments (ME) as the reference sector k_0. Starting from equation (B.2) and averaging across origin countries implies

$$\sum_i \frac{1}{I} DD_{ii_0,t}^{kME} \equiv \sum_i \frac{1}{I} \sum_j \frac{1}{J} \left[(\pi_{ij,t}^{k} - \pi_{i_0j,t}^{k}) - (\pi_{ij,t}^{ME} - \pi_{i_0j,t}^{ME}) \right]$$
$$\rightarrow_{J,I\rightarrow\infty} (\sum_i \frac{1}{I} N_{i,t} - N_{i_0,t})(n_t^k - n_t^{ME}) - (\xi_{i_0,t}^{k} - \xi_{i_0,t}^{ME}),$$

where we have applied the law of large numbers across I origin countries to eliminate the $(\xi_{i,t}^{k} - \xi_{i,t}^{ME})$ term. Averaging again over benchmark countries using weights $\omega_{i_0,t}$ such that $(\sum_i \frac{1}{I} N_{i,t} - \sum_{i_0} \omega_{i_0,t} N_{i_0,t}) \neq 0$ and $\sum_{i_0} \omega_{i_0,t} (\xi_{i_0,t}^{k} - \xi_{i_0,t}^{ME}) \rightarrow_{I\rightarrow\infty} 0$ implies

$$\hat{n}_t^k \equiv \sum_{i_0} \omega_{i_0,t} \sum_i \frac{1}{I} DD_{ii_0,t}^{kME} \rightarrow_{J,I\rightarrow\infty} (\sum_i \frac{1}{I} N_{i,t} - \sum_i \omega_{i,t} N_{i,t})(n_t^k - n_t^{ME}). \tag{B.5}$$

We can therefore use $\hat{n}_t^k$ as an estimator of n_t^k, up to affine transformation,

$$n_t^k = c_t \hat{n}_t^k + d_t, \tag{B.6}$$

with $c_t \equiv 1/(\sum_i \frac{1}{I} N_{i,t} - \sum_i \omega_{i,t} N_{i,t})$ and $d_t \equiv n_t^{ME}$.

Choosing weights. Our estimators of capability and complexity each require weights, ω_t^k and $\omega_{i,t}$, respectively. Provided that ω_t^k is such that $\sum_k \frac{1}{K} n_t^k - \sum_k \omega_t^k n_t^k \neq 0$ and $\sum_k \omega_t^k (\xi_{i,t}^k - \xi_{US,t}^k) \rightarrow_{K\rightarrow\infty} 0$ and $\omega_{i,t}$ is such that $\frac{1}{I} N_{i,t} - \sum_i \omega_{i,t} N_{i,t} \neq 0$ and $\sum_i \omega_{i,t} (\xi_{i,t}^k - \xi_{i,t}^{MED}) \rightarrow_{I\rightarrow\infty} 0$, the previous discussion establishes that $\hat{N}_{i,t}$ and $\hat{n}_t^k$ are consistent estimators of $N_{i,t}$ and n_t^k, up to affine transformation. In small samples, though, the choice of ω_t^k and $\omega_{i,t}$ may matter for our estimates of $N_{i,t}$ and n_t^k. We now describe how we choose those weights through an iterative procedure.

We start with initial weights $\omega_{i,t}^{(0)}$ that focus on whether country i is a G-10 country in 1962-1964,

$$\omega_{i,t}^{(0)} = \begin{cases} \frac{1}{11} & \text{if } i \in \text{G-10}, \\ 0 & \text{if } i \notin \text{G-10}. \end{cases}$$

By including 11 countries rather than a single one in our reference group, we expect $\sum_i \omega_{i,t}^{(0)} (\xi_{i,t}^k - \xi_{i,t}^{ME})$ to be close to zero. By only including countries that we expect to be more capable, we also expect $\sum_i \frac{1}{I} N_{i,t} - \sum_i \omega_{i,t}^{(0)} N_{i_0,t} < 0$ to hold. These weights give us an initial set of estimates of complexity, $\hat{n}_t^{k,(0)} = \sum_{i_0} \omega_{i_0,t}^{(0)} \sum_i \frac{1}{I} DD_{ii_0,t}^{kME}$, that are strictly decreasing in n_t^k by equation (B.6) and the previous inequality.

In any step $s \geq 1$, given country weights such that $\sum_i \frac{1}{I} N_{i,t} - \sum_i \omega_{i,t}^{(s-1)} N_{i,t} < 0$ and estimates of complexity $\hat{n}_t^{k,(s-1)} = \sum_{i_0} \omega_{i_0,t}^{(s-1)} \sum_i \frac{1}{I} DD_{ii_0,t}^{kME}$ obtained in step $s-1$, we set

$$\omega_t^{k,(s)} = \frac{\max_l (\hat{n}_t^{l,(s-1)}) - \hat{n}_t^{k,(s-1)}}{\sum_r [\max_l (\hat{n}_t^{l,(s-1)}) - \hat{n}_t^{r,(s-1)}]},$$

which is such that $\omega_t^{k,(s)} \in [0,1]$, $\sum_k \omega_t^{k,(s)} = 1$, and $\omega_t^{k,(s)}$ is strictly decreasing in $\hat{n}_t^{k,(s-1)}$ and strictly increasing in n_t^k, since $\sum_i \frac{1}{I} N_{i,t} - \sum_i \omega_{i,t}^{(s-1)} N_{i,t} < 0$. It follows that $\sum_k \frac{1}{K} n_t^k - \sum_k \omega_t^{k,(s)} n_t^k < 0$. These weights give us a new set of estimates of capability, $\hat{N}_{i,t}^{(s)} = \sum_{k_0} \omega_t^{k_0,(s)} \sum_k \frac{1}{K} DD_{iUS,t}^{k,k_0}$, and a new set of country weights,

$$\omega_{i,t}^{(s)} = \frac{\max_j \hat{N}_{j,t}^{(s)} - \hat{N}_{i,t}^{(s)}}{\sum_l [\max_j \hat{N}_{j,t}^{(s)} - \hat{N}_{l,t}^{(s)}]},$$

which is also such that $\omega_{i,t}^{(s)} \in [0,1]$, $\sum_i \omega_{i,t}^{(s)} = 1$, and $\omega_{i,t}^{(s)}$ is strictly decreasing in $\hat{N}_{i,t}^{(s)}$, and strictly increasing in $N_{i,t}$, since $\sum_k \frac{1}{K} n_t^k - \sum_k \omega_t^{k,(s)} n_t^k < 0$. Hence, it also satisfies $\sum_i \frac{1}{I} N_{i,t} - \sum_i \omega_{i,t}^{(s)} N_{i,t} < 0$. These weights give us a new set of estimates of complexity, $\hat{n}_t^{k,(s)} = \sum_{i_0} \omega_{i_0,t}^{(s)} \sum_i \frac{1}{I} DD_{ii_0,t}^{kME}$.

We iterate until convergence of weights $\omega_t^{k_0,(s)}$ and $\omega_{i_0,t}^{(s)}$ to $\omega_t^{k_0}$ and $\omega_{i_0,t}$. To aid replication, Box 1 presents a stripped-down version of the algorithm described above.

Box 1: A Simple Algorithm for Estimating Capability $N_{i,t}$ and Complexity n_t^k

i. For any year t, start with a dataset of extensive margin bilateral exports $\pi_{ij,t}^k$, where $\pi_{ij,t}^k$ is a dummy variable equal to 1 if the value of exports of good k between i and j in period t is equal or greater than \$100,000 in 2010 US dollars and 0 otherwise. Each row of the dataset is a separate product-origin-destination triplet.

ii. Create a product-origin level dataset "temp_Sjpi" with $\sum_j \frac{1}{J}\left[\pi_{ij,t}^k\right]$, the share of countries that country i exports k to, by averaging every product-origin pair over all destinations j.

iii. Create a product-level dataset "complexity_iteration0" by taking product-level means of $\sum_j \frac{1}{J}\left[\pi_{ij,t}^k\right]$ in temp_Sjp containing the following objects:

   (a) $\sum_i \frac{1}{I}\sum_j \frac{1}{J}\left[\pi_{ij,t}^k\right]$, the product k-level mean of the product-origin-level shares $\sum_j \frac{1}{J}\left[\pi_{ij,t}^k\right]$;

   (b) $\sum_i \omega_{i,t}^{(0)} \sum_j \frac{1}{J}\left[\pi_{ij,t}^k\right]$, the same object but taking the product k-level weighted mean where weights $\omega_{i,t}^{(0)}$ are positive and equal for countries coded as capable for the purposes of an initial guess and zero otherwise (in our case the 11 members of the G-10, $\sum_{i\in G10}\frac{1}{11}\sum_j \frac{1}{J}\left[\pi_{ij,t}^k\right]$);

   (c) $\hat{n}_t^{k,(0)} = \sum_i \frac{1}{I}\sum_j \frac{1}{J}\left[\pi_{ij,t}^k - \pi_{ij,t}^{k_0}\right] - \sum_i \omega_{i,t}^{(0)}\sum_j \frac{1}{J}\left[\pi_{ij,t}^k - \pi_{ij,t}^{k_0}\right]$, the difference between (a) and (a) for a single reference product and (b) and (b) for the same reference product (in our case medicines ME, $\sum_i \frac{1}{I}\sum_j \frac{1}{J}\left[\pi_{ij,t}^k - \pi_{ij,t}^{ME}\right] - \sum_{i\in G10}\frac{1}{11}\sum_j \frac{1}{J}\left[\pi_{ij,t}^k - \pi_{ij,t}^{ME}\right]$).

iv. Create an origin-level dataset "capability_iteration1" by taking origin-level means of $\sum_j \frac{1}{J}\left[\pi_{ij,t}^k\right]$ in temp_Sjp:

   (a) $\sum_k \frac{1}{K}\sum_j \frac{1}{J}\left[\pi_{ij,t}^k\right]$, the origin i-level mean of the product-origin-level shares $\sum_j \frac{1}{J}\left[\pi_{ij,t}^k\right]$;

   (b) $\sum_k \omega_t^{k,(1)}\sum_j \frac{1}{J}\left[\pi_{ij,t}^k\right]$, the same object but taking the origin i-level weighted mean with weights equal to functions of the product complexity estimates recovered in 3(c), $\omega_t^{k,(1)} = \frac{\max_l(\hat{n}_t^{l,(0)}) - \hat{n}_t^{k,(0)}}{\sum_r[\max_l(\hat{n}_t^{l,(0)}) - \hat{n}_t^{r,(0)}]}$;

   (c) $\hat{N}_{i,t}^{(1)} = \sum_k \frac{1}{K}\sum_j \frac{1}{J}\left[\pi_{ij,t}^k - \pi_{i_0 j,t}^k\right] - \sum_k \omega_t^{k,(1)}\sum_j \frac{1}{J}\left[\pi_{ij,t}^k - \pi_{i_0 j,t}^k\right]$, the difference between (a) and (a) for a single reference country, and (b) and (b) for the same reference country (in our case the US).

v. Create a product-level dataset "complexity_iteration1" as in 3 but replacing $\omega_{i,t}^{(0)}$ with $\omega_{i,t}^{(1)} = \frac{\max_j \hat{N}_{j,t}^{(1)} - \hat{N}_{i,t}^{(1)}}{\sum_l[\max_j \hat{N}_{j,t}^{(1)} - \hat{N}_{l,t}^{(1)}]}$ in 3(b).

vi. Create an origin-level dataset "capability_iteration2" as in 4 but replacing $\omega_t^{k,(1)}$ with $\omega_t^{k,(2)} = \frac{\max_l(\hat{n}_t^{l,(1)}) - \hat{n}_t^{k,(1)}}{\sum_r[\max_l(\hat{n}_t^{l,(1)}) - \hat{n}_t^{r,(1)}]}$ in 4(b), where $\hat{n}_t^{k,(1)}$ is recovered from 5.

vii. Iterate until $\omega_t^{k,(s-1)} = \omega_t^{k,(s)} \forall k$ and $\omega_{i,t}^{(s-1)} = \omega_{i,t}^{(s)} \forall i$.

Alternate initial weights. The choice of G-10 members for the initial country weights $\omega_{i,t}^{(0)}$ in the first step of our iterative procedure has very little effect on our ultimate estimates of capability and complexity. Using instead membership of other developed-country organizations (the G-7, the original 21 OECD members) generates identical estimates for $N_{i,t}$ and n_t^k. Furthermore, we obtain the exact same estimates if we supplement our G-10 list with countries chosen at random, simulating a procedure where we have only a very crude ability to select some subgroup of countries that are on average more sophisticated and thus the difference between the average export patterns of our initial guess of more capable countries and the average across all countries is slight. Specifically, we choose 10–140 random countries from our 146 country sample (in increments of 10) and further include any G-10 country not already selected. In all 14 cases, estimates converge within 3 iterations and recover the same $N_{i,t}$ and n_t^k as in our baseline. As a theoretical matter, counter-examples do exist. For instance, when we purely use these random lists of countries (without including all G-10 members), we only recover these same estimates in half of the 14 cases. This is not unexpected since identification critically relies on comparing groups of countries with different capabilities.

Measuring capability and complexity across time. For the purposes of estimating dynamic spillovers in Section 5.3, i.e. estimating β and ϕ in equation (14), and later quantifying the dynamic gains from trade in Section 6, which also requires estimates of $\bar{\pi}_{i,t}^k(\cdot)$, we make two additional assumptions:

$$\min_k(n_t^k) = 0 \text{ for all } t,$$
$$\max_k(n^k) = \bar{n} \text{ for all } t.$$

Combining these two conditions with equation (B.6), and recalling that weights $\{\omega_{i_0,t}\}$ are constructed so that $\sum_i \frac{1}{I} N_{i,t} - \sum_{i_0} \omega_{i_0,t} N_{i_0,t} < 0$, we obtain

$$n_t^k = \frac{\bar{n}(\max_k(\hat{n}_t^k) - \hat{n}_t^k)}{\max_k(\hat{n}_t^k) - \min_k(\hat{n}_t^k)} \text{ for all } k \text{ and } t.$$

In turn, equation (B.4) implies

$$N_{i,t} = -\frac{1}{\bar{n}} \frac{\max_k(\hat{n}_t^k) - \min_k(\hat{n}_t^k)}{\sum_k \frac{1}{K}\hat{n}_t^k - \sum_k \omega_t^k \hat{n}_t^k} \hat{N}_{i,t} + N_{US,t} \text{ for all } i \text{ and } t.$$

The specific values of $\bar{n}$ and $N_{US,t}$ are irrelevant for any of our subsequent conclusions. Alternative values of $\bar{n}$ are equivalent to changing the units in which dynamic spillovers are measured in equation (14), with the estimated coefficient $\hat{\phi}$ scaling one-for-one with $\bar{n}$. Alternative values of $N_{US,t}$, in turn, only affect the values of the fixed effects entering equation (14) and $\bar{\pi}_{i,t}^k(\cdot)$. Without loss of generality, we set $\bar{n} = 1$ and $N_{US,t} = 1 - \sum_i \frac{1}{I}\tilde{N}_{i,t} + \sum_t \sum_i \frac{1}{IT}\tilde{N}_{i,t}$, with $\tilde{N}_{i,t} \equiv -\frac{1}{\bar{n}} \frac{\max_k(\hat{n}_t^k) - \min_k(\hat{n}_t^k)}{\sum_k \frac{1}{K}\hat{n}_t^k - \sum_k \omega_t^k \hat{n}_t^k} \hat{N}_{i,t}$ and T the number of periods. This normalization ensures that the average capability across all countries is constant over time, $\sum_i \frac{1}{I} N_{i,t} = 1 + \sum_t \sum_i \frac{\tilde{N}_{i,t}}{IT}$ for all t, and that the US takes the value one averaging across years, $\sum_t \frac{1}{T} N_{US,t} = 1$.

B.3 GDP per Capita versus Capability

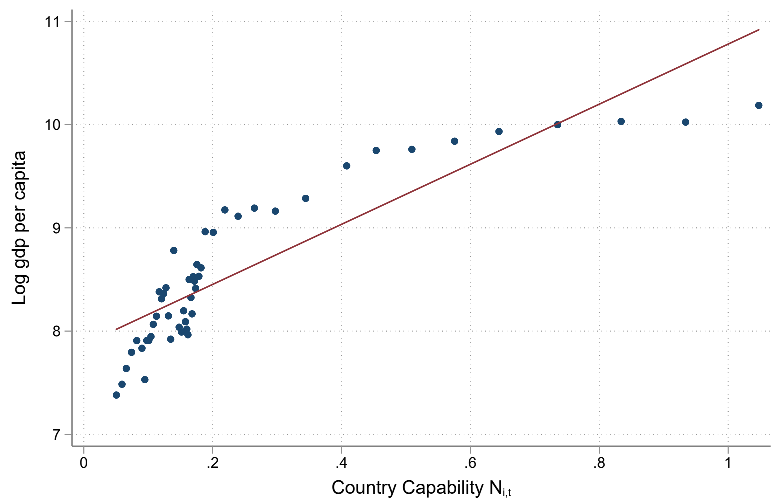


Figure B.2: GDP per capita vs. Capability (within years)

Notes: Figure B.2 is the binned scatter plot associated with a regression of log GDP per capita (RGDPE from the Penn World Tables 9.0) on both capabilities, recovered from the linear probability model estimation of equation (12) as described in Section 4.1, and year fixed effects.

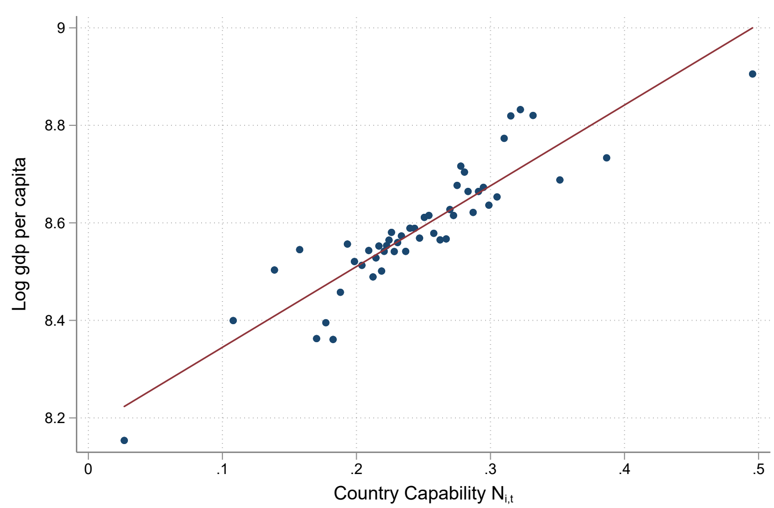


Figure B.3: GDP per capita vs. Capability (within years and countries)

Notes: Figure B.3 is the binned scatter plot associated with a regression of log GDP per capita (RGDPE from the Penn World Tables 9.0) on capabilities, recovered from the linear probability model estimation of equation (12) as described in Section 4.1, year fixed effects and country fixed effects.

B.4 Construction of Instrumental Variables

Our goal is to construct instrumental variables that predict average complexity, $S^x_{i,t}$, in a country i as a function of the entry of other countries c into the WTO at some date τ. To do so, we model the entry of any country c into the WTO as a uniform trade cost shock such that for all $t \geq \tau$,

$$(A^k_{ij,t})'_c = \begin{cases} e^{\alpha} A^k_{ij,\tau-\Delta} & \text{if } i = c \text{ and } j \neq c, \\ A^k_{ij,\tau-\Delta} & \text{otherwise.} \end{cases}$$

with $\alpha > 0$. We then compute, up to a first-order approximation, the counterfactual change in country i's average complexity, $(\Delta S^x_i)_c$, that would have been observed in any period $t \geq \tau$ if the entry of country c was the only shock occurring from period τ onward and all wages were to remain fixed. We finally sum the previous changes across all WTO entry events that are prior to date t to construct predictors of $S^x_{i,t}$.

Formally, let $\omega^k_{i,\tau-\Delta} \equiv \sum_{j\neq i} x^k_{ij,\tau-\Delta} / \sum_{k',j\neq i} x^{k'}_{ij,\tau-\Delta} x_{i,\tau-\Delta}$ denote the share of exports in sector k and country i at date $\tau - \Delta$, and let $(\omega^k_{i,t})'_c$ denote the counterfactual share associated with the entry of country c in the WTO if it were the only shock occurring up to date $t > \tau - \Delta$. The counterfactual value of $S^x_{i,t}$ is given by $(S^x_{i,t})'_c = \sum_k n^k_{t_c-1} (\omega^k_{i,t})'_c$. We can therefore express the associated change $(\Delta S^x_{i,t})_c \equiv (S^x_{i,t})'_c - S^x_{i,\tau-\Delta}$ as

$$(\Delta S^x_i)_c = \sum_k n^k_{\tau-\Delta} (\Delta\omega^k_{i,t})_c,$$

with $(\Delta\omega^k_{i,t})_c \equiv (\omega^k_{i,t})'_c - \omega^k_{i,\tau-\Delta}$. Up to a first-order approximation, we also have

$$\begin{aligned} (\Delta\omega^k_{i,t})_c / \omega^k_{i,\tau-\Delta} = & \\ & \sum_{j\neq c,i} \rho^k_{ij,\tau-\Delta} [(\sigma-1)\alpha + (\sigma-\epsilon)\Delta\ln(P^k_{j,t})_c + (\epsilon-1)\Delta\ln(P_{j,t})_c] \\ - \sum_{k'} \omega^{k'}_{i,\tau-\Delta} & \sum_{j\neq c,i} \rho^{k'}_{ij,\tau-\Delta} [(\sigma-1)\alpha + (\sigma-\epsilon)\Delta\ln(P^k_{j,t})_c + (\epsilon-1)\Delta\ln(P_{j,t})_c], \end{aligned}$$

with $\rho^k_{ij,\tau-\Delta} \equiv x^k_{ij,\tau-\Delta} / \sum_{j\neq i} x^k_{ij,\tau-\Delta}$ the share of exports in country i and sector k associated with destination j and the log-changes in prices $\Delta\ln(P^k_{j,t})_c \equiv \ln(P^k_{j,t})'_c - \ln P^k_{j,\tau-\Delta}$ and $\Delta\ln(P_{j,t})_c \equiv \ln(P_{j,t})'_c - \ln P_{j,\tau-\Delta}$ given by

$$\begin{aligned} \Delta\ln(P^k_{j,t})_c &= -\alpha\lambda^k_{cj,\tau-\Delta}, \text{ for all } j \neq c, \\ \Delta\ln(P_{j,t})_c &= -\alpha\lambda_{cj,\tau-\Delta}, \text{ for all } j \neq c, \end{aligned}$$

with $\lambda^k_{cj,\tau-\Delta}$ the share of country j's expenditure on good k allocated to country c at date $\tau - \Delta$ and $\lambda_{cj,\tau-\Delta}$ the total share of expenditure on goods from country c in destination j, which we proxy by

$\lambda^k_{cj,\tau-\Delta} \equiv x^k_{cj,\tau-\Delta} / \sum_{i \neq j} x^k_{ij,\tau-\Delta}$ and $\lambda_{cj,\tau-\Delta} \equiv \sum_k x^k_{cj,\tau-\Delta} / \sum_{i \neq j,k} x^k_{ij,\tau-\Delta}$. Regrouping terms, this leads to

$$(\Delta S^x_{i,t})_c = -\alpha(\sigma-\epsilon)\{\sum_k n^k_{\tau-\Delta}\omega^k_{i,\tau-\Delta}[\sum_{j\neq c,i}\rho^k_{ij,\tau-\Delta}\lambda^k_{cj,\tau-\Delta} - \sum_{k'}\omega^{k'}_{i,\tau-\Delta}\sum_{j\neq c}\rho^{k'}_{ij,\tau-\Delta}\lambda^{k'}_{cj,\tau-\Delta}]\}$$
$$-\alpha(\epsilon-1)(\sigma-\epsilon)\{\sum_k n^k_{\tau-\Delta}\omega^k_{i,\tau-\Delta}[\sum_{j\neq c,i}\rho^k_{ij,\tau-\Delta}\lambda_{cj,\tau-\Delta} - \sum_{k'}\omega^{k'}_{i,\tau-\Delta}\sum_{j\neq c}\rho^{k'}_{ij,\tau-\Delta}\lambda_{cj,\tau-\Delta}]\}.$$

Summing across all WTO entry events by a country $c \neq i$ at a given date τ, we obtain the following predictor $\hat{S}^x_{i,t}$ of average complexity in country i at date t,

$$\hat{S}^x_{i,t} \equiv S^x_{i,1962} + \sum_{c\neq i}\sum_{\tau} 1[t \geq \tau](\Delta S^x_{i,t})_c = -\alpha(\sigma-\epsilon)Z^I_{i,t} - \alpha(\epsilon-1)(\sigma-\epsilon)Z^{II}_{i,t},$$

where $Z^I_{i,t}$ and $Z^{II}_{i,t}$ are the two instrumental variables used to estimate equation (14). They satisfy

$$Z^I_{i,t} = \sum_{c\neq i}\sum_{\tau} s^I_{ic\tau,t} \times 1[\text{country } c \text{ joins the WTO at date } \tau],$$
$$Z^{II}_{i,t} = \sum_{c\neq i}\sum_{\tau} s^{II}_{ic\tau,t} \times 1[\text{country } c \text{ joins the WTO at date } \tau],$$

with $1[\text{country } c \text{ joins the WTO at date } \tau]$ an indicator functions that takes the value one if country c joins the WTO at date τ and zero otherwise and

$$s^I_{ic\tau,t} \equiv 1[t \geq \tau] \times \sum_k n^k_{\tau-\Delta}\omega^k_{i,\tau-\Delta}(\sum_{j\neq c,i}\rho^k_{ij,\tau-\Delta}\lambda^k_{cj,\tau-\Delta} - \sum_{k'}\omega^{k'}_{i,\tau-\Delta}\sum_{j\neq c,i}\rho^{k'}_{ij,\tau-\Delta}\lambda^{k'}_{cj,\tau-\Delta}),$$
$$s^{II}_{ic\tau,t} \equiv 1[t \geq \tau] \times \sum_k n^k_{\tau-\Delta}\omega^k_{i,\tau-\Delta}(\sum_{j\neq c,i}\rho^k_{ij,\tau-\Delta}\lambda_{cj,\tau-\Delta} - \sum_{k'}\omega^{k'}_{i,\tau-\Delta}\sum_{j\neq c,i}\rho^{k'}_{ij,\tau-\Delta}\lambda_{cj,\tau-\Delta}).$$

B.5 Time Path of the Instruments

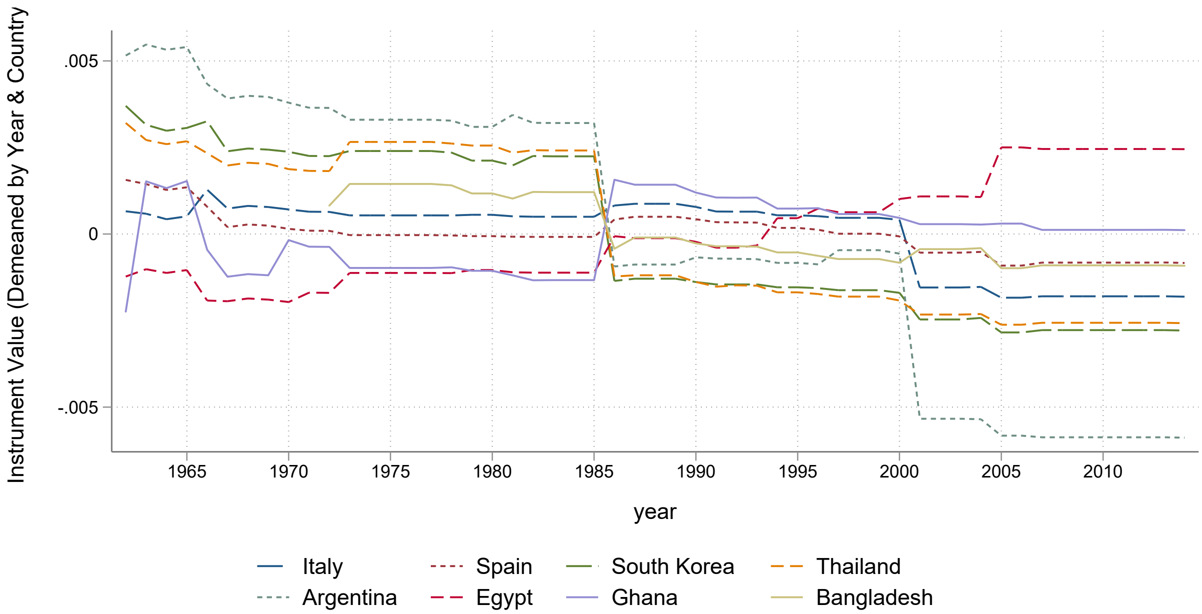


Figure B.4: Time Path of $Z_{i,t}^{II}$

Notes: Figure B.4 plots the value of the instrument $Z_{i,t}^{II}$ over time for a selection of similarly-sized countries in our sample. The instrument captures the change in complexity-weighted competition due to aggregate-level price index changes induced by other countries' entry into the WTO and derives from a first-order approximation of the change in average complexity due to trade cost shocks to WTO entrants, as described in Appendix B.4.

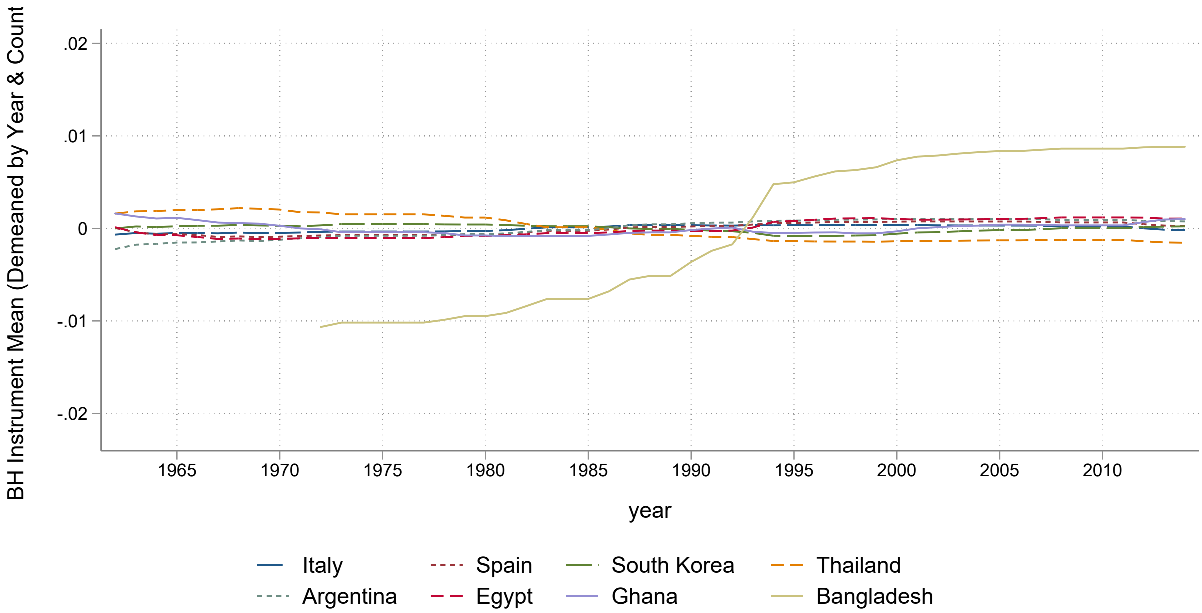


Figure B.5: Time Path of Expected Value of $Z^I_{i,t}$ Across Alternative WTO-Entry Histories
Notes: Figure B.5 plots the expected value of the instrument $Z^I_{i,t}$ over time for a selection of similarly-sized countries, with the expectation taken over alternative histories of WTO entry described in Section 5.4. The instrument captures the change in complexity-weighted competition due to sector-level price index changes induced by other countries' entry into the WTO and derives from a first-order approximation of the change in average complexity due to trade cost shocks to WTO entrants (see Appendix B.4).

B.6 Estimates of Dynamic Spillovers: Sensitivity

Appendix Table B.2 focuses on the sensitivity of our baseline estimates to alternative data samples and specifications. Recall our baseline utilizes the raw Comtrade data for consistency and applies the basic cleaning procedures outlined in Feenstra et al. (2005) but to the full 1962-2014 timespan of our data. Column 2 reproduces our results using the actual Feenstra et al. (2005) dataset for years where available. Columns 3 to 5 consider alternative samples of countries by removing the restriction that we observe a country for 40 years or that a country exports more than 100 million USD, or by enlarging this export threshold to 1 billion USD. [45]The coefficient on average complexity remains highly significant in all these cases, and rises substantially when restricting our sample to larger exporters.

Next, column 6 explores the sensitivity of our results to alternative lag structures and considers a 10-year rather than 5-year lag (and instruments using the export structure of the future entrant

[45]Column 3 expands our baseline sample of 146 countries to 200 countries by removing the restriction that we need to have observed a country for at least 40 years (and so includes countries such as those created with the fall of the Soviet Union and those with spotty reporting). Column 4 removes the restriction that a country must export a total of 100 million USD or more at some point in our sample (using 2010 US dollars and averaging annual exports over 5 year periods) leaving us with 149 countries, while column 5 enlarges this threshold to 1 billion USD reducing the sample to 126 countries.

10 years before entry). The dynamic spillovers become approximately one third larger over this extended time period. As an alternative to including all years of data and clustering standard errors at the 5-year-period-country level, column 7 only includes one observation from each cluster (observations from years ending in 5 or 0). The magnitude of the coefficient falls slightly but remains significant.

Although our 1962–2014 panel is relatively long, there may still be concerns that the inclusion of a lagged dependent variable generates Nickell bias, as discussed in footnote 20. To address this issue, we treat the initial level of capability as endogenous and use 5 year lags of our instruments as additional IVs.[46] Reassuringly, the β coefficient on the complexity of the industry mix changes little, and the coefficient on the initial level of capability only falls by a small amount, suggesting Nickell-bias worries are limited (column 8).

[46]Through the lens of our model, those lagged variables are correlated with initial capability and are orthogonal to capability shocks under the same conditions as our non-lagged IVs. As the WTO-entry events are relatively weak instruments for initial capability, our first-stage F-Stats fall somewhat.

Table B.2: Changes in Capability and Industrial Structure: Sensitivity (I)

	Country Capability $N_{i,t+\Delta}$							
	(1) Baseline	(2) Feenstra Dataset	(3) All Length Panels	(4) No Size Threshold	(5) High Size Threshold	(6) 10-year Lag	(7) 1 Obs. per 5-year	(8) IV $N_{i,t}$
Average Complexity $S^x_{i,t}$	0.279***	0.298**	0.218***	0.284***	0.390***	0.392***	0.200**	0.279***
	(0.0870)	(0.127)	(0.0717)	(0.0876)	(0.138)	(0.139)	(0.0844)	(0.0996)
Initial Capability $N_{i,t}$	0.856***	0.929***	0.869***	0.858***	0.811***	0.690***	0.875***	0.716***
	(0.0353)	(0.0414)	(0.0353)	(0.0345)	(0.0498)	(0.0635)	(0.0363)	(0.104)
Country and year FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	6,872	6,864	7,905	6,995	5,986	6,151	1,295	6,195
R-squared	0.707	0.721	0.716	0.695	0.667	0.322	0.753	0.664
Clusters	1438	1438	1673	1466	1249	723	1295	1303
CD F-Stat	37.25	17.62	38.63	34.97	29.01	38.10	7.239	11.98
KP F-Stat	8.767	4.167	9.542	8.701	6.053	9.548	5.293	3.326

Notes: Table B.2 reports estimates of β and ϕ in equation (14) using the baseline measures of complexity n^k_t and capability $N_{i,t}$ from the linear probability model estimation of equation (12). All columns use the two-instrument IV strategy. Column 1 reports our baseline estimates (column 5 of Table 2). Column 2 uses data from Feenstra et al. (2005) whenever possible. Column 3 expands our sample to include countries with fewer than 40 years of data. Column 4 removes the 100 million USD (at 2010 prices) threshold value of total exports required to be included in our sample. Column 5 raises the threshold value to 1 billion USD. Column 6 reports estimates using 10-year rather than 5-year lags. Column 7 uses one observation per 5-year cluster. Column 8 instruments initial capability using lagged-values of the WTO shocks $Z^{I}_{i,t}$ and $Z^{II}_{i,t}$. Standard errors clustered at the 5-year-period-country level. Standard errors clustered at the 5-year-period-country level.

B.7 Alternative Measures of Capability and Complexity in Section 6.4

B.7.1 Alternative Measures of Capability

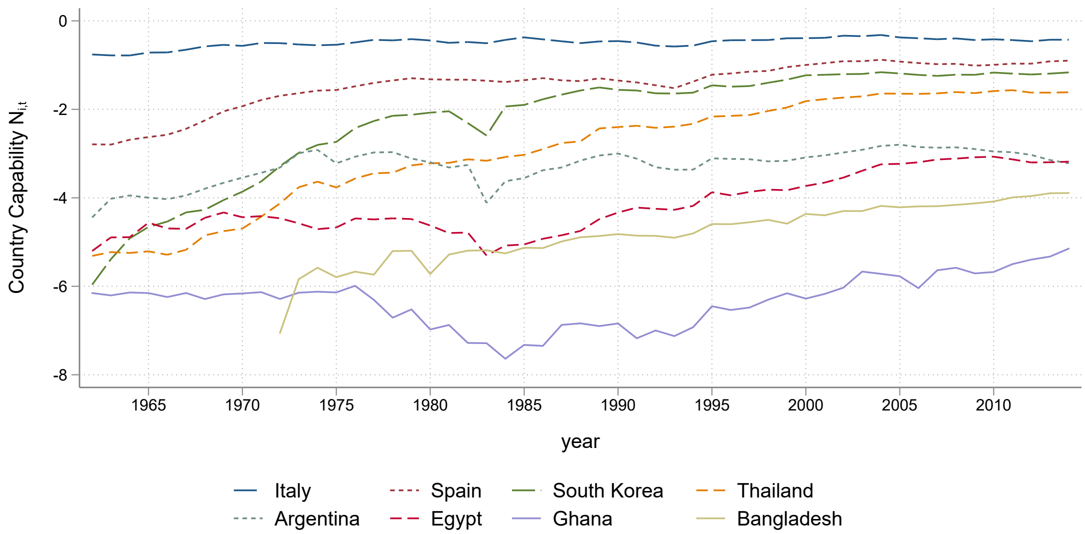


Figure B.6: Capability Across Countries ($\tilde{N}_{i,t}$)—Alternative Measures

Notes: Figure B.6 reports for a selection of similarly-sized countries the country fixed effects $\tilde{N}_{i,t}$ recovered from the maximum likelihood estimation of equation (20) in a given year t, as described in Section 4.1. Fixed effects are normalized such that $\tilde{N}_{US,t} = 0$ for all t.

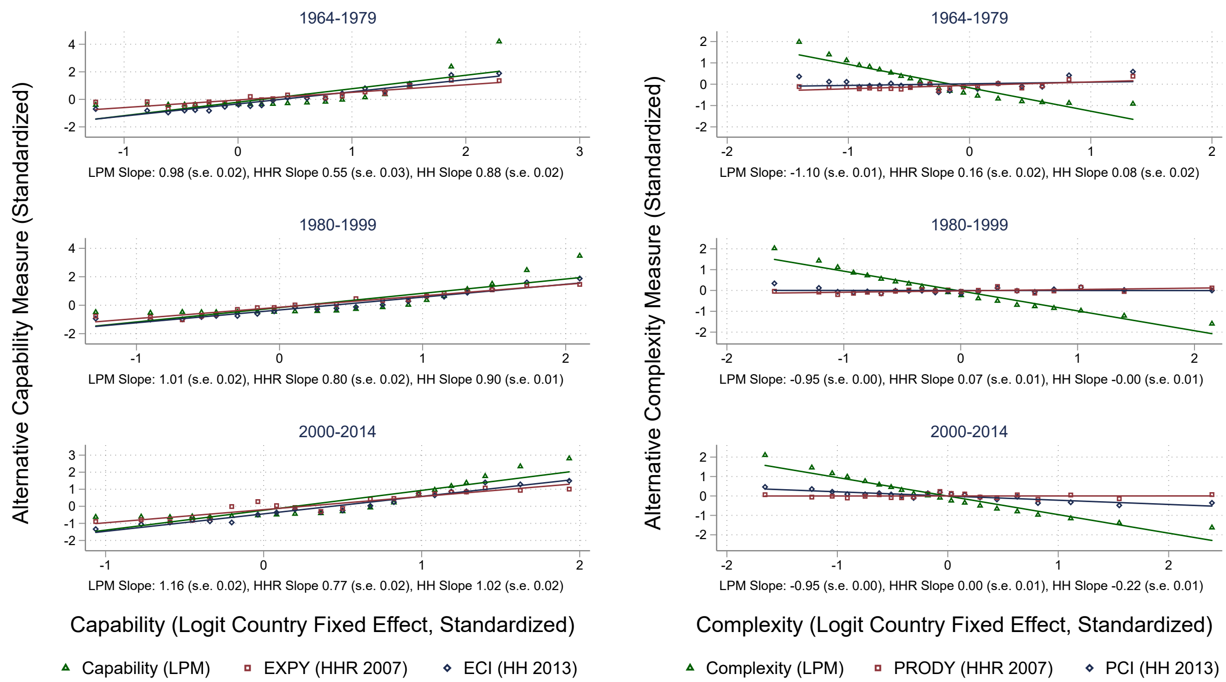
B.7.2 Alternative Measures of Complexity

Table B.3: Complexity Across Goods ($\tilde{n}_t^k$)—Alternative Measures

	Goods with highest n^k (Average Value and Rank, 1962-2014)				Goods with lowest n^k (Average Value and Rank, 1962-2014)		
1	Aircraft Tires	2.519	36.3	1	Medicaments	-1.622	497.8
2	Rotary Converters	2.552	38.7	2	Chemical Products	-1.233	487.7
3	Warships	3.193	41.3	3	Miscellaneous Non-Electrical Machinery Parts	-1.154	484.3
4	Wool Undergarments	2.449	42.9	4	Miscellaneous Electrical Machinery	-1.121	483.5
5	Undergarments of Other Fibres	2.207	53.5	5	Miscellaneous Non-Electrical Machines	-1.063	480.7
6	Railway Passenger Cars	3.216	54.0	6	Footwear	-0.997	477.5
7	Electric Trains	3.214	57.6	7	Electric Wire	-0.966	475.1
8	Retail Yarn of More Than 85% Synthetic Fiber	2.215	61.8	8	Cars	-0.959	475.1
9	Recorded Audio Players	2.243	63.5	9	Medical Instruments	-0.982	470.5
10	Mechanically Propelled Railway	2.878	65.4	10	Finished Cotton Fabrics	-1.002	468.8

Notes: Table B.3 reports the 10 highest and 10 lowest values of the goods fixed effects $\tilde{n}_t^k$ recovered from the maximum likelihood estimation of equation (20) based on each good's average rank across all years from 1962 to 2014 (for goods with at least 40 years of data). The third column of each panel displays the average n_t^k, the fourth column the average rank.

B.7.3 Comparison to Other Capability and Complexity Measures



(a) Capability Measures ($\tilde{N}_{it}$)

(b) Complexity Measures ($\tilde{n}^k_t$)

Figure B.7: Alternative Measures of Capability and Complexity

Notes: Figure B.7 compares our alternative measures of capability $\tilde{N}_{i,t}$ and complexity $\tilde{n}^k_t$ from the logit estimation of equation (20) to our baseline linear probability model measures of $N_{i,t}$ and n^k_t as well as those in Hausman et al. (2007) (labeled EXPY and PRODY) and Hausman et al. (2013) (labeled ECI and PCI). Figure plots binscatters of regressions of these three measures on the logit measures, absorbing year fixed effects and pooling observations by time period. Regression slope and standard error shown under each figure. All measures standardized mean 0 standard deviation 1 in each year.

B.8 Estimates of Dynamic Spillovers in Section 6.4

Table B.4: Changes in Capability and Industrial Structure Using Alternative Capability and Complexity Measures

	Average Complexity $S^x_{i,t}$		Country Capability $N_{i,t+\Delta}$			
	(1)	(2)	(3)	(4)	(5)	(6)
	FS	FS	OLS	IV ($Z^I_{i,t}$)	IV ($Z^I_{i,t}$, $Z^{II}_{i,t}$)	RF ($Z^I_{i,t}$, $Z^{II}_{i,t}$)
WTO Entrant Shock $Z^I_{i,t}$	-2.901***	-1.019				-1.106*
(Product-Destination Level)	(0.542)	(0.658)				(0.672)
WTO Entrant Shock $Z^{II}_{i,t}$		-12.06***				7.784***
(Destination Level)		(2.024)				(2.327)
Average Complexity $S^x_{i,t}$			0.0407	-0.0379	-0.397**	
			(0.0302)	(0.253)	(0.196)	
Initial Capability $N_{i,t}$			0.595***	0.587***	0.548***	0.585***
			(0.0210)	(0.0322)	(0.0297)	(0.0210)
Country and year FEs	Yes	Yes	Yes	Yes	Yes	Yes
Observations	7,617	7,617	6,872	6,872	6,872	6,872
R-squared	0.722	0.729	0.970	0.406	0.347	0.970
Clusters	1588	1588	1438	1438	1438	1438
CD F-Stat				105.1	120.2	
KP F-Stat				21.13	23.70	

Notes: Columns 1 and 2 of Table 2 report estimates of α_1 and α_2 in equation (17) using alternative complexity measures recovered from the maximum likelihood estimation of equation (20) to construct both average complexity and the instrumental variables. Columns 3–6 report estimates of β and ϕ in equation (14), again using the alternative measures of complexity n^k_t and capability $N_{i,t}$ recovered from the same maximum likelihood estimation. Columns 4 and 5 instrument average complexity $S^x_{i,t}$ by the WTO shocks $Z^I_{i,t}$ and $Z^{II}_{i,t}$ (in both cases using n^k_t calculated using the maximum likelihood model). Column 6 reports the reduced form regression corresponding to column 5. Standard errors clustered at the 5-year-period-country level.

C Online Appendix: Counterfactuals

C.1 Environment with Non-Tradable Sector and Trade Deficits

As discussed in Section 3, when conducting our counterfactual and welfare analysis, we augment the model of Section 2 to incorporate a non-tradable sector and trade deficits.

Instead of equation (1), we impose Cobb-Douglas preferences between tradable manufacturing goods and a homogeneous non-tradable good,

$$C_{i,t} = (C_{i,t}^{M})^{\theta_{i,t}} (C_{i,t}^{NT})^{1-\theta_{i,t}}, \tag{C.1}$$

where the aggregate consumption of manufacturing goods $C_{i,t}^{M}$ remains given by

$$C_{i,t}^{M} = \left(\int (C_{i,t}^{k})^{(\epsilon-1)/\epsilon} dk\right)^{\epsilon/(\epsilon-1)}; \tag{C.2}$$

$C_{i,t}^{NT}$ denotes the consumption of the non-tradable good; and $\theta_{i,t} \in [0,1]$ determines the share of expenditure on manufacturing goods. Output in the non-tradable sector is given by

$$Q_{i,t}^{NT} = A_{i,t}^{NT} L_{i,t}^{NT},$$

where $A_{i,t}^{NT} \geq 0$ denotes the productivity of firms in the non-tradable sector and $\ell_{i,t}^{NT} \geq 0$ denote their employment. Production in the non-tradable sector does not generate any spillover. The rest of the economic environment is unchanged, except for the existence of trade deficits, $D_{i,t}$, which we model as lump-sum transfers between countries, $\sum D_{i,t} = 0$.

Compared to the model of Section 2, the equilibrium consumption of manufacturing goods (previously given by equation A.2) is now equal to

$$c_{ij,t}^{k} = \theta_{j,t} \frac{(p_{ij,t}^{k})^{-\sigma}}{(P_{j,t}^{k})^{1-\sigma}} \frac{(P_{j,t}^{k})^{1-\epsilon}}{(P_{j,t})^{1-\epsilon}} (w_{j,t} L_{j,t} + D_{j,t}), \tag{C.3}$$

whereas the consumption in the non-tradable sector is given by

$$C_{j,t}^{NT} = (1-\theta_{j,t})(w_{j,t} L_{j,t} + D_{j,t}) / P_{j,t}^{NT}, \tag{C.4}$$

with the price of the non-tradable good given by the zero-profit-condition

$$P_{j,t}^{NT} = w_{j,t} / A_{j,t}^{NT}. \tag{C.5}$$

Finally, good market clearing in the non-tradable sector requires

$$C_{i,t}^{NT} = A_{i,t}^{NT} L_{i,t}^{NT}, \tag{C.6}$$

whereas labor market clearing requires

$$\sum_j \int \ell_{ij,t}^k dk + L_{i,t}^{NT} = L_{i,t}. \tag{C.7}$$

All other equilibrium conditions—equations A.1, A.3, A.4, and A.5—are unchanged.

C.2 Identification of Productivity Draws and Labor Supply

Let $x_{ij,t}^k$ denote the value of sales by country i to country j in sector k at date t. Equations (A.1) and (C.3) imply

$$\frac{x_{ij,t}^k}{x_{jj,t}^1} = \frac{(w_{i,t}/A_{ij,t}^k)^{1-\sigma}}{(w_{j,t}/A_{jj,t}^1)^{1-\sigma}} \frac{(P_{j,t}^k)^{\sigma-\epsilon}}{(P_{j,t}^1)^{\sigma-\epsilon}}. \tag{C.8}$$

Combined with equation (A.3), equations (A.1) and (A.2) further imply

$$\frac{\sum_i x_{ij,t}^k}{\sum_i x_{ij,t}^1} = \frac{(P_{j,t}^k)^{1-\epsilon}}{(P_{j,t}^1)^{1-\epsilon}}. \tag{C.9}$$

Using equation (C.9) to substitute for $P_{j,t}^k/P_{j,t}^1$ in equation (C.8), we obtain, after rearrangements,

$$\frac{A_{ij,t}^k}{A_{jj,t}^1} = \left(\frac{w_{i,t}}{w_{j,t}}\right) \left(\frac{x_{ij,t}^k}{x_{jj,t}^1}\right)^{\frac{1}{\sigma-1}} \left(\frac{\sum_l x_{lj,t}^k}{\sum_l x_{lj,t}^1}\right)^{\frac{(\sigma-\epsilon)}{(\sigma-1)(\epsilon-1)}}.$$

Without loss of generality, we choose units so that wages per efficiency unit are equal to one, $w_{i,t}=1$, for each country i and each year t. Given estimates of ϵ and σ as well as data on bilateral trade flows, $x_{ij,t}^k$, productivity levels $A_{ij,t}^k$ are then exactly identified, up to a time-and-destination productivity shifter,

$$\frac{A_{ij,t}^k}{A_{jj,t}^1} = \left(\frac{x_{ij,t}^k}{x_{jj,t}^1}\right)^{\frac{1}{\sigma-1}} \left[\frac{\sum_i x_{ij,t}^k}{\sum_i x_{ij,t}^1}\right]^{\frac{(\epsilon-\sigma)}{(\sigma-1)(1-\epsilon)}} \equiv \hat{A}_{ij,t}^k, \tag{C.10}$$

To deal with this indeterminacy, we further impose the normalization: $A_{jj,t}^1 = 1$ for all j and t, both in the autarkic and trade equilibria.[47] We impose the same normalization for nontradables: $A_{j,t}^{NT} = 1$. These two normalizations affect the level of real consumption $C_{j,t}$ in the autarkic and trade equilibria, but not the proportional changes between the two, which is what we are interested in.

Finally, note that given our choice of units of labor, $L_{i,t}$ is simply equal to the total sales, across all destinations and sectors, from country i at date t. More specifically, the good and labor market clearing conditions imply

$$w_{i,t} L_{i,t} = \sum_j \sum_k x_{ij,t}^k + (1-\theta_{i,t})(w_{i,t} L_{i,t} + D_{i,t}).$$

[47] If export data is missing for a country at some intermediate t, we set the unobserved $\hat{A}_{ij,t}^k = \hat{A}_{ij,t-\Delta}^k$.

Under the normalization $w_{i,t} = 1$, we therefore have

$$L_{i,t} = [\sum_j \sum_k x^k_{ij,t} + (1-\theta_{i,t})D_{i,t}]/\theta_{i,t},$$

which can be computed using trade data and estimates of $\theta_{i,t}$.

C.3 Construction of Autarky Counterfactuals

In our empirical analysis, we have assumed that a country i is able to produce good k for its domestic market at date t if and only if it is able to export it to at least one foreign market. Let $\pi^k_{i,t}$ denote the dummy variable equal to one if country i produces good k at date t under trade. Given our linear probability model, the previous assumption implies

$$E[\pi^k_{i,t}] = 1 - \prod_{j \neq i} \min\{\max\{1 - \pi^k_{ij,t}(N_{i,t}), 0\}, 1\} \equiv \bar{\pi}^k_{i,t}(N_{i,t}), \tag{C.11}$$

where $\pi^k_{ij,t}(N_{i,t}) \equiv \delta_{ij,t} + \gamma^k_{j,t} + N_{i,t} n^k_t$ and the min and max operators guarantee that the probabilities in equation (9) are between 0 and 1. For the counterfactual dummies $(\pi^k_{i,t})'$ to be consistent with the previous assumptions, we require instead

$$E[(\pi^k_{i,t})'] = 1 - \prod_{j \neq i} \min\{\max\{1 - \pi^k_{ij,t}((N_{i,t})'), 0\}, 1\} = \bar{\pi}^k_{i,t}((N_{i,t})'). \tag{C.12}$$

To create a counterfactual autarkic equilibrium that satisfies the previous restriction and is as close as possible to the observed trade equilibrium, we set

$$(\pi^k_{i,t})' = \begin{cases} \pi^k_{i,t} + (1 - \pi^k_{i,t}) d^k_{i,t} & \text{if } (N_{i,t})' \geq N_{i,t}, \\ \pi^k_{i,t} + \pi^k_{i,t}(1 - d^k_{i,t}) & \text{if } N'_{i,t} < N_{i,t}, \end{cases} \tag{C.13}$$

where $d^k_{i,t} \in \{0,1\}$ is a random Bernoulli variable, independently drawn across all k, equal to 1 with probability $[\bar{\pi}^k_{i,t}((N_{i,t})') - \bar{\pi}^k_{i,t}(N_{i,t})]/[1 - \bar{\pi}^k_{i,t}(N_{i,t})]$ if $(N_{i,t})' \geq N_{i,t}$, and equal to 1 with probability $1 + [\bar{\pi}^k_{i,t}((N_{i,t})') - \bar{\pi}^k_{i,t}(N_{i,t})]/\bar{\pi}^k_{i,t}(N_{i,t})$ if $(N_{i,t})' < N_{i,t}$.[48]

By construction, equation (C.13) implies that regardless of whether $N'_{i,t}$ is greater or less than $N_{i,t}$, the probability that country i produces good k at date t under autarky is equal to $\bar{\pi}^k_{i,t}((N_{i,t})')$. Furthermore, equation (C.13) guarantees that if country i produces good k at date t under trade ($\pi^k_{i,t} = 1$) and its capability goes up under autarky ($N'_{i,t} \geq N_{i,t}$), then country i still produces that good in the autarky counterfactual ($(\pi^k_{i,t})' = 1$ with probability one). Likewise , if a good is not produced under trade ($\pi^k_{i,t} = 0$) and capability goes down ($N'_{i,t} < N_{i,t}$), then country is still unable to produce that good under autarky ($(\pi^k_{i,t})' = 0$ with probability one).

[48]Computing $\bar{\pi}^k_{i,t}(\cdot)$ requires an estimate of $\delta_{ij,t} + \gamma^k_{j,t}$. Consistent with our analysis in Section 4, we estimate $\delta_{ij,t} + \gamma^k_{j,t}$ by regressing $\pi^k_{ij,t} - N_{i,t} n^k_t$ on a full set of origin-destination-year and destination-sector-year fixed effects.

C.4 Additional Counterfactual Results

C.4.1 Static and Dynamic Gains in 2012 for All Countries

Country Name	Static Gains (%)	Dynamic Gains (%)	Country Name	Static Gains (%)	Dynamic Gains (%)	Country Name	Static Gains (%)	Dynamic Gains (%)
Afghanistan	34.56	-24.57	Germany	2.87	0	Pakistan	7.58	-1.82
Albania	13.24	-6.86	Ghana	24.86	-11.25	Panama	5.18	-0.67
Algeria	32.45	-11.52	Greece	5.28	-0.4	Papua New Guinea	39.85	-21
Angola	22.18	-8.98	Greenland	64.49	-56.3	Paraguay	32.81	-20.41
Argentina	2.98	-0.29	Guatemala	10.55	-2.47	Peru	11.73	-2.43
Australia	5.27	-0.08	Guyana	31.16	-33.02	Philippines	6.85	-0.75
Austria	6.14	-0.1	Honduras	7.12	-3.63	Poland	4.91	-0.11
Bahamas	20.74	-18.82	Hong Kong	13.93	-0.09	Portugal	4.78	-0.16
Bahrain	11.97	-3.83	Hungary	8.97	-0.21	Qatar	13.29	-3.19
Bangladesh	7.82	-2.74	Iceland	16.39	-7.67	Romania	3.85	-0.24
Barbados	13.12	-7.66	India	2.03	-0.1	Rwanda	48.15	-42.82
Belgium-Luxembourg	3.7	-0.03	Indonesia	4.21	-0.18	Saudi Arabia	16.06	-0.94
Belize	33.05	-31.77	Ireland	5.03	-0.01	Senegal	11.7	-6.74
Benin	32.8	-27.11	Israel	2.48	-0.24	Seychelles	24.23	1.2
Bermuda	24.83	-36.26	Italy	1.89	-0.02	Singapore	8.05	-0.04
Bolivia	30.19	-17.69	Jamaica	24.81	-16.72	South Africa	3.61	-0.45
Brazil	1.89	-0.14	Japan	0.68	0	South Korea	1.66	-0.03
Bulgaria	9.9	-0.73	Jordan	10.29	-4.42	Spain	2.35	-0.02
Burkina Faso	40.74	-31.49	Kiribati	30.7	2.36	Sri Lanka	9.09	-3.14
Burundi	49.12	9.1	Lebanon	14.09	-4.12	Sudan	42.97	-29.24
Cambodia	11.78	-1.76	Macao	12.02	-2.17	Suriname	38.72	-21.15
Cameroon	28.58	-17.76	Madagascar	16.75	-14.51	Sweden	4.54	0
Canada	5.02	-0.04	Malawi	31.14	-21.41	Switzerland	3.45	0
Central African Republic	16.45	-39.25	Malaysia	4.6	-0.09	Tanzania	24.32	-13.24
Chile	19.53	-2.64	Mali	34	-5.17	Thailand	7.45	-0.19
China	0.72	0	Malta	9.75	-0.98	Togo	11.93	-12.9
Colombia	6.22	-1.14	Mauritania	44.33	2.53	Trinidad & Tobago	6.58	-3.16
Congo - Brazzaville	37.85	-17.1	Mauritius	10.14	-4.81	Tunisia	11.65	-2.58
Costa Rica	2.65	-0.33	Mexico	5.43	-0.09	Turkey	4.93	-0.19
Cyprus	3.47	-0.89	Morocco	12.55	-2.73	UK	2.89	-0.03
Côte d'Ivoire	20.53	-11.04	Mozambique	31.57	-21.46	US	1.58	0
Denmark	3.6	0	Nambia	14.17	-6.61	Uganda	23.79	-14.23
Dominican Republic	11.05	-4.63	Nepal	27.59	-21.86	United Arab Emirate	8.91	-0.05
Ecuador	16.49	-4.92	Netherlands	2.83	-0.06	Uruguay	10.43	-3.99
Egypt	10.15	-1.71	New Caledonia	20.11	-15.6	Venezuela	28.52	-11.46
El Salvador	7.42	-2.37	New Zealand	5.35	-0.31	Vietnam	4.8	-0.42
Ethiopia	40.73	-27.97	Nicaragua	11.96	-7.31	Yemen	40.01	-20.14
Fiji	30.29	-28.65	Niger	37.34	-29.1	Zambia	28.12	-16.87
Finland	3.7	-0.2	Nigeria	31.77	-12.44	Zimbabwe	20.28	-10.43
France	3.33	0	Norway	5.13	-0.17			
Gambia	54.48	-66.21	Oman	11.17	-4.54			

Table C.1: Static and Dynamic Gains in 2012 for all Countries

Notes: Table C.1 reports estimates of static and dynamic gains in 2012 for all countries included in our counterfactual analysis.

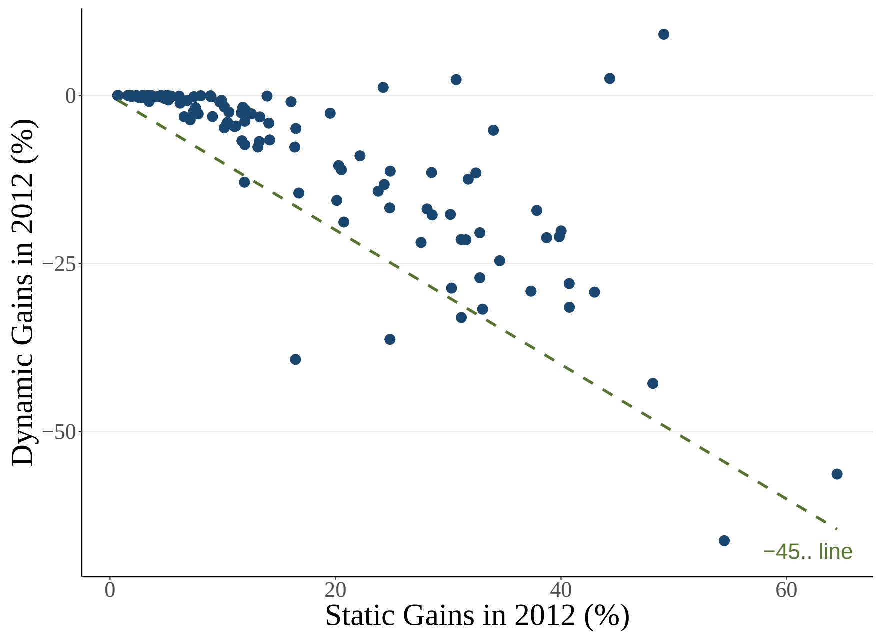


Figure C.1: Dynamic Gains vs. Static Gains from Trade

Notes: Figure C.1 reports reports the dynamic gains from trade, $GT^D_{i,t}$, as described in equation (19), in 2012 against the static gains from trade, $GT^S_{i,t}$, as described in equation (18), in the same year.

C.4.2 Dynamic Gains from Trade versus GDP per Capita

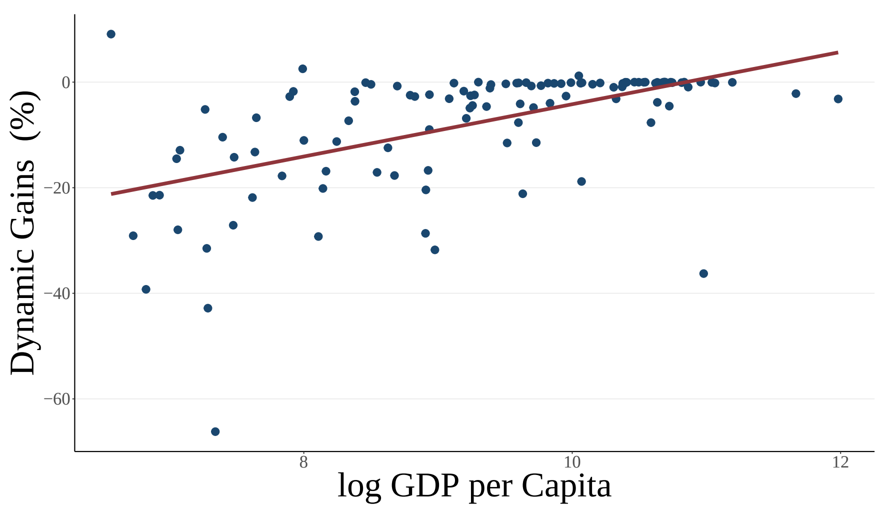
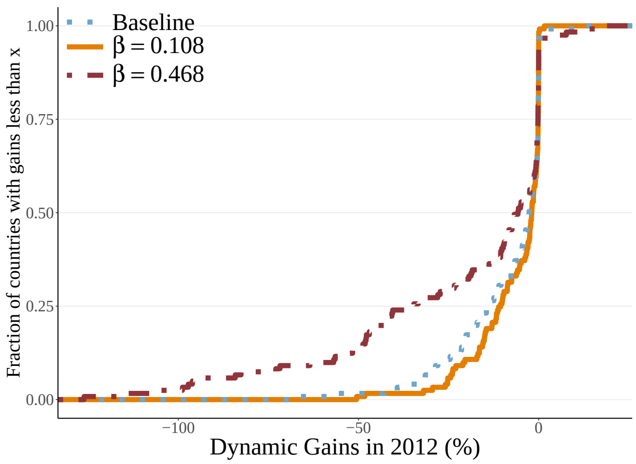


Figure C.2: Dynamic Gains vs. GDP per Capita

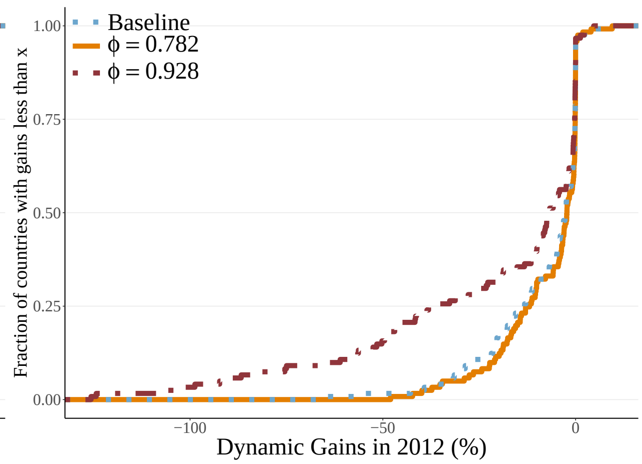
Notes: Figure C.2 reports reports the dynamic gains from trade, $GT^D_{i,t}$, as described in equation (19), in 2012 against log GDP per Capita in 2012. The solid line is the line of best fit (slope = 4.95, s.e. = 0.73).

C.5 Robustness

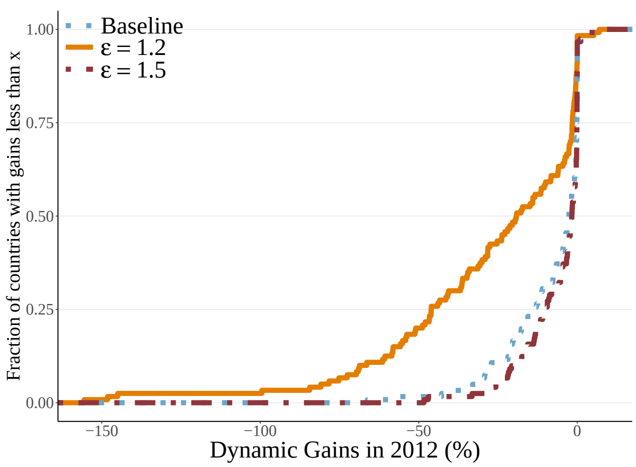
C.5.1 Alternative Calibration of the Baseline Economy



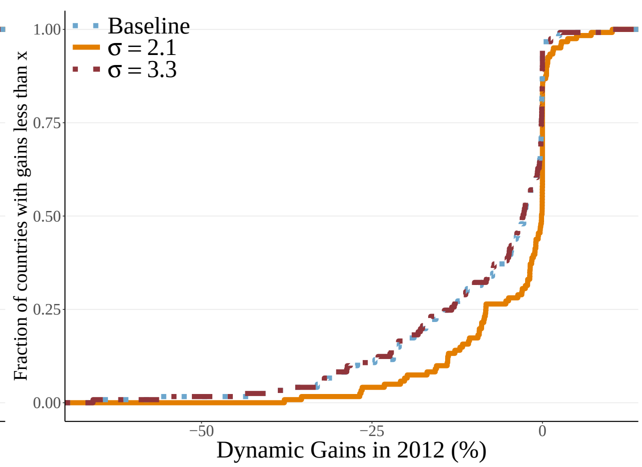
(a) Spillover Parameter, β



(b) Persistence Parameter, ϕ

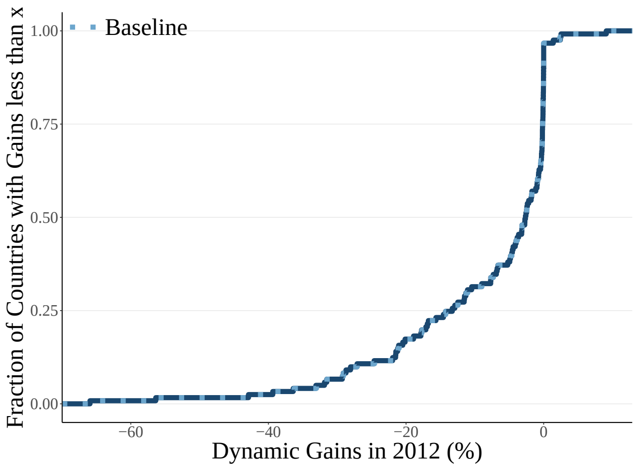


(c) Upper-Level Elasticity of Substitution, ϵ

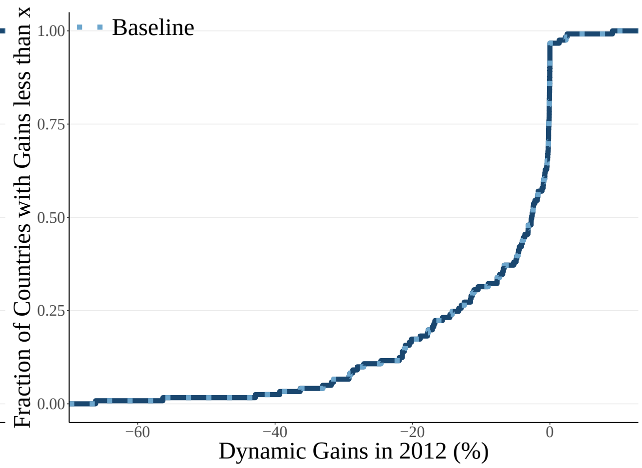


(d) Lower-Level Elasticity of Substitution, σ

Figure C.3: Dynamic Gains from Trade: Alternative Dynamic Spillovers and Preferences
Notes: Figures C.3a and C.3b are the counterparts of Figure 5b where we vary the spillover parameter, β, and the persistence parameter, ϕ, respectively. We consider parameter values that are two standard deviations above and below our point estimates reported in Table 2, Column 3. Figures C.3c and C.3d are the counterparts of Figure 5b where we vary the upper- and lower-level elasticities of substitution, ϵ and σ, respectively. We consider the alternative parameter values of $\epsilon \in \{1.2, 1.5\}$ and $\sigma \in \{2.1, 3.3\}$. The dotted lines show the results for our baseline economy.



(a) Pareto Distribution

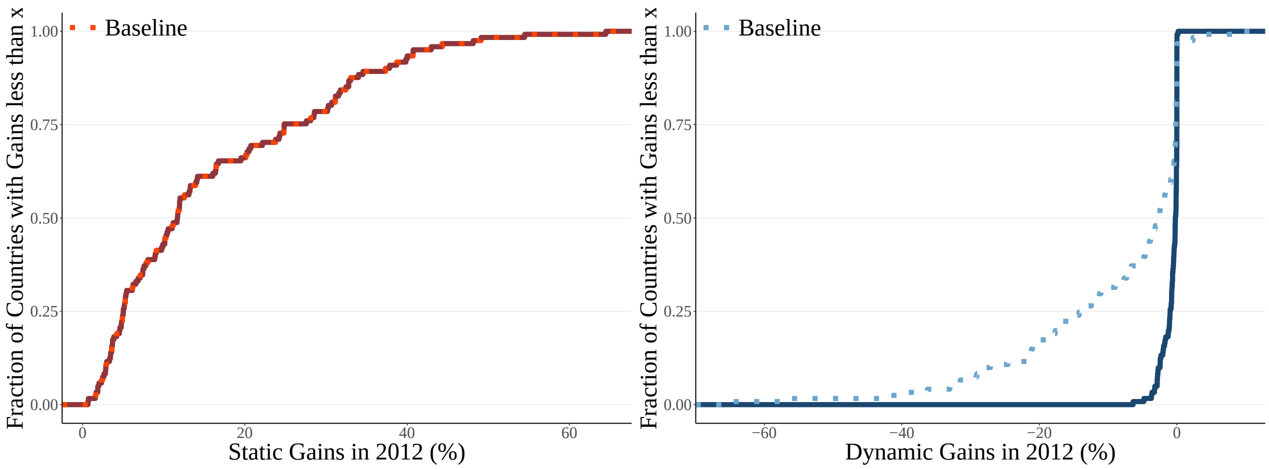


(b) Fréchet Distribution

Figure C.4: Dynamic Gains from Trade: Alternative Productivity Distributions

Notes: Figures C.4a and C.4b are the counterparts of Figure 5b, but drawing counterfactual productivities under autarky from Pareto and Fréchet distributions, respectively, instead of the log-normal distribution assumed in our baseline. In both cases, we choose shape and scale parameters of the new distribution such that the mean is equal to the sum of the country-time and sector-time fixed effects, $A_{i,t}$ and A_t^k, estimated from the following log-linear regression, $\ln A_{ii,t}^k = A_{i,t} + A_t^k + \alpha_{i,t}^k$, with a standard deviation equal to the standard deviation of the estimated residuals. The dotted lines show the results for our baseline economy.

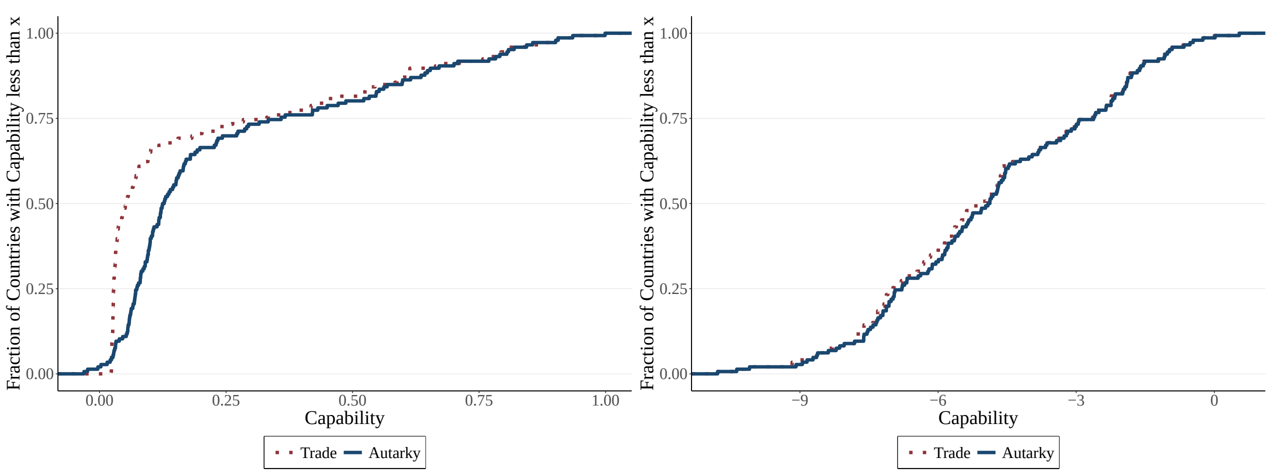
C.5.2 Alternative Measures of Capability and Complexity



(a) Distribution of the Static Gains from Trade **(b)** Distribution of the Dynamic Gains from Trade

Figure C.5: Welfare Consequences of International Trade: Alternative Measures of Capability and Complexity

Notes: Figure C.5 is the counterpart of Figure 5 when capability and complexity measures are estimated using the logit model described in equation (20). Estimates of dynamic spillovers are from Table B.4, column 3. The dotted lines show results for our baseline economy.

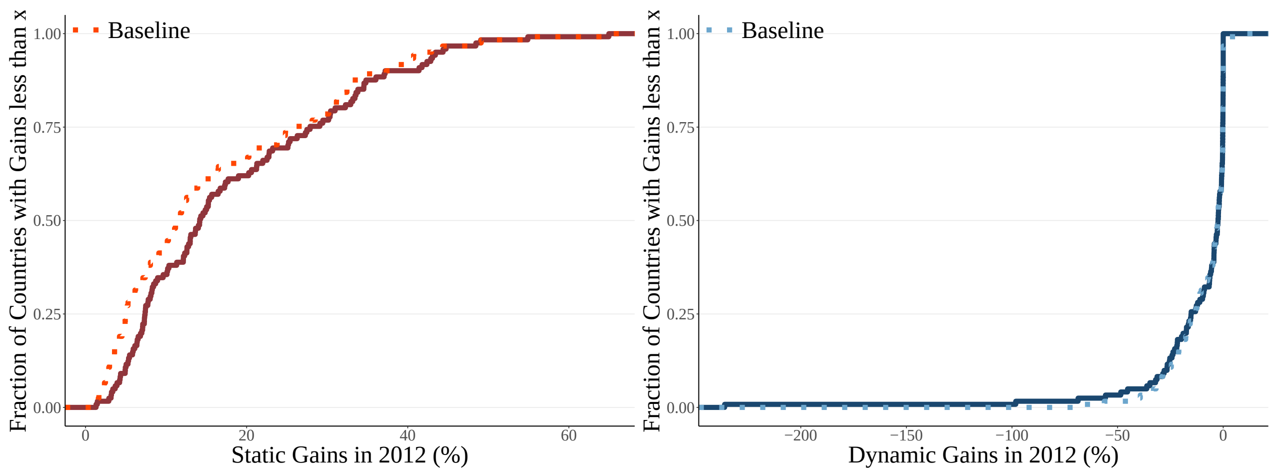


(a) Distribution of Capability: Baseline Economy **(b)** Distribution of Capability: Alternative Measures of Capability and Complexity

Figure C.6: Distribution of Capability

Notes: Figure C.6a reports the distribution of capability in the trade and autarkic equilibria in our baseline economy. Figure C.6b reports the counterpart of Figure C.6a when capability and complexity are estimated using equation (20).

C.5.3 Complexity and Foreign Competition



(a) Distribution of the Static Gains from Trade **(b)** Distribution of the Dynamic Gains from Trade

Figure C.7: Welfare Consequences of International Trade: Heterogeneous Elasticities of Substitution

Notes: Figure C.7 is the counterpart of Figure 5 with heterogeneous elasticities of substitution σ^k from Broda and Weinstein (2006). The dotted lines show results for our baseline economy.

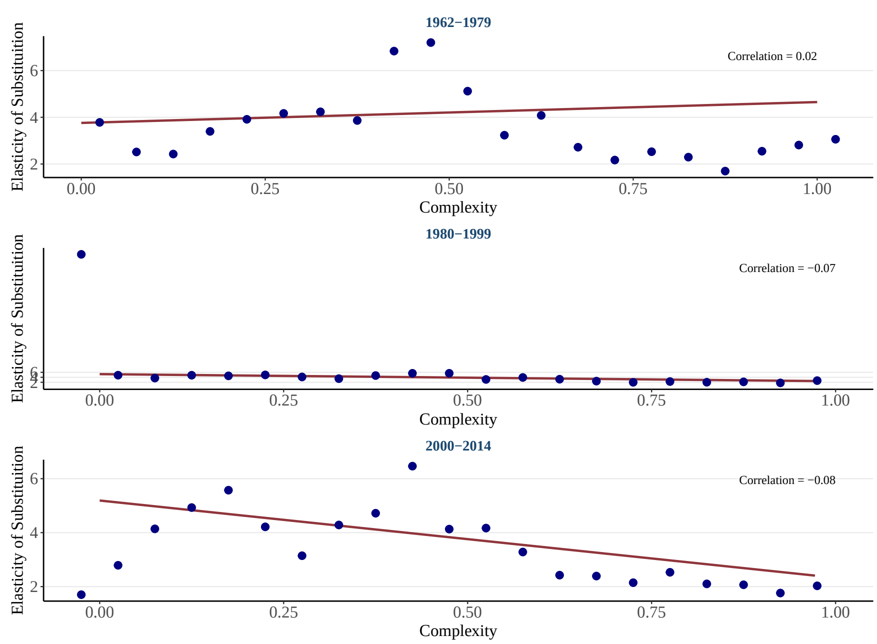


Figure C.8: Elasticity of Substitution and Complexity

Figure C.8 plots the elasticity of substitution, σ_k, in Broda and Weinstein (2006) against our baseline estimates of complexity n_t^k. Each dot represents the binned scatter plot with 20 bins, and the line represents the best linear fit.

C.5.4 Global Input-Output Linkages

Environment with Input-Output Linkages. We extend the model of Appendix C.1 to include global input-output linkages at the 2-digit level, as in Caliendo and Parro (2015). Let K_s denote the set of goods k that belong to a given 2-digit sector s and let S denote the set of all 2-digit sectors. This includes all 2-digit manufacturing sectors and the non-tradable sector.[49]

For each $k \in K_s$ and $s \neq NT$, gross output is given by the following nested CES technology,

$$q_{ij,t}^{k} = A_{ij,t}^{k} (\ell_{ij,t}^{k} / \gamma_{i,t}^{s})^{\gamma_{i,t}^{s}} \prod_{r \in S} (M_{ij,t}^{rk} / \gamma_{i,t}^{rs})^{\gamma_{i,t}^{rs}}, \tag{C.14}$$

$$M_{ij,t}^{rk} = \int_{l \in K_r} (m_{ij,t}^{lk})^{(\epsilon-1)/\epsilon} dl)^{\epsilon/(\epsilon-1)}, \tag{C.15}$$

$$m_{ij,t}^{lk} = (\sum_{o} (m_{oij,t}^{lk})^{(\sigma-1)/\sigma})^{\sigma/(\sigma-1)}, \tag{C.16}$$

where $m_{oij,t}^{lk}$ denotes the demand for an intermediate good l produced in an origin country o by firms producing good k in country i for a destination country j and the exogenous technology parameters satisfy $\gamma_{i,t}^{s} \geq 0$, $\gamma_{i,t}^{rs} \geq 0$, and $\gamma_{i,t}^{s} + \sum_{r \in S} \gamma_{,t}^{rs} = 1$. Gross output in the non-tradable sector takes a similar form,

$$Q_{i,t}^{NT} = A_{i,t}^{NT} (L_{i,t}^{NT} / \gamma_{i,t}^{NT})^{\gamma_{i,t}^{NT}} \prod_{r \in S} (M_{i,t}^{rNT} / \gamma_{i,t}^{rNT})^{\gamma_{i,t}^{rNT}} \tag{C.17}$$

$$M_{i,t}^{rNT} = \int_{l \in K_r} (m_{i,t}^{lNT})^{(\epsilon-1)/\epsilon} dl)^{\epsilon/(\epsilon-1)}, \tag{C.18}$$

$$m_{i,t}^{lNT} = (\sum_{o} (m_{oi,t}^{lNT})^{(\sigma-1)/\sigma})^{\sigma/(\sigma-1)}. \tag{C.19}$$

Dynamic spillovers now depend on the cumulative distribution of the value of gross output across sectors of different complexity,

$$\dot{N}_{i,t} = H_{i,t}(N_{i,t}, F_{i,t}^{q}), \tag{C.20}$$

with cumulative distribution $F_{i,t}^{q}(n)$ such that

$$F_{i,t}^{q}(n) = \frac{\sum_j \int_{0 \leq n^k \leq n} p_{ij,t}^{k} q_{ij,t}^{k} dk}{\sum_j \int p_{ij,t}^{k} q_{ij,t}^{k} dk} \text{ for all } n \geq 0. \tag{C.21}$$

This guarantees that the empirical analysis of Section (5) remains consistent with the existence of input-output linkages. All other assumptions are unchanged and as described in Appendix C.1.

[49] Since there is only one homogeneous good produced in non-tradable sector, $K_{NT} = \{NT\}$.

Competitive Equilibrium with Input-Output Linkages. In terms of equilibrium conditions, the first-order conditions associated with firms' cost-minimization problem now also imply

$$w_{i,t}\ell_{ij,t}^{k} = \gamma_{i,t}^{s} p_{ij,t}^{k} q_{ij,t}^{k}, \text{ for all } k \in K_s \text{ and } s \neq NT, \tag{C.22}$$

$$p_{oi,t}^{l} m_{oij,t}^{lk} = \frac{(p_{oi,t}^{l})^{1-\sigma}}{\sum_{o'}(p_{o'i,t}^{l})^{1-\sigma}} \frac{(P_{i,t}^{l})^{1-\epsilon}}{\sum_{l' \in K_r}(P_{i,t}^{l'})^{1-\epsilon}} \times \gamma_{i,t}^{rs} p_{ij,t}^{k} q_{ij,t}^{k}, \text{ for all } l \in K_r,\ k \in K_s, \text{ and } s \neq NT, \tag{C.23}$$

$$w_{i,t} L_{ij,t}^{NT} = \gamma_{i,t}^{NT} P_{i,t}^{NT} Q_{i,t}^{NT}, \tag{C.24}$$

$$p_{oi,t}^{l} m_{oi,t}^{lNT} = \frac{(p_{oi,t}^{l})^{1-\sigma}}{\sum_{o'}(p_{o'i,t}^{l})^{1-\sigma}} \frac{(P_{i,t}^{l})^{1-\epsilon}}{\sum_{l' \in K_r}(P_{i,t}^{l'})^{1-\epsilon}} \times \gamma_{i,t}^{rNT} P_{i,t}^{NT} Q_{i,t}^{NT}, \text{ for all } l \in K_r,\ k \in K_s, \text{ and } s \neq NT. \tag{C.25}$$

In turn, the zero-profit conditions (previously given by equations A.1 and C.5) are now given byX

$$p_{ij,t}^{k} = [(w_{i,t})^{\gamma_{i,t}^{s}} \prod_{r \in S} (\mathcal{P}_{i,t}^{r})^{\gamma_{i,t}^{rs}}] / A_{ij,t}^{k}, \text{ for all } k \in K_s \text{ and } s \neq NT, \tag{C.26}$$

$$P_{i,t}^{NT} = [(w_{i,t})^{\gamma_{i,t}^{NT}} \prod_{r \in S} (\mathcal{P}_{i,t}^{r})^{\gamma_{i,t}^{rNT}}] / A_{i,t}^{NT}, \tag{C.27}$$

where $\mathcal{P}_{i,t}^{r}$ is the CES price index of a given 2-digit sector $r \in S$ in country i,

$$\mathcal{P}_{i,t}^{r} = \left(\int_{k \in K_r} (P_{i,t}^{k})^{1-\epsilon} dk \right)^{\frac{1}{1-\epsilon}}, \text{ for all } r \neq NT, \tag{C.28}$$

$$P_{i,t}^{k} = (\sum_{j} (p_{ji,t}^{k})^{1-\sigma})^{1/(1-\sigma)}, \text{ for all } k \in K_r \text{ and } r \neq NT, \tag{C.29}$$

$$\mathcal{P}_{i,t}^{NT} = P_{i,t}^{NT}. \tag{C.30}$$

Finally, the good market clearing conditions (previously given by equation A.5 and C.6) now requires

$$c_{ij,t}^{k} + \sum_{d} \sum_{s \in S} \sum_{l \in K_s} m_{ijd,t}^{kl} = q_{ij,t}^{k}, \tag{C.31}$$

$$C_{i,t}^{NT} + \sum_{d} \sum_{s \in S} \sum_{l \in K_s} m_{iid,t}^{NTl} = Q_{i,t}^{NT}, \tag{C.32}$$

with gross-output $q_{ij,t}^{k}$ and $Q_{i,t}^{NT}$' given by equations (C.14)-(C.16) and (C.17)-(C.19), respectively.

A competitive equilibrium in the environment with input-output linkages corresponds to capabilities, $\{N_{i,t}\}$, wages, $\{w_{i,t}\}$, good prices, $\{p_{ij,t}^{k}, P_{j,t}^{k}, \mathcal{P}_{j,t}^{s}, P_{j,t}\}$, interest rates, $\{r_{i,t}\}$, consumption levels, $\{c_{ij,t}^{k}, C_{j,t}^{k}, C_{j,t}^{M}, C_{j,t}^{NT}, C_{j,t}\}$, input levels, $\{m_{oij,t}^{lk}, m_{ij,t}^{lk}, M_{ij,t}^{sk}, m_{oi,t}^{lNT}, m_{i,t}^{lNT}, M_{i,t}^{sNT}\}$, employment levels, $\{\ell_{ij,t}^{k}\}$, gross output levels, $\{q_{ij,t}^{k}, Q_{i,t}^{NT}\}$, and gross output distributions, $\{F_{i,t}^{q}\}$, such that equations (C.1)-(C.4), C.7, and C.14-C.32 hold.

Calibration of Preferences, Technology, and Labor Endowments. We calibrate preferences in the same way as in the baseline economy of Section 6.1. We set the elasticities of substitution such that $\epsilon = 1.36$ and $\sigma = 2.7$, as described in Table 4, and we set the Cobb-Douglas preference parameters $\theta_{i,t}$ so that we match the shares of final expenditure on manufacturing goods in each country and year in the OECD input-output tables.

To calibrate the Cobb-Douglas technology parameters $\gamma_{i,t}^{rs}$, we use equations (C.23) and (C.25). For every pair of 2-digit sectors r and $s \in S$, they imply that $\gamma_{i,t}^{rs}$ is equal to the share of revenues of firms from sector s in country i spent on goods from sector r, which we again measure those directly from the OECD input-output tables.[50] We then set the labor share $\gamma_{i,t}^{s} = 1 - \sum_{r \in S} \gamma_{i,t}^{rs}$.

To calibrate labor endowments in each country i and year t, we again use the labor market clearing condition (C.7). In value terms, this can be expressed as

$$w_{i,t} L_{i,t} = \sum_{s \neq NT} \gamma_{i,t}^{s} \sum_{k \in K_s} \sum_{j} x_{ij,t}^{k} + \gamma_{i,t}^{NT} X_{i,t}^{NT},$$

with total expenditure in the non-tradable sector, $X_{i,t}^{NT}$, given by

$$X_{i,t}^{NT} = \sum_{r \neq NT} \gamma_{i,t}^{NTr} \sum_{k \in K_r} \sum_{j} x_{ij,t}^{k} + \gamma_{i,t}^{NTNT} X_{i,t}^{NT} + (1 - \theta_{i,t})(w_{i,t} L_{i,t} + D_{i,t}).$$

Like in the baseline economy of Section 6.1, we choose units so that wages per efficiency unit are equal to one, $w_{i,t} = 1$. Under this normalization, the two previous expressions imply

$$\begin{aligned} L_{i,t} = & \frac{1 - \gamma_{i,t}^{NTNT}}{1 - \gamma_{i,t}^{NTNT} - \gamma_{i,t}^{NT}(1 - \theta_{i,t})} \\ & \times \left\{ \sum_{s \neq NT} \gamma_{i,t}^{s} \sum_{k \in K_s} \sum_{j} x_{ij,t}^{k} + \frac{\gamma_{i,t}^{NT}}{1 - \gamma_{i,t}^{NTNT}} \left[\sum_{r \neq NT} \gamma_{i,t}^{NTr} \sum_{k \in K_r} \sum_{j} x_{ij,t}^{k} + (1 - \theta_{i,t}) D_{i,t} \right] \right\}. \end{aligned}$$

To identify productivity levels in manufacturing sectors, we follow the same strategy as in Appendix (C.2). For any $k \in K_s$ with $s \neq NT$ and any reference good $1 \in K_1$, combining equations (C.3), (C.23), (C.26), and (C.29) and using the normalization, $w_{i,t} = w_{j,t} = 1$, we obtain

$$\frac{A_{ij,t}^{k}}{A_{jj,t}^{1}} = \frac{\prod_{r \in S} (\mathcal{P}_{i,t}^{r})^{\gamma_{i,t}^{rs}}}{\prod_{r \in S} (\mathcal{P}_{j,t}^{r})^{\gamma_{j,t}^{r1}}} \left(\frac{x_{ij,t}^{k}}{x_{jj,t}^{1}} \right)^{\frac{1}{\sigma - 1}} \left(\frac{x_{j,t}^{k}}{x_{j,t}^{1}} \right)^{\frac{\sigma - \epsilon}{(\epsilon - 1)(\sigma - 1)}} \left(\frac{X_{j,t}^{1}}{X_{j,t}^{s}} \frac{D_{j,t}^{s}}{D_{j,t}^{1}} \right)^{\frac{1}{\epsilon - 1}}, \tag{C.33}$$

where $x_{j,t}^{k} \equiv \sum_{o} x_{oj,t}^{k}$ denotes total expenditure on good $k \in K_s$ in country j; $X_{j,t}^{s} \equiv \sum_{o, l \in K_s} x_{oj,t}^{l}$ denotes expenditure on a 2-digit sector s in country j; and $D_{j,t}^{s} \equiv \sum_{o, l \in K_s} p_{oj,t}^{l} c_{oj,t}^{l}$ denotes final expenditure in the same sector.

Like in Section 6.1, we normalize productivity such that $A_{jj,t}^{1} = A_{j,t}^{NT} = 1$ both in the autarkic and trade equilibria, for all j and t. This second normalization implies $\mathcal{P}_{i,t}^{NT} = P_{i,t}^{NT} = 1$. Using equations

[50] Whenever a year is missing, we use the value from the last year available; whenever a country is missing, we use the median value over the countries from the same continent. We map 2-digit SITC code to the industry classification in OECD input-table tables (ISIC) using the concordance tables from WITS (https://wits.worldbank.org/product_concordance.html). In some cases, the values of $\{\gamma_{i,t}^{rs}\}$ implies that final consumption is negative for some sectors and countries. For any such sector r and country i, we lower $\gamma_{i,t}^{rs}$ uniformly for all s such that final consumption is zero instead.

(C.26), (C.28), (C.29), and (C.33), we can then solve for the cost of intermediates, $\prod_{r\in S}(\mathcal{P}^r_{j,t})^{\gamma^{r1}_{j,t}}$ and $\prod_{r\in S}(\mathcal{P}^r_{i,t})^{\gamma^{rs}_{i,t}}$,

$$\prod_{r\in S}(\mathcal{P}^r_{j,t})^{\gamma^{r1}_{i,t}} = \prod_{r\neq NT}\left\{\int_{k\in K_r}\left[\sum_i\left(\frac{x^k_{ij,t}}{x^1_{jj,t}}\right)\left(\frac{x^k_{j,t}}{x^1_{j,t}}\right)^{\frac{\sigma-\epsilon}{\epsilon-1}}\left(\frac{X^1_{j,t}}{X^r_{j,t}}\frac{D^r_{j,t}}{D^1_{j,t}}\right)^{\frac{\sigma-1}{\epsilon-1}}\right]^{\frac{\epsilon-1}{\sigma-1}} dk\right\}^{\frac{\gamma^{r1}_{i,t}}{(1-\epsilon)\gamma^1_{i,t}}}, \tag{C.34}$$

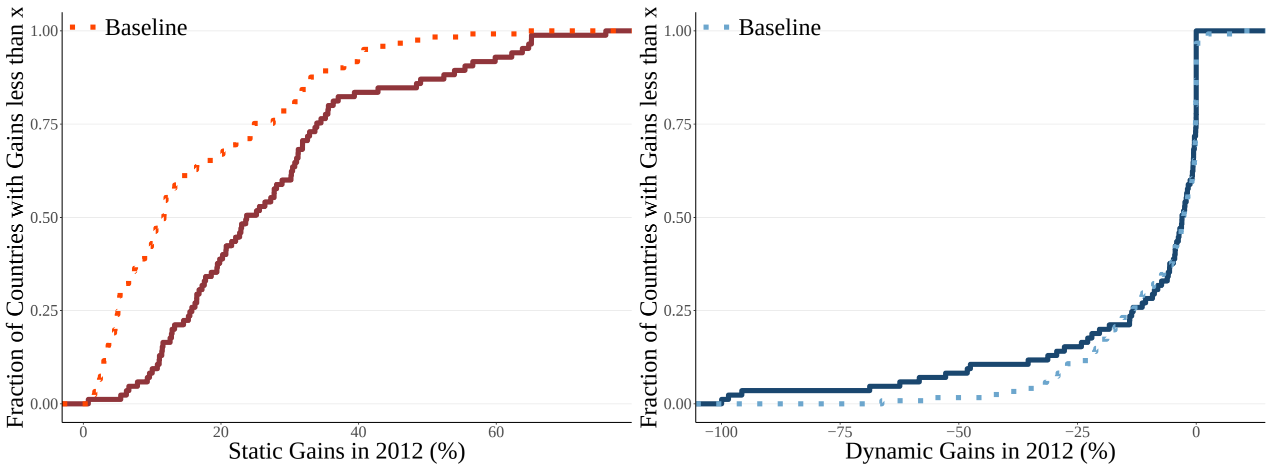
$$\prod_{r\in S}(\mathcal{P}^r_{i,t})^{\gamma^{rs}_{i,t}} = \prod_{r\neq NT}\left\{\int_{k\in K_r}\left[\sum_i\left(\frac{x^k_{ij,t}}{x^1_{jj,t}}\right)\left(\frac{x^k_{j,t}}{x^1_{j,t}}\right)^{\frac{\sigma-\epsilon}{\epsilon-1}}\left(\frac{X^1_{j,t}}{X^r_{j,t}}\frac{D^r_{j,t}}{D^1_{j,t}}\right)^{\frac{\sigma-1}{\epsilon-1}}\right]^{\frac{\epsilon-1}{\sigma-1}} dk\right\}^{\frac{\gamma^{r1}_{i,t}(1-\gamma^s_{i,t})+\gamma^{rs}_{i,t}\gamma^1_{i,t}}{(1-\epsilon)\gamma^1_{i,t}}}. \tag{C.35}$$

From equations (C.33)-(C.35), we can then identify productivity across manufacturing goods as

$$\begin{aligned}A^k_{ij,t} = &\prod_{r\in S}\left\{\int_{k\in K_r}\left[\sum_i\left(\frac{x^k_{ij,t}}{x^1_{jj,t}}\right)\left(\frac{x^k_{j,t}}{x^1_{j,t}}\right)^{\frac{\sigma-\epsilon}{\epsilon-1}}\left(\frac{X^1_{j,t}}{X^r_{j,t}}\frac{D^r_{j,t}}{D^1_{j,t}}\right)^{\frac{\sigma-1}{\epsilon-1}}\right]^{\frac{\epsilon-1}{\sigma-1}} dk\right\}^{\frac{\gamma^{rs}_{i,t}\gamma^1_{i,t}-\gamma^{r1}_{i,t}\gamma^s_{i,t}}{(1-\epsilon)\gamma^1_{i,t}}}\\ &\times\left(\frac{x^k_{ij,t}}{x^1_{jj,t}}\right)^{\frac{1}{\sigma-1}}\left(\frac{x^k_{j,t}}{x^1_{j,t}}\right)^{\frac{\sigma-\epsilon}{(\epsilon-1)(\sigma-1)}}\left(\frac{X^1_{j,t}}{X^s_{j,t}}\frac{D^s_{j,t}}{D^1_{j,t}}\right)^{\frac{1}{\epsilon-1}} \text{ for all } k\in K_s \text{ and } s\neq NT.\end{aligned}$$

For dynamic considerations, we impose the same assumptions as in Section 6.1 and set $\beta = 0.288$ and $\phi = 0.855$, as described in Table 4. The rest of our counterfactual analysis proceeds exactly as in Section 6.2 and Appendix C.3.

Counterfactual Results with Input-Output Linkages.



(a) Distribution of the Static Gains from Trade **(b)** Distribution of the Dynamic Gains from Trade

Figure C.9: Welfare Consequences of International Trade: Input-Output Linkages
Notes: Figure C.9 is the counterpart of Figure 5 in the environment with global input-output linkages. Around 20% of countries are unable to produce anything in autarkic equilibrium due to Cobb-Douglas assumptions on input-output linkages. We remove such countries from the above figure. The dotted lines show results for our baseline economy.

C.5.5 Other External Economies of Scale

Environment with Other External Economies of Scale. We extend the model of Appendix C.1 to include external economies of scale at the 2-digit level, as in Bartelme et al. (2021). As in our previous extension with global input-output linkages, we let K_s denote the set of goods k that belong to a given 2-digit sector s and let S denote the set of all 2-digit sectors. This includes all 2-digit manufacturing sectors and the non-tradable sector.

For each $k \in K_s$, production is subject to sector-level economies of scale,

$$q^k_{ij,t} = \mathcal{A}^k_{ij,t}(L^s_{i,t})\ell^k_{ij,t},$$
$$\mathcal{A}^k_{ij,t}(L^s_{i,t}) = A^k_{ij,t} \times (L^s_{i,t})^{\psi^s_{i,t}},$$
$$L^s_{i,t} = \sum_{k \in K_s} \sum_j \ell^k_{ij,t},$$

where $\mathcal{A}^k_{ij,t}(L^s_{i,t})$ denotes the productivity of firms producing good k for country j in country i at date t as a function of the total employment $L^s_{i,t}$ of the two-digit sector s of country i at time t. The scale elasticity $\psi^s_{i,t}$ governs the magnitude of external economies of scale in sector s. Our baseline model is nested as a special case with $\psi^s_{i,t} = 0$.

Competitive Equilibrium with Other External Economies of Scale. For each $k \in K_s$, perfectly competitive firms maximize profits taking sector-level employment $L^s_{i,t}$ as given. This requires the price of a variety of good k produced in country i and sold in country j to be equal to its unit cost,

$$p^k_{ij,t} = w_{i,t} / \mathcal{A}^k_{ij,t}(L^s_{i,t}).$$

Sector	Scale elasticity, ψ^s
Textiles	0.12
Wood Products	0.13
Paper Products	0.15
Coke/Petroleum Products	0.09
Chemicals	0.24
Rubber and Plastics	0.42
Mineral Products	0.17
Basic Metals	0.09
Fabricated Metals	0.12
Computers and Electronics	0.08
Electrical Machinery, NEC	0.08
Machinery and Equipment	0.24
Motor Vehicles	0.18
Other Transport Equipment	0.18
Other Manufacturing	0.16

Table C.2: Calibration of Scale Elasticities

Notes: Table C.2 reports the values of scale elasticities used in our sector-level economies of scale counterfactual analysis. All estimates are from Bartelme et al. (2021), except for "Other Manufacturing." Since they do not provide estimates for this sector, we set its scale elasticity equal to the average across all the manufacturing sectors with available estimates.

All other equilibrium conditions are as described in Appendix C.1.

Calibration of Preferences, Labor Endowment, and Technology. We calibrate preferences and labor endowments in the same way as in the baseline economy of Section 6.1. We set the elasticities of substitution such that $\epsilon = 1.36$ and $\sigma = 2.7$, as described in Table 4. We set $\theta_{i,t}$ to match shares of final expenditure on manufacturing goods in each country and year in the OECD input-output tables and set $D_{i,t}$ to be equal to the difference between the value of imports and exports of manufacturing goods. Finally, we normalize all wages to one, $w_{i,t} = 1$, and set $L_{i,t} = [\sum_j \sum_k x^k_{ij,t} + (1 - \theta_{i,t}) D_{i,t}] / \theta_{i,t}$.

To calibrate $\mathcal{A}^k_{ij,t}(L^s_{i,t})$, we assume that scale elasticities are constant over time and across countries, $\psi^s_{i,t} = \psi^s$, and set ψ^s to the value estimated by Bartelme, Costinot, Donaldson and Rodriguez-Clare (2021) for each two-digit manufacturing sector, as reported in Table C.2. Following Bartelme, Costinot, Donaldson and Rodriguez-Clare (2021), we also set the scale elasticity in the non-tradable sector to zero: $\psi^{NT} = 0$.

Given the knowledge of $\{\psi^s\}$, we can then use the relationship (C.10),

$$\frac{\mathcal{A}^k_{ij,t}(L^s_{i,t})}{\mathcal{A}^k_{ij,t}(L^1_{i,t})} = \frac{A^k_{ij,t}\times(L^s_{i,t})^{\psi^s}}{A^1_{jj,t}\times(L^1_{i,t})^{\psi^1}} = \left(\frac{x^k_{ij,t}}{x^1_{jj,t}}\right)^{\frac{1}{\sigma-1}}\left[\frac{\sum_i x^k_{ij,t}}{\sum_i x^1_{ij,t}}\right]^{\frac{(\epsilon-\sigma)}{(\sigma-1)(1-\epsilon)}}.$$

Under the same normalization as in our baseline analysis, $A^1_{jj,t}=1$, we obtain the productivity shifter $A^k_{ij,t}$ as

$$A^k_{ij,t} = \frac{(L^s_{i,t})^{-\psi^s}}{(L^1_{i,t})^{-\psi^1}}\left(\frac{x^k_{ij,t}}{x^1_{jj,t}}\right)^{\frac{1}{\sigma-1}}\left[\frac{\sum_i x^k_{ij,t}}{\sum_i x^1_{ij,t}}\right]^{\frac{(\epsilon-\sigma)}{(\sigma-1)(1-\epsilon)}},$$

with employment at the two-digit level given by $L^s_{i,t} = \theta_{i,t}L_{i,t}\times(\sum_{j,k\in K_s}x^k_{ij,t})/(\sum_{s\in S}\sum_{j,k\in K_s}x^k_{ij,t})$. Finally, similarly to our baseline analysis, we further normalize productivity for nontradables: $A^{NT}_{j,t}=1$ for all j and t.

Construction of Autarky Counterfactuals. Compared to our baseline analysis, the only difference comes from the need to solve for employment across 2-digit sectors in the autarkic equilibrium. For any country i and date t, any equilibrium vector of sector-level employment $\{L^s_{i,t}\}$ must satisfy

$$L^s_{i,t} = \theta_{i,t}\frac{\sum_{k\in K_s}(A^k_{ii,t})^{\epsilon-1}(L^s_{i,t})^{(\epsilon-1)\psi^s}}{\sum_{u\in\mathcal{S}}\sum_{m\in K_u}(A^m_{ii,t})^{\epsilon-1}(L^u_{i,t})^{(\epsilon-1)\psi^u}}L_{i,t}\text{ for all } s\in S. \tag{C.36}$$

In line with the results of Kucheryavyy et al. (2017), we now demonstrate that if $(\epsilon-1)\psi^s<1$ for all $s\in S$, then there exists a unique interior equilibrium $\{L^s_{i,t}\}$ satisfying (C.36) and $L^s_{i,t}>0$ for all $s\in\mathcal{S}$ such that $A^k_{ii,t}>0$ for some $k\in K_s$.

Defining $\bar{A}_{i,t}\equiv\theta_{i,t}L_{i,t}/\sum_{u\in\mathcal{S}}\sum_{m\in K_u}(A^m_{ii,t})^{\epsilon-1}(L^u_{i,t})^{(\epsilon-1)\psi^u}$, we can rearrange (C.36) as

$$L^s_{i,t} = \bar{A}_{i,t}\sum_{k\in K_s}(A^k_{ii,t})^{\epsilon-1}(L^s_{i,t})^{(\epsilon-1)\psi^s}\text{ for all } s\in S.$$

For any interior $\{L^s_{i,t}\}$, i.e. satisfying $L^s_{i,t}>0$ for all $s\in S$ such that $A^k_{ii,t}>0$ for some $k\in K_s$, this is equivalent to

$$L^s_{i,t} = \left(\bar{A}_{i,t}\sum_{k\in K_s}(A^k_{ii,t})^{\epsilon-1}\right)^{\frac{1}{1-(\epsilon-1)\psi^s}}.$$

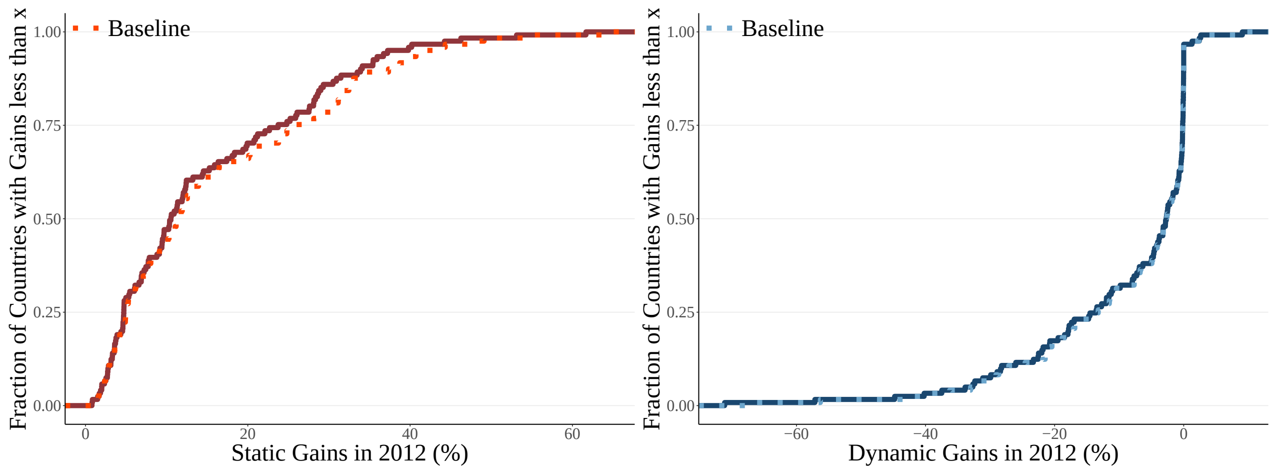
Since $\sum_{s\in\mathcal{S}}L^s_{i,t}=\theta_{i,t}L_{i,t}$, finding an interior equilibrium $\{L^s_{i,t}\}$ amounts to finding $\bar{A}_{i,t}$ that solves

$$\mathcal{G}_{i,t}(\bar{A}_{i,t})\equiv\sum_{s\in\mathcal{S}}\left(\bar{A}_{i,t}\sum_{k\in K_s}(A^k_{ii,t})^{\epsilon-1}\right)^{\frac{1}{1-(\epsilon-1)\psi^s}} = \theta_{i,t}L_{i,t}.$$

If $(\epsilon-1)\psi^s<1$ for all $s\in S$, $\mathcal{G}_{i,t}(\bar{A}_{i,t})$ is strictly increasing in $\bar{A}_{i,t}$, $\mathcal{G}_{i,t}(0)=0$, $\lim_{A\to\infty}\mathcal{G}_{i,t}(A)=\infty$. Therefore, there exists unique $\bar{A}_{i,t}$ that solve $\mathcal{G}_{i,t}(\bar{A}_{i,t})=\theta_{i,t}L_{i,t}$. In turn, there exists a unique interior equilibrium.

To conclude we note that in our baseline calibration, we set $\epsilon=1.36$. Therefore, the sufficient condition for existence and uniqueness of an interior autarky equilibrium is $\psi^s < 2.77$ for all $s \in S$, which is satisfied by the estimates from Bartelme et al. (2021), as can be seen from Table C.2.

Counterfactual Results with Other External Economies of Scale.

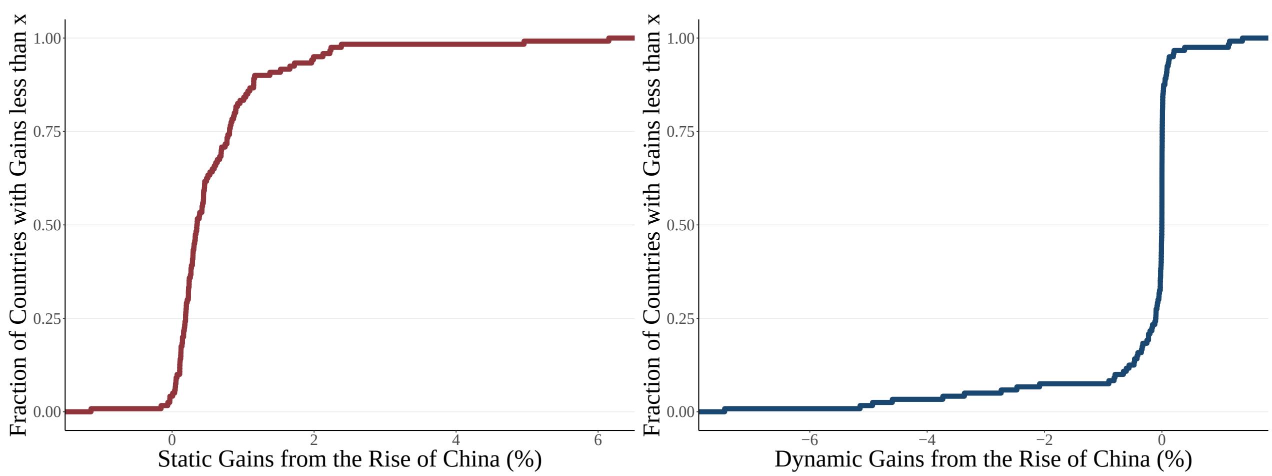


(a) Distribution of the Static Gains from Trade **(b)** Distribution of the Dynamic Gains from Trade

Figure C.10: Welfare Consequences of International Trade: Other External Economies of Scale

Notes: Figure C.10 is the counterpart of Figure 5 in the environment with other external economies of scale. The dotted lines show results for our baseline economy.

C.6 The Rise of China



(a) Distribution of the Static Gains **(b)** Distribution of the Dynamic Gains

Figure C.11: Welfare Consequences from the Rise of China Redux

Notes: Figure C.11a reports the distribution of the static gains from the rise of China, as described in Section 7.1, in 2012. Figure C.11b reports the distribution of the dynamic gains from the rise of China, as described in Section 7.1, for the same countries and year.