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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 because: (i) the average complexity of a country's industry mix raises its capability growth, and (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, appears to hold in the data. Through the lens of our model, these two empirical observations imply dynamic welfare losses from trade that are small for the median country, but pervasive and large among a number of African countries.

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1 Introduction

A popular metaphor about development is that countries sit at different rungs of a ladder, each associated with a different set of economic activities. As countries develop, they become more capable, move up the ladder, and start to produce and export more complex goods. In this paper, we propose to take this metaphor seriously and use it as a starting point to study the relationship between international trade and development.

As simple as it is, the previous metaphor points towards two distinct mechanisms through which international trade and development may be related. On the one hand, countries that develop—because of technological innovations, the adoption of better domestic policies, or any other channel unrelated to trade—may acquire a comparative advantage in more complex goods and, in turn, tilt their exports towards these goods. On the other hand, countries that specialize in more complex goods—because of changes in trade policy, improvements in the quality of transportation services, or technological innovations in the rest of the world—may start growing faster, as a result of greater opportunities for knowledge accumulation and technological spillovers in those sectors.

The distinction between the two mechanisms has potentially important implications, both from a normative and a positive perspective. The first mechanism corresponds to the static channel between productivity and trade at the core of any Ricardian model. In such a model, changes in trade patterns are a by-product of technological progress, specialization according to comparative advantage is Pareto efficient, and laissez-faire policy is optimal. The second mechanism corresponds to the dynamic effects of trade more often emphasized by models with external economies of scale. It suggests, in contrast, that industrial policies subsidizing more complex sectors at the expense of others could be welfare improving. 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.

Our paper offers a formalization of these ideas and an exploration of their empirical validity. As a theoretical matter, we show that if two key features of the ladder metaphor are satisfied, namely that specialization in more complex goods generates positive spillovers and that fewer countries (the more capable ones) produce more complex goods, then it is possible for international trade to raise capability and welfare in all countries. As an empirical matter, although we find support for the first of these two qualitative features, the data show that more complex goods tend to be produced by more rather than fewer countries. Through the lens of our model, this implies pervasive dynamic welfare losses from trade, rather than the pervasive gains the ladder metaphor predicts.

We proceed as follows. Section 2 develops a Ricardian model of international trade with nested CES preferences and static and dynamic effects. There are many countries and many sectors. Within each sector, goods produced by different countries are imperfect substitutes. In line with the ladder metaphor, we assume that countries can be ranked in terms of their capability, while goods can be ranked in terms of their complexity. In a given period, capability and complexity determine the distribution of productivity across countries and sectors. Over time, capability may increase in all countries, but technological progress is unequal and depends, in part, on what countries specialize in, which atomistic firms do not internalize. Specifically, we assume that more complex goods generate more opportunities for learning. So, when the distribution of employment is tilted towards those goods, capability growth increases.

Beside the fact that goods and countries may each be ranked along a single dimension, the ladder metaphor also points towards productivity differences manifesting themselves at the extensive margin. Capable countries sitting at the top of the ladder can produce the most complex goods, whereas countries at lower rungs cannot. To shed light on the implications of these extensive margin considerations, we first focus on a special case of our general Ricardian environment in which the only difference across goods is that some goods, the most complex ones, are produced by fewer countries, the most capable ones, as in Krugman (1979). In terms of dynamics, we do not impose any restriction on the law of motion for capability, except for the aforementioned assumption that shifts in employment towards more complex sectors raise capability growth. We refer to this benchmark environment as a pure ladder economy.

Without international trade, all countries in that economy would produce all the goods that they know how to produce. With international trade, they can source some of those goods from the rest of the world. From the point of view of any individual country, among the goods that it knows how to produce, the rest of the world tends to have a comparative advantage in its less complex goods, since a greater number of foreign competitors knows how to produce those goods. More competition at the bottom of the ladder tends to push all countries to specialize in their most complex sectors and, in turn, to raise capability and real income around the world. Thus, dynamic gains from trade, like static ones, are not zero sum.

To explore the empirical relevance of the pervasive dynamic gains predicted by our pure ladder economy, we adopt two polar strategies. In our baseline analysis, we start with measures of complexity and capability that, in light of earlier empirical work by Hausman et al. (2007) and Hausman et al. (2013), are likely to generate positive spillovers; we then estimate the magnitude of those spillovers (if any); and finally we assess the extent to which opening up to trade indeed shifts most countries towards their more complex sectors. In our sensitivity analysis, we proceed in reverse. We start by defining the more complex goods as those that fewer countries produce before testing whether or not these goods, i.e. the goods the rest of the world has a comparative disadvantage in, generate positive spillovers.

Section 3 presents our baseline measures of complexity and capability. Keeping the focus of our analysis on extensive margin considerations and taking inspiration from the work of Hausman et al. (2013), we propose using 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. We then infer complexity and capability from the assumption that more capable countries are more likely to export more complex goods. 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 revealed measures of complexity and capability should then be consistent with both types of observations.

Overall, measures of complexity and capability reveal reasonable patterns. 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 Vietnam experience rapid increases in capability growth while much of Latin America sees relative declines. Across goods, Medicaments, Cars, and Medical Instruments are consistently revealed to be among the most complex, whereas Men's Underwear, Wood Panels, and Plastic Ornaments are among the least complex.

Section 4 focuses on the estimation of dynamic spillovers. For empirical purposes, we specify the law of motion for capability as an auto-regressive process of order 1, similar to the one followed by aggregate productivity in endogenous and semi-endogenous growth models. The novel feature of our law of motion is that in every period, shocks are drawn from a distribution whose mean linearly depends on the average complexity of a country's output mix. Dynamic spillovers are positive if the mean of a country's capability shocks is increasing with average complexity.

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. For example, a kleptocratic government may both weaken growth-enhancing institutions and subsidize complex sectors. 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, allowing 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. 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 pure ladder economy, the same exogenous shifts in sectoral employment are also associated with significant increases in real GDP per capita.

Section 5 returns to our Ricardian model, in its most general form, allowing patterns of international specialization to be shaped both by intensive and extensive margin considerations. In order to quantify the static and dynamic effects of trade, we first ask the following counterfactual question. Suppose that a country were to move to autarky in 1962, the first year of our sample, while still being subject to the same domestic technological shocks, what would happen to the path of its capability and real consumption? Combining our estimates of dynamic spillovers with a non-parametric specification of productivity differences across origin, destination, and sectors, we conclude that about 97% of countries in our sample would experience *higher* capability under autarky. 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 benchmark predictions of our pure ladder economy—sectors that we have identified as more complex in Section 3 tend to face more rather than less foreign competition.[1]

A related, but distinct question, more closely related to the reduced form of our IV, is whether the entry of a country like China into the world economy push some countries up the ladder, while pulling other countries down. Our second counterfactual exercise shed lights on this issue by constructing a counterfactual trade equilibrium without China from 1992 onward. Our model suggests 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 were pushed into less complex sectors either because of competition with Chinese exports or because of the

[1] The correlation between our complexity measure and the average number of exporters per destination is 0.81, averaging over the years 1962–2014.

pattern of imports demanded by China.

Section 6 explores the robustness of our conclusions regarding the dynamic consequences of trade. As mentioned above, we consider alternative 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, the goods we now define as more complex are those that trade tends to push all countries to make more of (rather than our baseline measure which was based on ideas in Hausman et al. (2007) and Hausman et al. (2013) that the types of goods exported by more capable countries generate faster growth). While these new measures of capability remain positively correlated with our earlier measures, the correlation between the two measures of complexity is negative. As a result, when using the same IV strategy, we conclude that there are negative dynamic spillovers in the sectors that fewer countries export.

Our bottom line regarding the dynamic consequences of trade, however, remains unchanged. For dynamic gains to arise, two conditions need to be simultaneously satisfied. First, more complex sectors need to be associated with dynamic positive spillovers (so that their expansion creates capability growth); and second, they need to face less foreign competition (so that they expand under free trade). In our baseline analysis, the first condition holds, but not the second. In our sensitivity analysis, the second condition holds, but not the first. In both cases, the goods that more countries produce generate higher spillovers and we therefore conclude that there are pervasive dynamic losses from trade. As the final part of Section 6 shows, we draw the same conclusions when we allow foreign competition to vary across sectors—as a result of differences in substitutability across varieties from different countries—or input-output linkages that break the mechanical link between cheaper foreign goods and comparative disadvantage in a sector.

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).[2] The special case of a pure ladder economy, which we study analytically, is a strict generalization of Krugman (1979). Like Krugman (1979), our

[2] 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.

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.[3] But unlike Krugman (1979), our model allows for more than two countries and imperfect substitutability between goods from different 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 simple 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. In the pure 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 (2015), Sampson (2016), and Buera and Oberfield (2017). 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. In the previous papers, large firms should be subsidized; in our paper, if there

[3]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.

are positive dynamic spillovers, the most complex sectors should be subsidized.

On the empirical side, we view our revealed measures 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 reveal capability and complexity. 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). 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. (2019b) 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, caused by the removal of trade barriers or productivity growth in China, on direct measures of innovation across sectors.

2 Theory

2.1 Environment

We consider an economy with many countries, indexed by i, and a continuum of goods, 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, with $L_{i,t}$ the labor supply in country i at date t.

Preferences. In each country, there is a representative agent who derives utility from an infinite stream of consumption,

$$U_i = \int_0^\infty e^{-\rho_i t} u_i(C_{i,t}) dt,$$

where $\rho_i > 0$ is the discount factor and u_i is strictly increasing, strictly concave, and twice differentiable. Aggregate consumption $C_{i,t}$ itself derives from consuming varieties from different countries in different sectors,

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

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

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. Goods differ in their complexity, n_t^k, whereas countries differ in their capability, $N_{i,t}$. We let F_t denote the cumulative distribution of complexity across goods,

$$F_t(n) = \int_{0 \le n_t^k \le n} dk, \text{ for all } n \ge 0.$$

For all goods, production functions are linear,

$$q_{ij,t}^k = A_{ij,t}^k \ell_{ij,t}^k, \tag{3}$$

where $A_{ij,t}^k \ge 0$ denotes the productivity of firms producing good k for country j in country i at date t, inclusive of any transport cost, and $\ell_{ij,t}^k \ge 0$ denote their employment. Conditional on a good's complexity and a country's capability, we assume that the vector of productivity, $A_{i,t}^k = \{A_{ij,t}^k\}$, is drawn independently across all k and i from a general multivariate distribution,

$$\text{Prob}(A_{i,t}^k \le a) = G_{i,t}(a | n_t^k = n, N_{i,t} = N).$$

Over time, changes in a country's capability are determined by its present capability and its endogenous pattern of specialization,

$$\dot{N}_{i,t} = H_{i,t}(N_{i,t}, F_{i,t}^\ell), \tag{4}$$

where $F_{i,t}^\ell$ denotes the cumulative distribution of employment across sectors of different complexity,

$$F_{i,t}^\ell(n) = \frac{\sum_j \int_{0 \le n^k \le n} \ell_{ij,t}^k dk}{\sum_j \int \ell_{ij,t}^k dk} \text{ for all } n \ge 0. \tag{5}$$

To derive our main theoretical predictions, we assume that $H_{i,t}$ is increasing in $F^{\ell}_{i,t}$ in the sense that if $F^{\ell'}_{i,t}$ stochastically dominates $F^{\ell}_{i,t}$ in terms of the Monotone Likelihood Ratio Property (MLRP), then $H_{i,t}(N_{i,t},F^{\ell'}_{i,t}) > H_{i,t}(N_{i,t},F^{\ell}_{i,t})$. In words, complex sectors are "good" sectors in the sense that employment in more complex sectors, perhaps due to international trade, causes higher capability growth.[4] The estimation of such spillover effects will be the main focus of our empirical analysis.

2.2 Competitive Equilibrium

We focus on a competitive equilibrium with free trade in goods and financial autarky. At each date t, firms maximize profits, consumers maximize their utility, and goods and labor markets clear. Conditional on the vector of countries' capabilities $\{N_{i,t}\}$, these static equilibrium conditions determine wages, good prices, consumption, and employment. Employment shares across countries and sectors then determine countries' future capabilities, whereas the path of aggregate consumption determines the interest rate in each country, without any further consequences for our analysis.

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,

$$p^k_{ij,t} = w_{i,t} / A^k_{ij,t} \tag{6}$$

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

$$c^k_{ij,t} = \frac{(p^k_{ij,t})^{-\sigma}}{(P^k_{j,t})^{1-\sigma}} \frac{(P^k_{j,t})^{1-\epsilon} w_{j,t} L_{j,t}}{(P_{j,t})^{1-\epsilon}}, \tag{7}$$

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

$$P^k_{j,t} = [\sum_i (p^k_{ij,t})^{1-\sigma}]^{1/(1-\sigma)}, \tag{8}$$

$$P_{j,t} = [\int (P^k_{j,t})^{1-\epsilon} dk]^{1/(1-\epsilon)}. \tag{9}$$

Good market clearing requires

$$c^k_{ij,t} = A^k_{ij,t} \ell^k_{ij,t}, \tag{10}$$

[4] At this point, it is worth noting that this restriction is no less general than assuming that $H_{i,t}$ is monotonic in $F^{\ell}_{i,t}$. Indeed, if $H_{i,t}$ is decreasing in $F^{\ell}_{i,t}$, then one can always reindex goods by a new complexity index $\tilde{n}^k \equiv -n^k$, such that $H_{i,t}$ is increasing in $\tilde{F}^{\ell}_{i,t}$ with $\tilde{F}^{\ell}_{i,t}(n) \equiv \int_{0 \le \tilde{n}^k \le n} \sum_j \ell^k_{ij,t} dk / \int \sum_j \ell^k_{ij,t} dk$.

whereas labor market clearing requires

$$\sum_j \int \ell_{ij,t}^k dk = L_{i,t}. \quad (11)$$

Dynamic Equilibrium Conditions. For given employment levels $\{\ell_{ij,t}^k\}$, the evolution of capabilities across countries is described by equations (4) and (5). Finally, the consumer's Euler equation pins down the interest rate in each country,

$$\frac{\dot{C}_{i,t}}{C_{i,t}} = \frac{1}{\nu_i(C_{i,t})}(r_{i,t} - \frac{\dot{P}_{i,t}}{P_{i,t}} - \rho_i). \quad (12)$$

where $\nu_i(C) \equiv -d\ln u_i'/d\ln C$ is the elasticity of the consumer's marginal utility.

Definition of a Competitive Equilibrium. A competitive equilibrium corresponds to capabilities, $\{N_{i,t}\}$, wages, $\{w_{i,t}\}$, good prices, $\{p_{ij,t}^k, P_{j,t}^k, P_{j,t}\}$, interest rates, $\{r_{i,t}\}$, consumption levels, $\{c_{ij,t}^k, C_{j,t}^k, C_{j,t}\}$, employment levels, $\{\ell_{ij,t}^k\}$, and employment distributions, $\{F_{i,t}^\ell\}$, such that equations (1)-(12) hold. Provided that F_t, $\{G_{i,t}\}$, and $\{H_{i,t}\}$ are smooth enough, such a competitive equilibrium exists and is unique. We maintain this assumption throughout. Appendix A.1 offers a formal discussion.

2.3 Pushed to the Top or Held at the Bottom?

Beside the fact that goods and countries may each be ranked along a single dimension, a distinctive feature of the ladder metaphor is that productivity differences across countries and sectors manifest themselves at the extensive margin: capable countries sitting at the top of the ladder can produce the most complex goods, whereas countries at lower rungs cannot. Before turning to our empirical and quantitative analysis, we propose to home in on those extensive margin considerations and explore their implications for the relationship between trade, technological capability, and welfare.

The Pure Ladder Economy. Consider an economy, which we refer to as the pure ladder economy, where the only difference across goods is that some goods, the most complex ones, are produced by fewer countries, the most capable ones sitting at the top of the ladder. Formally, we assume that the distribution of productivity $G_{i,t}$ is such that

$$A_{ij,t}^k = \begin{cases} A_{ij,t} & \text{if } n_t^k \leq N_{i,t}, \\ 0 & \text{otherwise.} \end{cases} \quad (13)$$

Equation (13) allows for arbitrary trading frictions: $A_{ij,t}^k$ may vary across origin and destination countries and over time. The critical restriction that we impose is that $A_{ij,t}^k$ is independent of k for all goods below a country's capability. Hence, comparative advantage is a purely extensive-margin affair.

***All* Pushed to the Top.** To evaluate the consequences of globalization, we 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

$$(A^k_{ij,t})' = \begin{cases} A_{ij,t} & \text{if } n^k_t \leq N_{i,t} \text{ and } i = j, \\ 0 & \text{otherwise.} \end{cases} \tag{14}$$

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 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 $F^{\ell,A}_{i,t}$ is equal to F_t in all countries. In the trade equilibrium, this is not the case. By equations (6)-(10), country i's employment in a sector k with complexity $n^k_t \leq N_{i,t}$ is given by

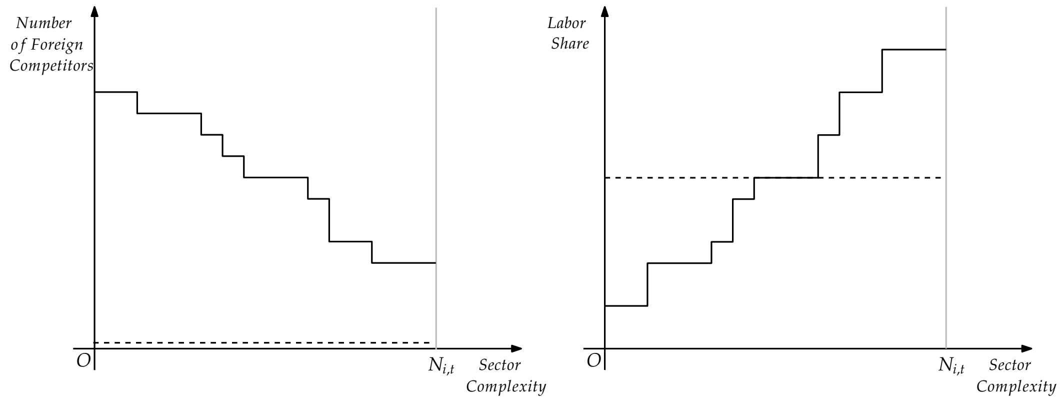
$$\ell^k_{i,t} = \sum_j \frac{(A_{ij,t})^{\sigma-1}(w_{i,t})^{-\sigma}}{(\sum_{l:N_{l,t} \geq n^k_t}(w_{l,t}/A_{lj,t})^{1-\sigma})^{\frac{\epsilon-\sigma}{1-\sigma}}} \frac{w_{j,t}L_{j,t}}{(P_{j,t})^{1-\epsilon}}.$$

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 fewer foreign competitors, as illustrated in Figure 1a. Under the assumption that $\sigma > \epsilon > 1$, this increases the price index in that sector, $P^k_{j,t} = [\sum_{l:N_{l,t} \geq n^t_k}(w_{l,t}/A_{lj,t})^{1-\sigma}]^{1/(1-\sigma)}$, which further raises sales and employment in country i. For a given level of capability, the distribution of employment $F^{\ell}_{i,t}$ therefore shifts up in terms of MLRP, as illustrated in Figure 1b. Going from trade to autarky therefore causes a decrease in growth capability, at impact, and a decrease in the level of capability, at all subsequent dates. From a welfare standpoint, these dynamic considerations always 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.2.1.

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

In the pure ladder economy, all countries gain from trade both because of static and dynamic considerations. The static considerations are standard. For fixed capability levels, countries must achieve higher aggregate consumption under trade than under autarky because the autarkic consumption bundle remains achievable under free trade, as



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

Figure 1: Changes in the Employment Distribution 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 the employment distribution across sectors for the same country before (dashed line) and after (solid line) opening up to trade.

in Samuelson (1939). The dynamic considerations are the focus of our analysis and pertain to the endogenous evolution of countries' capabilities under trade and autarky.

At arbitrary points in time, changes in capability may well be lower under trade than what it would have been under autarky. Nevertheless, whenever capability levels coincide in the trade and autarky equilibria, differences in the distribution of employment between the two equilibria imply higher capability growth in the former. This is sufficient to guarantee higher levels of capability under trade at all dates, which further raises aggregate consumption relative to autarky. Dynamic gains from trade are not zero-sum, in the sense that some countries experience dynamic gains at the expense of others by specializing in the good sectors, whereas other countries specialize in bad sectors. Here, globalization pushes all countries up the ladder. 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 exactly the same in all sectors in which it is actively producing, the distribution of employment across sectors remains given by F_t after opening up to trade.

Although the pure ladder economy imposes strong restrictions on the distribution of productivity across countries and sectors—restrictions that we think capture well the original ladder metaphor—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 $L_{i,t}$. We can also generalize Proposition 1 in a straightforward manner to environments where productivity differences across countries and sectors take the form $A^k_{ij,t} = A_{ij,t} B^k_{j,t}$, which allows sectors with the same complexity to have different sizes as well as countries with the same capability to have different distributions of expenditures across sectors.

The critical feature of a pure ladder economy, already emphasized above, is that comparative advantage only expresses itself at the extensive margin. More generally, if we were to allow more capable countries to have a comparative in more complex goods—in the sense that $A^k_{ij,t}$ is log-supermodular in $(n^k_t, N_{i,t})$, but does not necessarily satisfy condition (13)—then there would be dynamic gains for the most capable country at the top of the ladder, dynamic losses for the least capable one at the bottom, and either dynamic losses or gains for any country in between. The basic logic is unchanged. The most capable country still faces tougher foreign competition for its least complex products, now both through intensive and extensive margin considerations. In contrast, the least capable country now faces tougher competition for its most complex products, exclusively through intensive margin considerations.

Valuation of the Gains from Trade. A natural way to measure the extent to which dynamic economies of scale affect the gains from trade is to compare gains from trade in the present environment to those predicted by the formula in Arkolakis, Costinot and Rodríguez-Clare (2012) (ACR). In line with the static analysis in ACR, we assume that the world economy is initially at a steady state, with no technological shocks ($F_t = F$, $G_{i,t} = G_i$, and $H_{i,t} = H_i$) and 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 to this new steady state 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.

Our second proposition offers bounds on the gains from trade. The formal proof can be found in Appendix A.2.2.

Proposition 2. *In the pure 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 steady state under free trade; $e_i(n)$ is its share of total expenditure on goods with complexity n in that same steady state; and $H_i^{-1}(0,\tilde{F})$ is the capability level $\tilde{N}$ that solves $0 = H_i(\tilde{N},\tilde{F})$.

The first term, $\left[\int e_i(n)(\lambda_{ii}(n))^{\frac{\epsilon-1}{\sigma-1}} dF(n)\right]^{\frac{1}{\epsilon-1}}$, is standard in the quantitative trade literature. It corresponds to the static gains from trade, as previously described by Costinot and Rodríguez-Clare (2013) in the case of a similar multi-sector Armington model with nested CES utility.[5] The second term, $\left[H_i^{-1}(0,F_i^{\ell})/H_i^{-1}(0,F)\right]^{\frac{1}{(1-\epsilon)}}$, is the main focus of our analysis. It captures the fact that, in addition to the previous welfare losses, country i's production possibility frontier would also be affected by moving back to autarky. In the trade steady state, country i's capability is given by $N_i = H_i^{-1}(0,F_i^{\ell})$. In the autarky steady state, in contrast, uniform employment across sectors implies $(N_i)' = H_i^{-1}(0,F)$. The (inverse of the) function H_i determines by how much changes in the pattern of sectoral employment, from F_i^{ℓ} to F, affects the growth of capability along the transition path and, in turn, the level of capability in steady state. With F_i^{ℓ} stochastically dominating F, moving back to autarky also reduces aggregate productivity in country i, with the mapping between the change in the number of goods that country can produce, $N_i/(N_i)'$, and aggregate productivity given by $\frac{1}{1-\epsilon}$, a standard "love of variety" adjustment.

Our two bounds on the gains from trade derive from the observation that any point along the transition path from the trade steady state to the autarky steady state, country i's capability must always lie between N_i and $(N_i)'$. As a result, the welfare losses from autarky, and hence the gains from trade, must be bounded from below by $\underline{GT}_i$, the welfare loss that would occur absent any change in capability. Likewise, the gains from trade must be bounded from above by $\overline{GT}_i$, the welfare loss that would occur if capability jumped immediately and permanently to its lower steady state level under autarky.

[5] Like the original one-sector ACR formula, this expression uses expenditure shares in the current trade equilibrium, $\{\lambda_{ii}(n)\}$ and $\{e_i(n)\}$, to infer by how much country i's terms-of-trade would worsen as the economy goes back to autarky, a terms-of-trade adjustment that also depends on the elasticities of substitution across and within sectors, ϵ and σ. The lower those two elasticities are, the more a country's terms-of-trade worsen, and the larger the gains from trade are.

3 Measuring Capability and Complexity

The end goal of our paper is to test empirically whether, as illustrated by Proposition 1, trade openness is a force that tends to push all countries up the capability ladder by allowing them to specialize in their more complex sectors. To confront that hypothesis with data, we first require measures of capability and complexity.

3.1 Empirical Strategy

Our general empirical strategy is to use zero and non-zero trade flows in order to partially identify the distribution of productivity $G_{i,t}(\cdot|n,N)$ and, in turn, the capability and complexity indices that shape that distribution. For our baseline analysis, we restrict the productivity distribution $G_{i,t}$ to be such that

$$\text{Prob}(A^k_{ij,t} > 0) = \delta_{ij,t} + \gamma^k_{j,t} + N_{i,t} n^k_t, \tag{15}$$

with independence across origins and sectors, but not necessarily across destinations within the same origin and sector. Consistent with the original ladder metaphor discussed in the introduction, equation (15) captures well the notion that "complex goods are what capable countries do" in the sense that more complex goods are more likely to be 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.

Note that equation (15) includes exporter-importer-year and importer-good-year specific terms, $\delta_{ij,t}$ and $\gamma^k_{j,t}$, respectively. In line with recent work on revealed comparative advantage (e.g. Costinot, Donaldson and Komunjer 2012, Levchenko and Zhang, 2016, and Hanson, Lind and Muendler 2016), this allows us to separate the determinants of comparative advantage, capability and complexity, from bilateral trading frictions and demand differences across countries.

In our model, 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 strictly positive if and only if productivity $A^k_{ij,t}$ is strictly positive. Thus, under the assumption above, we can estimate $N_{i,t}$ and n^k_t as interacted country-year and sector-year fixed effects in a linear probability model of the form,

$$\pi^k_{ij,t} = \delta_{ij,t} + \gamma^k_{j,t} + N_{i,t} n^k_t + \epsilon^k_{ij,t}, \tag{16}$$

where $\pi^k_{ij,t}$ is the dummy variable for whether or not $x^k_{ij,t} > 0$ and the error term $\epsilon^k_{ij,t} \equiv \pi^k_{ij,t} - E[\pi^k_{ij,t}]$. Intuitively, if a country is known to be more capable than another, say the United States (US) versus Bangladesh (BG), then one can identify any good k as more complex than another reference good k_0 if, relative to the reference good, it is more likely to be exported by the United States than Bangladesh. Indeed, if there are no error terms, then equation (16) directly implies

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

Conversely, if a good is known to be more complex than another, say medicines (ME) versus men's underwear (UW), then one can identify any country i_1 as more capable than another reference country i_0 if, relative to the reference country, it is more likely to export medicines than underwear. Again, in the absence of error terms, equation (16) implies

$$N_{i,t} - N_{i_0,t} = [(\pi_{ij,t}^{ME} - \pi_{ij,t}^{UW}) - (\pi_{i_0j,t}^{ME} - \pi_{i_0j,t}^{UW})] / (n_t^{ME} - n_t^{UW}).$$

Our estimators of capability and complexity generalizes the previous idea to the case where there are error terms, but those are mean zero.[6] Our procedure requires an initial guess of either which countries are more capable or which goods are more complex. We follow the first path and assert that the original members of the G-10 are more capable which provides complexity measures for all goods which can then be used to recover capabilities for all countries. Using these new capability measures, we then reestimate complexity, which we use to recover another round of capability measures, etc., until both sets of measures have converged. The details of that estimation procedure can be found in Appendix B.2.[7]

Our procedure identifies capability and complexity, up to affine transformation. For the purposes of identifying dynamic spillovers in Section 4.3 and quantifying the dynamic gains from trade in Section 5, we will further assume that the lowest and highest complexity levels are time-invariant and always equal to 0 in the least complex sector. The first assumption implies that moving from specializing in the least to the most complex product generates the same-sized spillover in any period, whereas the second implies that there is no spillover from producing the least complex product. Without further loss of generality, we can then normalize the time-invariant level of complexity $\bar{n}$ in the most

[6] Specifically, we assume $\epsilon_{ij,t}^k = \zeta_{i,t}^k + u_{ij,t}^k$, where $\zeta_{i,t}^k$ 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. Thus, we allow some countries to be unexpectedly good at producing particular products.

[7] As discussed in Appendix B.2, for the purposes of constructing consistent estimators of capability and complexity, the first round of this iterative procedure would be sufficient. That is, with a large enough sample, estimates of capability and complexity based solely on the assumption that original members of the G-10 are more capable would converge towards (an affine transformation of) the true values $N_{i,t}$ and n_t^k. The benefit of this iterative procedure is to deliver estimators of capability and complexity that are mutually consistent even in small samples.

complex sector as well as the level of capability in the US in all years, $N_{US,t}$.[8] In what follows, we normalize $\bar{n}$ to 1 and set $N_{US,t}$ so that its average value is equal to 1 and the average capability across all countries is constant over time.

3.2 Data

Our baseline empirical analysis uses trade data from the UN Comtrade database for 146 countries and 715 4-digit SITC Rev. 2 manufacturing products from 1962 to 2014.

The UN Comtrade database 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 233 countries in the database.[9] 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 the cleaning exercise outlined in 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 Kong).[10] This procedure gives us the value of trade flows $x^k_{ij,t}$ from country i to country $j \neq i$ in sector k at date $t = 1962,...,2014$. To ensure that estimates of the linear probability model (16) are picking up genuine exporting relationships as opposed to sending samples or small quantities of re-exports, we set the dummy variable $\pi^k_{ij,t}$ for a strictly positive trade flow equal to 1 if the value of exports is equal or greater than \$100,000 in 2010 US dollars and zero otherwise.

We restrict our attention to manufacturing sectors. These are the sectors where we expect the technological spillovers emphasized in our theory to be relevant. Out of 1067 4-digit SITC rev 2 products in the full dataset, this leaves us with 715 sectors.

Our baseline sample of countries satisfies two restrictions. First, as we will ultimately be running panel regressions exploring how capability growth responds to the complexity of goods being produced, we eliminate countries with fewer than 40 years of data. This restriction eliminates 84 countries that are either newly formed, no longer exist, or

[8] Choosing different values of $\bar{n}$ is equivalent to measuring dynamic spillovers in different units in Section 4.3, whereas choosing different values of $N_{US,t}$ merely affects the value of the year fixed effects that are swept out in our empirical exercises.

[9] 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.

[10] 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).

infrequently report. Second, to ensure that results are not driven by the world's smallest countries, we eliminate 33 countries whose exports, averaged over any 5 year period, never rise above $100 million in 2010 prices. As there is substantial overlap in the countries eliminated by these two restrictions, the final sample contains 146 countries that we list in Appendix Table B.1. For robustness we explore additional samples that remove the panel requirement, remove the size threshold, or expand the size threshold to US $1 billion of annual exports.

3.3 Baseline Estimates of Capability and Complexity

Before using our capability and complexity estimates to uncover the sign and strength of dynamic spillovers in Section 4, we start by describing how capability and complexity vary over across countries and sectors.

Baseline 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.[11] The estimates of $N_{i,t}$ resonate well with widespread priors about levels of economic development across countries and over time. Recall that our normalization sets average capability in the US to 1. 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 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 52 year sample.

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 ("RGDPE") from the Penn World Tables. 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

[11] Larger countries tend to export more products than smaller ones and the additional products 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.

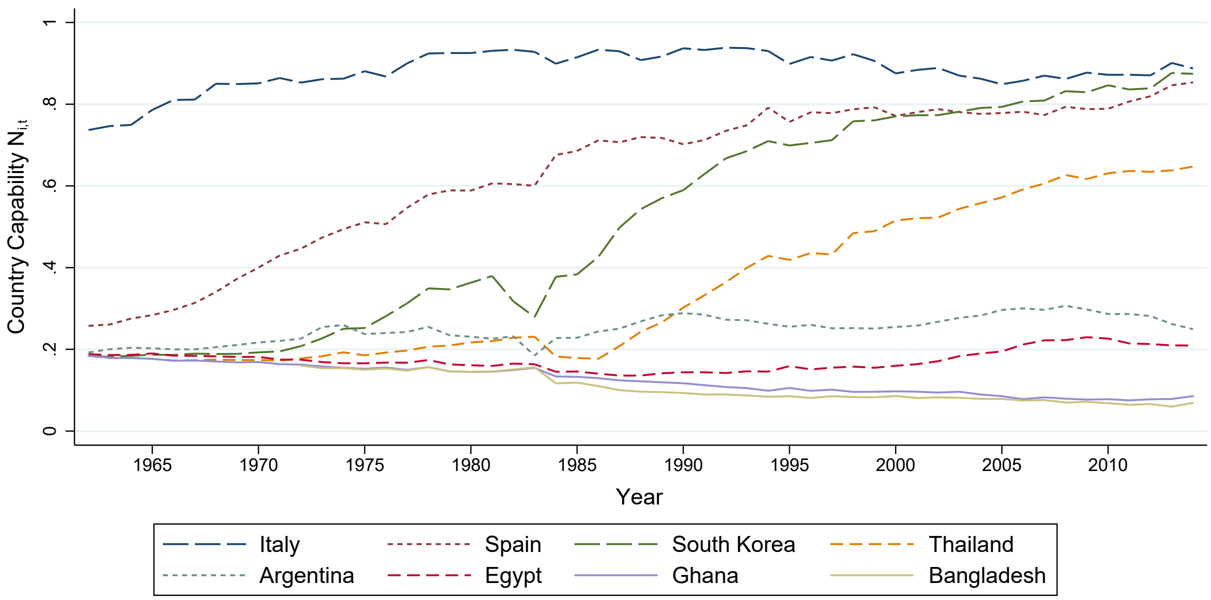


Figure 2: The Evolution of Capability ($N_{i,t}$)

Notes: Figure 2 reports the country capability measure $N_{i,t}$ from the linear probability model estimation of equation (16) 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 1 on average.

error of 0.05. If we additionally include country fixed effects, and so are also exploiting variation across time within countries, we still find a strong relationship (a coefficient of 1.7 with a standard error of 0.06).[12]

Baseline 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 average complexity across all years from 1962 to 2014. The ranking of those products also fits well our priors about technological sophistication across sectors, and hence the potential for knowledge spillovers. Medicaments, 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.

3.4 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 across products and countries.

In Hausman et al. (2007), the counterpart to product complexity, $PRODY^k$, is defined

[12]Figures B.1 and B.2 in the appendix present these relationships visually via binned scatterplots.

Table 1: Baseline Complexity (n_t^k)

	Sectors with highest n^k (Average Value, 1962-2014)			Sectors with lowest n^k (Average Value, 1962-2014)	
1	Medicaments	0.964	1	Wool Undergarments	0.067
2	Miscellaneous Non-Electrical Machinery Parts	0.878	2	Undergarments of Other Fibres	0.083
3	Chemical Products	0.872	3	Men's Underwear	0.100
4	Cars	0.861	4	Wood Panels	0.096
5	Miscellaneous Non-Electrical Machines	0.857	5	Aircraft Tires	0.089
6	Miscellaneous Electrical Machinery	0.831	6	Rotary Converters	0.081
7	Miscellaneous Hand Tools	0.808	7	Sheep and Lamb Leather	0.110
8	Medical Instruments	0.805	8	Retail Yarn of More Than 85% Synthetic Fiber	0.091
9	Electric Wire	0.768	9	Women's Underwear	0.115
10	Fasteners	0.759	10	Plastic Ornaments	0.137

Notes: Table 1 reports the sectors with the 10 highest and 10 lowest average values of n_t^k from 1962 to 2014 (among sectors with at least 40 years of data). Complexity n_t^k is estimated year-by-year using the linear probability model described in equation (16). Complexity is set to 0 and 1 for the least and most complex sector, respectively, at every date t.

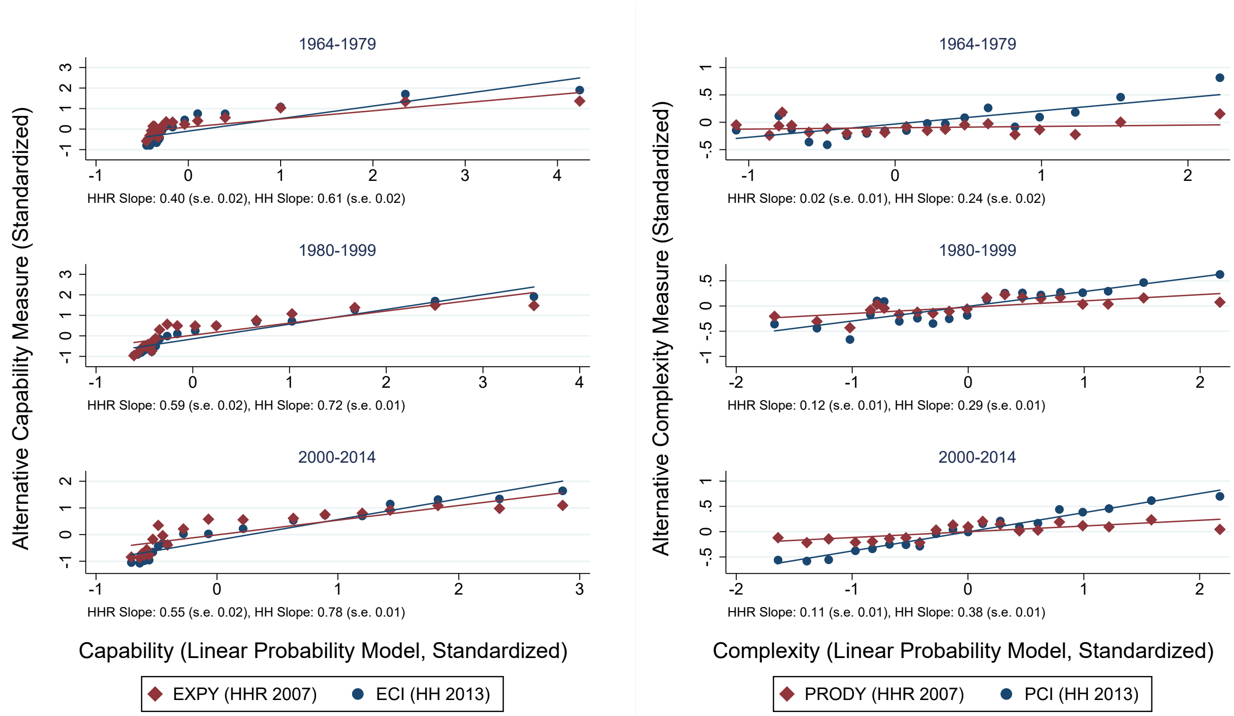
as the weighted-sum of GDP per capita, Y_i, with weights equal to Balassa's (1965) measure of revealed comparative of comparative advantage in country i and sector k, whereas the counterpart of a country's capability, $EXPY_i$, is equal to the weighted sum of $PRODY^k$, with weights equal to the share 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 focus on the extensive margin of trade. In practice, Hausman et al. (2013) go first from the raw matrix of zero trade flows to a matrix whose entries take a value of one if Balassa's (1965) revealed measure of comparative advantage 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.[13]

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.[14] As can be clearly seen from Figures 3a and 3b, the three empirical measures are strongly and positively

[13] Schetter (2019) uses a similar approach, but starts from structural estimates of productivity in a multi-sector model à la Costinot et al. (2012) rather than Balassa's (1965) measure.

[14] 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.



(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 (16) 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.

correlated, both for product complexity and country capability. This derives from the fact that all three are designed to capture the same general idea that complex goods are what capable countries exports, and vice versa. A benefit of our linear probability model, and the reason why we use it instead of those existing measures, is that it directly maps into primitive assumptions about technology. We will use this feature to conduct counterfactual and welfare analysis in Section 5.

4 Estimating Dynamic Spillovers

4.1 Baseline Specification

The theoretical framework of Section 2 focuses on an environment with continuous time and a general law of motion for capability. To estimate dynamic spillovers, and later to quantify their implications, we assume instead that time is discrete,

$$N_{i,t+\Delta} - N_{i,t} = H_{i,t}(N_{i,t}, F^{\ell}_{i,t})$$

with Δ corresponding to a 5-year period in our baseline analysis, and we impose the following parametric restrictions on the law of motion for capability,

$$H_{i,t}(N_{i,t}, F^{\ell}_{i,t}) = \beta \int n dF^{\ell}_{i,t}(n) + (\phi - 1)N_{i,t} + \gamma_i + \delta_t + \varepsilon_{i,t}.$$

Finally, given the lack of comparable production data at the product level across many countries and time periods, we use trade data to proxy country i's distribution of employment, $F^{\ell}_{i,t}(n)$, by its distribution of exports, $F^{x}_{i,t}(n) = \sum_j \int_{0 \le n^k \le n} x^k_{ij,t} dk / \sum_j \int x^k_{ij,t} dk$.[15] For future reference, note that this implies that country i is able to produce good k for the domestic market, $A^k_{ii,t} > 0$, if and only if it is able to export it to at least one of its 145 trading partners. We will maintain this assumption in our quantitative analysis.

Combining the two previous equations and letting $S_{i,t} = \int n dF^{x}_{i,t}(n)$ denote the average complexity of country i's industry mix at date t, we obtain the following baseline specification,

$$N_{i,t+\Delta} = \beta S_{i,t} + \phi N_{i,t} + \gamma_i + \delta_t + \varepsilon_{i,t}. \tag{17}$$

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 $F^{\ell}_{i,t}$ and a shift in the distribution of employment that increases the average complexity of country i's industry mix—for example, opening up to international trade that exposes the least complex goods to the largest increases in foreign competition—also increases capability growth at impact. If $\beta < 0$, the converse is true and increases in average complexity reduce capability growth.

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 leads to an increase in capability changes, in the short-run, and convergence to a new

[15] This is equivalent to assuming that the unobserved sector-level domestic sales, $x^k_{ii,t}$, are proportional to total exports in each sector, $x^k_{ii,t} = \zeta_{i,t}(\sum_{j \neq i} x^k_{ij,t})$, for some time-and-country specific shifter $\zeta_{i,t}$. In Section 5, 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.

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.[16]

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 origin 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.[17]

4.2 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, $S_{i,t}$. 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, leading to upward bias in β. Or, "bad" policies, such as subsidies to more complex sectors associated with rent-seeking or crony capitalism, expand more complex sectors but reduce capability growth or accompany other growth-reducing policies put in place by bad governments, leading to downward bias in β. We now describe how we construct instrumental variables to deal with this issue.[18]

The general idea behind our IV strategy is to use the entry of countries into the WTO as an exogenous shifter of other countries' distribution of employment, $F^{\ell}_{i,t}$, and, in turn, the average complexity of their exports, $S_{i,t}$. As country c enters the WTO at date t_c, 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 the entry of country c on another country i's average complexity

[16]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 $\phi < 1$. See Jones Jones (1999) and Atkeson and Burstein (2019) for general discussions. Quantitatively, the magnitude of the dynamic gains from trade depends both on β and ϕ. For instance, in the case of the pure ladder economy described in Section (2.3), if $H_i(N_i, F^{\ell}_i) = \gamma_i + \beta \int n dF^{\ell}_i(n) + (\phi - 1) N_i$, then dynamic gains are given by

$$\left[H_i^{-1}(0, F^{\ell}_i) / H_i^{-1}(0, F)\right]^{\frac{1}{(1-\epsilon)}} = \left[\beta\left[\int n dF^{\ell}_i(n) - \int n dF(n)\right] / (1-\phi)\right]^{\frac{1}{(1-\epsilon)}}.$$

[17]Although $L_{i,t}$ does not appear on the right-hand side of the previous specification, it is worth noting that it implicitly allows for some scale effects. Here, 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.

[18]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. We briefly discuss how we deal with this issue as well at the end of this section.

$S_{i,t}$ 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 changes in trade costs associated with country c's accession to the WTO, and hence any function of them, are orthogonal to shocks to capability, $\{\varepsilon_{i,t}\}$, in other countries.

More specifically, as described in Appendix B.4, we model the entry of any given country c into the WTO at some date t_c as a uniform and permanent decrease in trade costs of α%. We then compute, up to a first-order approximation, the counterfactual change in the average complexity of other countries that that would have been observed at dates $t \geq t_c$, assuming the entry of country c was the only shock occurring from period t_c onward and ignoring general equilibrium adjustments in wages.[19] Finally, we sum the previous changes across all WTO entry events prior to date t, to obtain the following predictor of country i's average complexity at date t,

$$\hat{S}_{i,t} = -\alpha(\sigma - \epsilon) Z^{I}_{i,t} - \alpha(\epsilon - 1)(\sigma - \epsilon) Z^{II}_{i,t},$$

where $Z^{I}_{i,t}$ is the change in average complexity caused by the changes in sector-level price indices associated with the trade cost shock and $Z^{II}_{i,t}$ is the change in average complexity caused by the changes in aggregate-level price indices. Thus, under the assumption that the timing of other countries' WTO entry is orthogonal to i's capability shocks, both $Z^{I}_{i,t}$ and $Z^{II}_{i,t}$ serve as valid instruments for i's average complexity.[20]

Our two IVs are functions of a small number of observable shares:

$$Z^{I}_{i,t} = \sum_{c \neq i} 1[t \geq t_c] \sum_{k} n^{k}_{t_c - 1} \times \underbrace{\omega^{k}_{i,t_c-1} \Big(\sum_{j \neq c} \rho^{k}_{ij,t_c-1} \lambda^{k}_{cj,t_c-1} - \sum_{k'} \omega^{k'}_{i,t} \sum_{j \neq c} \rho^{k'}_{ij,t_c-1} \lambda^{k'}_{cj,t_c-1} \Big)}_{\text{shift in } k\text{'s employment share predicted by sector-level price changes}},$$

$$Z^{II}_{i,t} = \sum_{c \neq i} 1[t \geq t_c] \sum_{k} n^{k}_{t_c - 1} \times \underbrace{\omega^{k}_{i,t_c-1} \Big(\sum_{j \neq c} \rho^{k}_{ij,t_c-1} \lambda_{cj,t_c-1} - \sum_{k'} \omega^{k'}_{i,t} \sum_{j \neq c} \rho^{k'}_{ij,t_c-1} \lambda_{cj,t_c-1} \Big)}_{\text{shift in } k\text{'s employment share predicted by aggregate-level price changes}},$$

[19] 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. As mentioned above, the assumption that we impose is that any function of changes in trade costs associated with country c's accession to the WTO is orthogonal to capability shocks in other countries.

[20] As noted in the recent literature on closely-related shift-share instruments, identification can either come from many exogenous shocks or from exogenous shares. In our setting we rely on the exogeneity of the many shocks coming from our sample of 146 countries' timing of WTO entry. As shown by Borusyak and Hull (2020), we are implicitly relying on the expected value of the instruments $Z^{I}_{i,t}$ and $Z^{II}_{i,t}$, averaging over all possible realizations of the WTO-entry data generating process, to be uncorrelated with capability growth shocks $\varepsilon_{i,t}$.

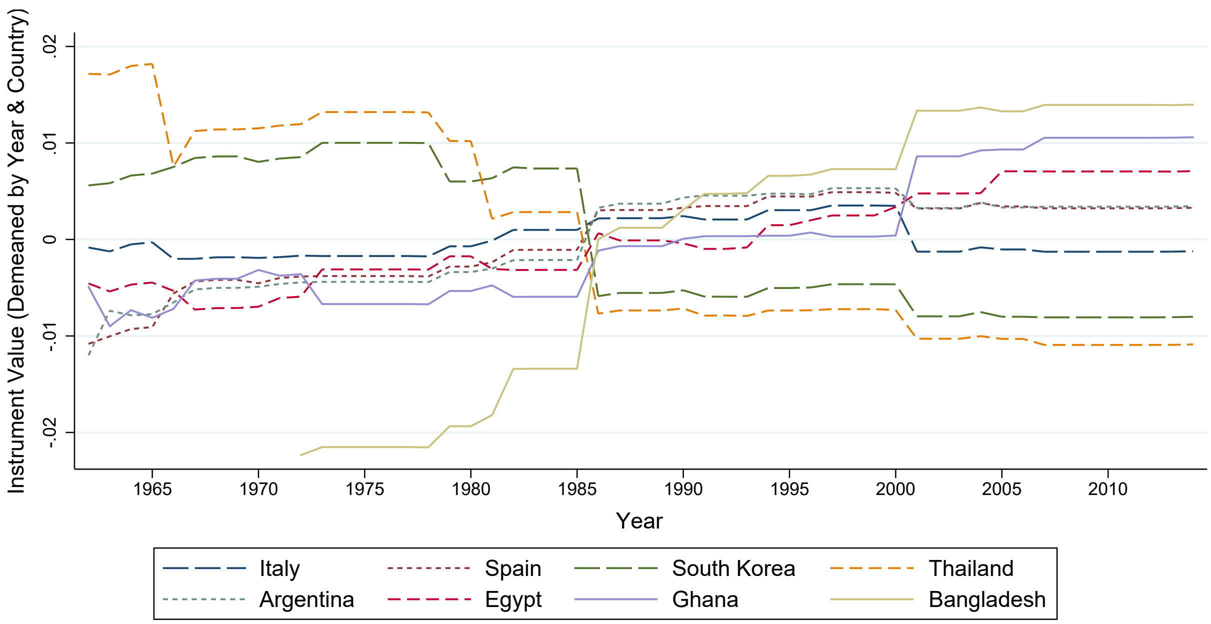


Figure 4: Time Path of $Z^I_{i,t}$

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 (see Appendix B.4).

where $1[t \geq t_c]$ is an indicator function that takes the value 1 if country c is a member of the WTO in year t, $\omega^k_{i,t} \equiv \ell^k_{i,t}/L_{i,t}$ is the employment share of sector k in country i at date t; $\rho^k_{ij,t} \equiv \ell^k_{ij,t}/\ell^k_{i,t}$ is the share of employment in country i and sector k associated with destination j at that date; $\lambda^k_{cj,t}$ is the share of expenditures on goods from country c in sector k and destination j; and $\lambda_{cj,t}$ is the share of expenditure on goods from country c (across all sectors) in country j at date t. Intuitively, $Z^I_{i,t}$ captures the overlap between i's and the WTO-entrant's export mix across both products and destinations, while $Z^{II}_{i,t}$ just focuses on the overlap between the destinations the two countries sell to.[21]

Figure 4 illustrates the time path of $Z^I_{i,t}$, the instrument that captures i's overlap with WTO-entrants across both products and destinations, for the same subset of countries as in Figure 2. To illustrate our identifying variation, consider the jump in $Z^I_{i,t}$ in 2001 for Ghana and Bangladesh associated with the entry of China into the WTO. That is, ac-

[21]While the destination-level variation in λ_{cj,t_c-1} is subsumed in the destination-product level variation $\lambda^k_{cj,t}$, the first order approximation requires both $Z^I_{i,t}$ and $Z^{II}_{i,t}$ are included when the elasticity of substitution between sectors, ϵ, is not unity. Note that since equation (17) features country and year fixed effects, the identifying variation comes from whether new entrants in a particular time period disproportionately affect country i's more and less complex products based on the entrants pre-entry export patterns.

cording to our first-order approximation, competition from new WTO entrants in 2001 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, and to a lesser degree 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.[22]

4.3 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 B.5 we regress the average complexity of country i's industry mix, $S_{i,t}$, on the instruments described above,

$$S_{i,t} = \alpha_1 Z^{I}_{i,t} + \alpha_2 Z^{II}_{i,t} + \gamma_i + \delta_t + u_{i,t} \tag{18}$$

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, either when focusing on sector-level price shifts or when adding aggregate-level price effects. 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.[23]

We now turn to estimating dynamic spillovers, β in equation (17) above. Columns 3–6 of Table 2 present the regressions of country capability on the average complexity of the product mix in the previous period.[24] Column 3 shows the ordinary least squares regres-

[22] Appendix Figure B.3 reports the time path for our second IV, $Z^{II}_{i,t}$.

[23] 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 5, we therefore prefer using existing estimates of ϵ from the literature.

[24] Recall that the period length $\Delta = 5$ years, as is common in growth regressions. Given the 5-year lead on the dependent variable, observations within 5-year periods are not independent and so we cluster standard errors at the 5-year-period-country level. Section 4.4 finds similar results using one observation per period.

Table 2: Changes in Capability and Industrial Structure

	Average Complexity $S_{i,t}$		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 $Z^{I}_{i,t}$	-0.674***	-0.186				-0.167***
(Product-Destination Level)	(0.212)	(0.223)				(0.0515)
WTO Entrant Shock $Z^{II}_{i,t}$		-4.017***				-0.599***
(Destination Level)		(0.793)				(0.224)
Average Complexity $S_{i,t}$			0.00840**	0.368***	0.288***	
			(0.00390)	(0.141)	(0.0902)	
Initial Capability $N_{i,t}$			0.936***	0.831***	0.855***	0.934***
			(0.0211)	(0.0468)	(0.0364)	(0.0213)
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	0.988	0.619	0.701	0.988
Clusters	1588	1588	1438	1438	1438	1438
CD F-Stat				32.66	36.03	
KP F-Stat				9.330	8.445	

Notes: Columns 1 and 2 of Table 2 report estimates of α_1 and α_2 in equation (18) using the baseline measure of complexity n^k_t from the linear probability model estimation of equation (16). Columns 3–6 report estimates of β and ϕ in equation (17) 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 $S_{i,t}$ by the WTO shocks $Z^{I}_{i,t}$ and $Z^{II}_{i,t}$ (in both cases using n^k_t calculated using the linear probability model). Column 6 reports the reduced form regression corresponding to column 5. Standard errors clustered at the 5-year-period-country level.

sions 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 overlap in both destinations and products with the WTO entrant's export mix, while our preferred column 5 allows these two dimensions to have different effects on the average complexity of i's product 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 complexity-weighted product 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 picking-winners type 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 like China'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. In the case of China, which enters the WTO in 2000, these are countries like Ghana and Bangladesh, as can be seen from Figure 4. Conversely, the entry of countries competing with i's relatively less complex goods raises capability growth. This is what happens, for instance, in Italy, South Korea and Thailand after China's entry, as can also be seen from Figure 4.

4.4 Sensitivity

The previous conclusions are robust to a range of alternative specifications and robustness checks described in Appendix B.6. We briefly summarize them here.

Alternative Samples. Appendix Table B.2 focuses on the sensitivity of our baseline estimates (column 3 of Table 2 which we reproduce in column 1) to alternative data samples. 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. [25]The coefficient on average complexity remains highly significant in all these cases, and rises substantially when restricting our sample to larger exporters.

Alternative Specifications. Appendix Table B.3 first explores the sensitivity of our results to alternative lag structures and considers a 10-year rather than 5-year lag (and the instruments use the export structure of the future entrant 10 years before entry). The dynamic spillovers become approximately one third larger over this extended time period (column 2). As an alternative to including all years of data and clustering standard errors at the 5-year-period-country level, column 3 only includes one observation from each cluster (observations from years ending in five or zero). 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 18. To address this issue, we treat the initial level of capability as endogenous and use 5 year lags of our instruments as additional IVs.[26] 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 (see column 4 of Table B.3).

Finally, we replace the capability of country i with its GDP per capita (column 5). As with capability, we find that the changes in the complexity of the industry 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 result is of independent interest, with the specification having close similarities to the growth regressions in Hausman et al. (2007) among others. It also distinguishes the predictions of our theory from those of a Ricardian model with uniform external economies of scale, i.e. $A^k_{ij,t} \propto (\ell^k_{i,t})^\beta$ 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 since the economy remains efficient.

[25]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.

[26]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.

5 Does Trade Push All Countries to the Top?

In Section 2, we have provided sufficient conditions under which international trade raises capability in all countries. In Section 4, we have estimated positive dynamic positive spillovers in more complex sectors. In a pure ladder economy, the finding of positive dynamic spillovers implies pervasive dynamic gains from trade. We now explore whether the same result holds in a less stylized environment that is flexible enough to match the pattern of trade flows observed in the data.

5.1 Baseline Economy

Throughout this section, we maintain the functional form assumptions imposed on preferences in Section 2 as well as those imposed on technology in Sections 3 and 4. Time is discrete, with each period t corresponding to a 5-year period. In addition to the manufacturing sectors analyzed in our empirical analysis, we 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, and allow for trade deficits, $D_{i,t}$, in the form of exogenous lump-sum transfers across countries, as described in Appendix C.1.

On the demand side, 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).[27] 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.[28]

On the supply side, we need to specify the labor endowments, $L_{i,t}$, as well as the productivity draws in the manufacturing sectors, $A^k_{ij,t}$, and in the non-tradable sector, $A^{NT}_{i,t}$.[29] For each country i and each year t, we choose units so that wages per efficiency unit are equal to one, $w_{i,t} = 1$. Under this normalization, $L_{i,t}$ is equal to the total sales, across

[27] 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, whereas the preferred estimate of Bartelme et al. (2019a) is 1.47. As already mentioned in Section 4.3, our first stage coefficients point towards an elasticity of substitution between sectors ϵ that is greater than one.

[28] From 1968 to 1990, OECD input-output tables only include nine countries with gaps in available 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. 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.

[29] Given the absence of taste shifters in the specification of preferences in equations (1) and (2), one should think of the productivity draws entering our baseline economy as capturing both differences in physical productivity and quality across countries.

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	0.288	Baseline estimate (Table 2, Column 3)
ϕ	0.855	Baseline estimate (Table 2, Column 3)

Table 3: Baseline Economy

all destinations and sectors, from country i at date t.[30] We then set the realization of the productivity draws $A^k_{ij,t}$ so that the baseline economy matches the trade data. As demonstrated in Appendix C.2, given estimates of ϵ and σ as well as data on bilateral trade flows, $x^k_{ij,t}$, productivity levels $A^k_{ij,t}$ are exactly identified, up to a time-and-destination productivity shifter,

$$\frac{A^k_{ij,t}}{A^1_{jj,t}} = \left(\frac{x^k_{ij,t}}{x^1_{jj,t}}\right)^{\frac{1}{\sigma-1}} \left[\frac{\sum_i x^k_{ij,t}}{\sum_i x^1_{ij,t}}\right]^{\frac{(\epsilon-\sigma)}{(\sigma-1)(1-\epsilon)}} \equiv \hat{A}^k_{ij,t}. \tag{19}$$

In what follows, we set $A^1_{jj,t} = A^{NT}_{j,t} = 1$ both in the autarkic and trade equilibria, for all j and t.[31] This affects 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.

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 (17). We use $\beta = 0.288$ and $\phi = 0.855$, as reported in column 3 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 3.3, the baseline economy perfectly matches the path of capability $N_{i,t}$ estimated in the same section, $\hat{\varepsilon}_{i,t} = N_{i,t+1} - \beta S_{i,t} - \phi N_{i,t}$.[32] Table 3 reports the values of the main structural parameters used in our baseline economy.

[30] More specifically, the good and labor market clearing conditions imply

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

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 $\theta_{i,t}$.

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

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

5.2 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 2.3: 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 5-year period t from 1962 to 2012, 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. In any period $t \geq 1962$, given the counterfactual autarkic capability $(N_{i,t})'$ and the observed measures of complexity n_t^k, we determine the set of goods that country i produces at that date under autarky, i.e. those such that $(A_{ii,t}^k)' > 0$, using equation (15), as described in Appendix C.3.[33] 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 $(A_{ij,t}^k)' = 0$.

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 equations (6), (7), (8), (9), and (10) to solve for all autarky prices and quantities at date t in country i: $(p_{ii,t}^k)'$, $(c_{ii,t}^k)'$, and $(l_{ii,t}^k)'$.[34] Once the counterfactual employment distribution $(F_{i,t}^\ell)'$ is known, the counterfactual autarkic capability at date $t + \Delta$ can be computed using equation (17),

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

For each country, we simulate the full counterfactual autarkic path 1000 times and take averages over these 1000 simulations.[35]

[33] Two technical issues about our procedure are worth pointing out. First, the linear probability model described in equation (15) may generate probabilities above one or below zero, in which case we truncate them at one and zero, respectively. Second, in order to keep the counterfactual autarkic equilibrium as close as possible to the initial trade equilibrium, we require that if country i produces good k at date t under trade and its capability goes up under autarky, then country i still produces that good in the autarky counterfactual, and conversely, that if a good is not produced under trade and capability goes down, then country i is still unable to produce that good under autarky.

[34] 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.

[35] In a very small number of simulations, a country may be unable to produce at a given date t. If so, we

5.3 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.[36] The values of the structural parameters in the trade equilibrium are those described in Section 5.1, with productivity levels set to $\hat{A}^k_{ij,t}$ for all goods with positive productivity. By construction, the original trade equilibrium matches bilateral trade flows for all countries and sectors at date t. Aggregate consumption under trade can be computed using $c^k_{ji} = x^k_{ji,t} / (w_{j,t} / \hat{A}^k_{ji,t})$ and substituting into equations (1) and (2). Aggregate consumption in the autarkic equilibrium can be computed in a similar manner using the counterfactual consumption levels $(c^k_{ii,t})'$ from Section 5.2.

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

$$GT^S_{i,t} = 1 - \frac{(C_{i,t})''}{C_{i,t}}, \tag{20}$$

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 between the total gains from trade and the static component,

$$GT^D_{i,t} = GT_{i,t} - GT^S_{i,t}. \tag{21}$$

For expositional purposes, we focus on 2012, the end of our last 5-year period.[37] Figure 5 reports the static and dynamic gains from trade across countries. In Figure 5a, we

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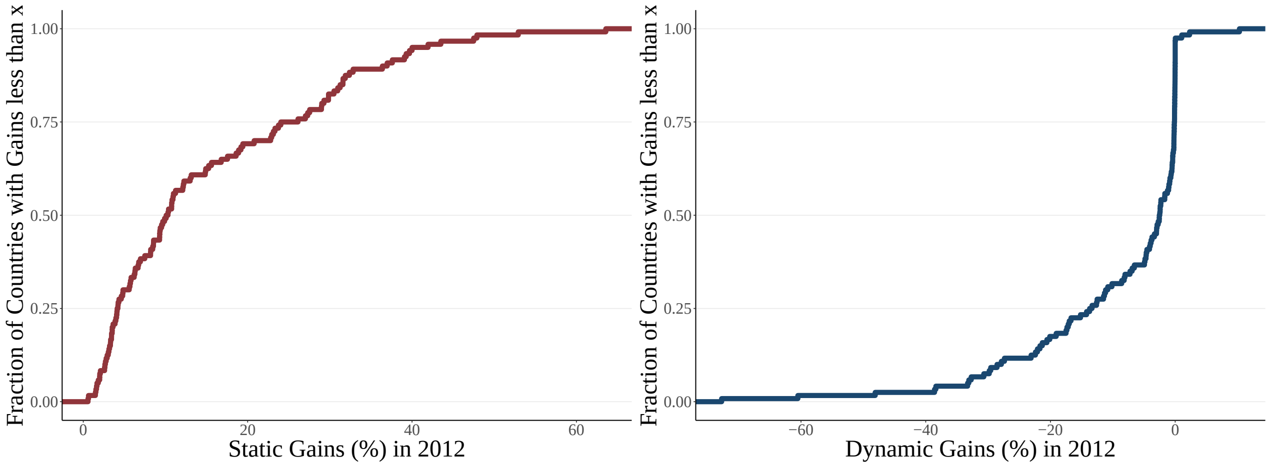
infer $(N_{i,t+\Delta})'$ by setting $\int n d(F^{\ell}_{i,t})'(n) = \int n d(F^{\ell}_{i,t-\Delta})'(n)$.

[36] As in Section 2.3, this corresponds to the difference between the income level required to achieve the utility under free trade (at date t) and the income level required to achieve the utility under autarky (at that same date t), both evaluated at the free trade prices and expressed as a fraction of a country i's income level under free trade.

[37] Out of the 146 countries included in the empirical analysis of Sections 3 and 4, 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.



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

Figure 5: Welfare Consequences of International Trade

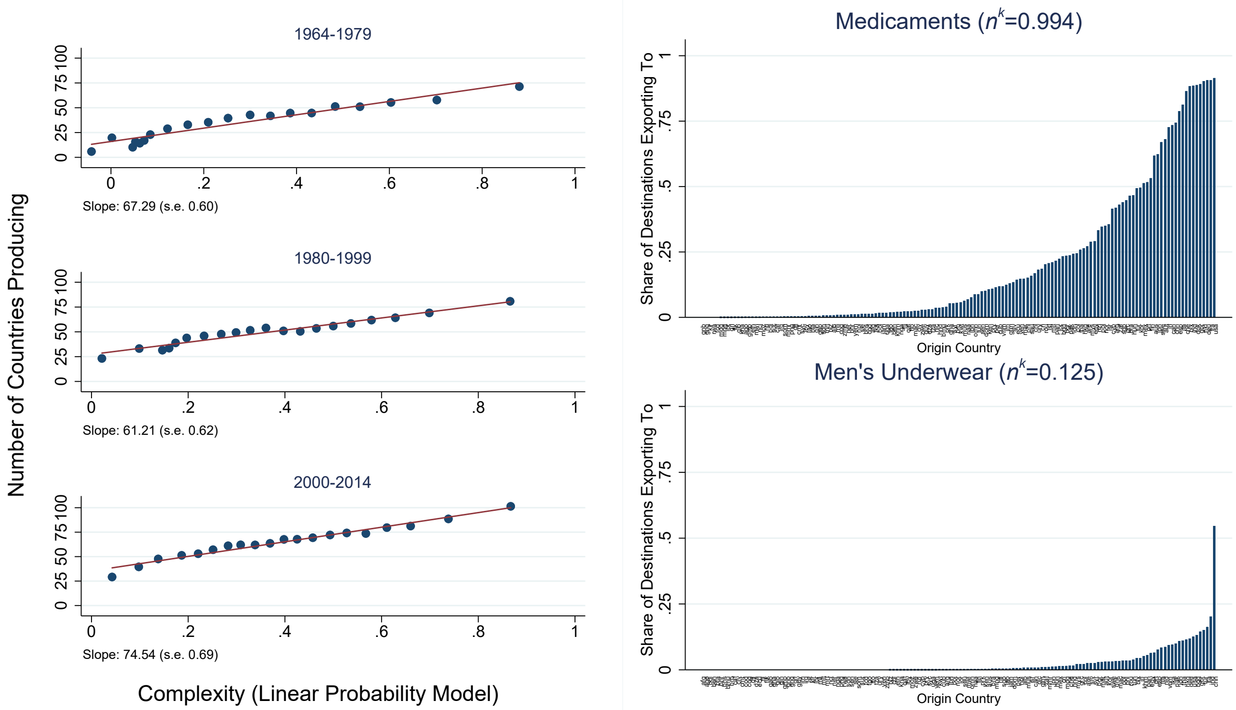
Notes: Figure 5a reports the distribution of the static gains from trade, $GT_{i,t}$, as described in equation (20), in 2012. Figure 5b reports the distribution of the dynamic gains from trade, $GT^D_{i,t}$, as described in equation (21), for the same countries and year.

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.[38] 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 pure ladder economy.[39]

Figure 6 explains why. In sharp contrast to the assumptions imposed in the pure ladder economy, more complex goods tend to be produced by more countries, not fewer, as can be seen from Figure 6a. 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

[38]As shown in Proposition 2, these are the two considerations that shape the size of the static gains from trade in the simpler pure ladder economy.

[39]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 number of countries in our sample.



(a) Complexity and Number of Exporters **(b)** Complexity and Share of Destinations Exported To

Figure 6: Complexity vs. Foreign Competition

Notes: Figure 6 plots measures of foreign competition against our measures of product complexity from the linear probability model estimation of equation (16), as described in Section 3.1. 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.

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 terms of magnitudes, the dynamic losses are 8.7% on average, 2.5% 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 0.53, as can be seen from Appendix Figure C.2.[40]

[40]Interestingly, 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 3. This is reported in Figure C.4 in Appendix C.4a. Likewise, our results do not appear to be sensitive to the lower-level elasticity of substitution, σ, as can be seen from Figure C.4d, though they are are sensitive to the value upper-level elasticity of substitution, ϵ, with the size of the losses increasing as ϵ approaches 1 in Figure C.4c. We come back to the robustness of our results to various

5.4 The Dynamic Consequences of 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 4, 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?

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 5.2 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 $i \neq$ China.[41] By definition, a country i experiences welfare gains from the rise of China if its welfare is higher at date t 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 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.

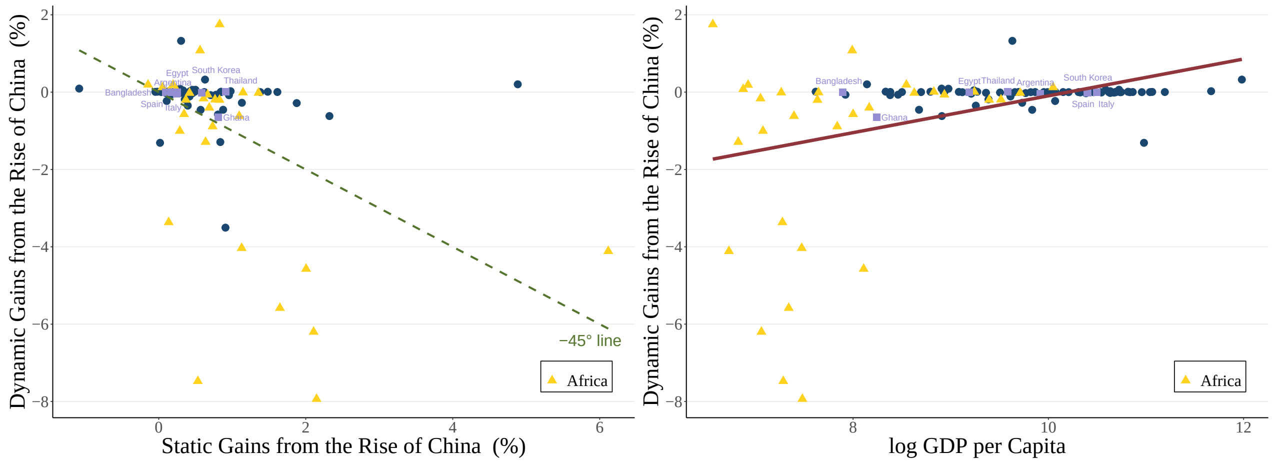
Figure 7 describes these welfare consequences from the rise of China from 1992 to 2012. Since most observations in Figure 7a lie above the -45 degree line, we see that most countries benefit from trading with China over this time period, though the bulk of these gains occur through static considerations.[42] 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.

assumptions in Section 6.

[41]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.

[42]The counterpart of Figure 5 can be found in Appendix C.4.3.



(a) Dynamic Gains vs. Static Gains **(b)** Dynamic Gains vs. GDP per Capita

Figure 7: Dynamic Consequences of the Rise of China, 1992-2012

Notes: Figure 7a reports reports the dynamic gains from the Rise of China, as described in Section 5.4, against the associated static gains in the same year. Figure 7b reports the dynamic gains from the Rise of China, as described in Section 5.4, in 2012 against log GDP per Capita in 2012. The solid line is the line of best fit (slope = 0.74, s.e. = 0.21).

First, and consistent with the time path of our instrument shown in Figure 4, China's rise pushes African countries such as Ghana into less complex sectors slowing their capability growth. The correlation between our destination-level instrument ($Z^{II}_{i,t}$), averaged across years, and the dynamic gains is -0.28. 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 and find that the African countries experiencing the largest dynamic losses also tend to be those that export their least complex goods to China in the original equilibrium. The correlation between dynamic gains and the difference in average complexity of exports to China and the rest of the world is 0.27. 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.

6 Robustness

6.1 Alternative Measures of Complexity and Capability

A natural concern with the previous analysis is that there is some arbitrariness in how we have defined our measures of complexity and capability. This begs the question: if we had made different functional-form assumptions about how complexity and capability map into trade flows, would we have reached very different conclusions?

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) that these types of goods generate faster growth. Instead, motivated by the pure ladder economy of Section 2.3, we propose to identify sectors as more complex if they face less foreign competition and then check whether or not these sectors generate more spillovers.[43] If they do, then according to Proposition 1, there should be pervasive dynamic gains rather than losses from trade.

Alternative Measures. Rather than imposing the linear probability model described in equation (15), we assume that the productivity distribution $G_{i,t}$ is such that,

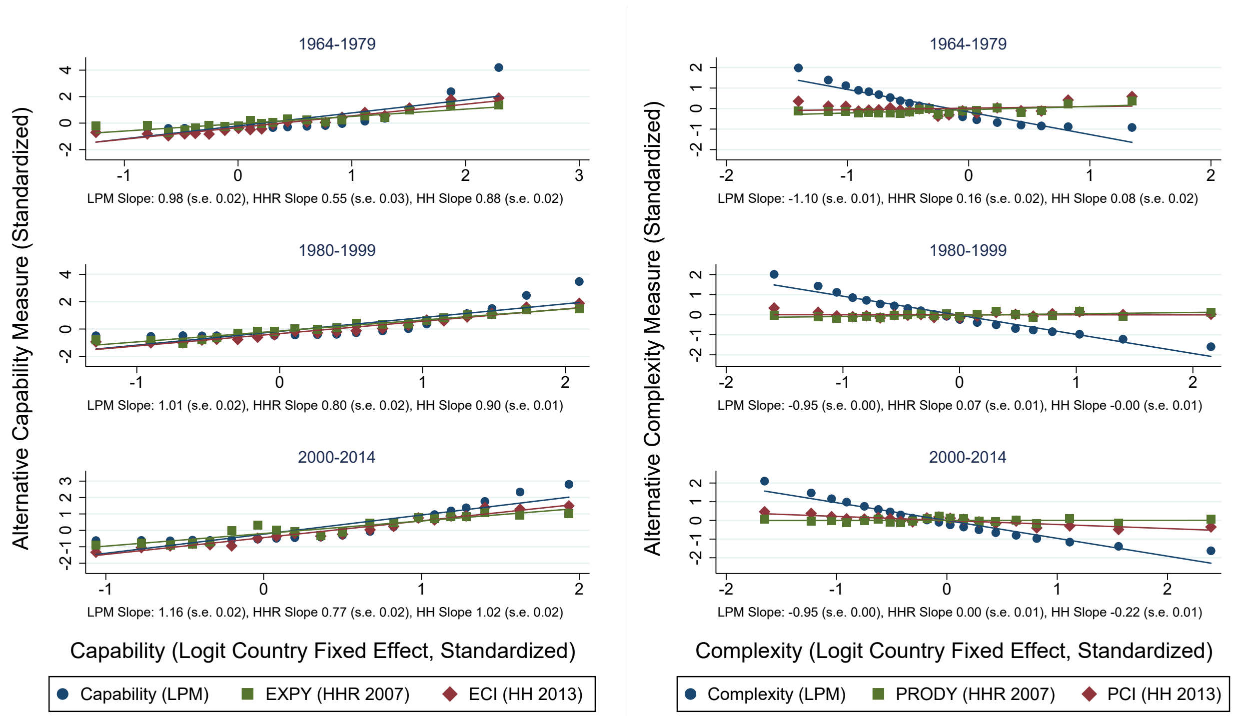
$$\text{Prob}(A^k_{ij,t} > 0) = \frac{e^{(N_{i,t} - n^k_t)}}{1 + e^{(N_{i,t} - n^k_t)}}, \text{ for all } i \neq j, k, \text{ and } t, \tag{22}$$

with independence across origins, destinations, and sectors. Consistent with our pure ladder economy, this standard logistic function implies that the probability of a strictly positive productivity draw and hence a non-zero trade flow is: (i) increasing with capability, (ii) decreasing in complexity, and (iii) log-supermodular in both. By construction, more complex goods are therefore those that tend to face less foreign competition, since fewer countries are able to export them on average.

Given the productivity distribution above, it is straightforward to recover estimates of $N_{i,t}$ and n^k_t 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. Since sets of fixed effects are only identified up to a constant, we normalize $N_{US,t}$ to 0 in every period (i.e. we omit the US fixed effect in the logit specification). Figure 8 plots these alternative measures of capability and complexity against those already presented in Section 3.4. While all capability measures are positively correlated, this is not the case for the complexity measures. As can be seen from Panel (b) in Figure 8, our new logit estimate—which infers complexity from the number of countries that export in a particular sector—is strongly negatively correlated with our baseline measure.[44] Note that this inverse relationship is not unique to our

[43]In so doing we also go back to original motivation of the empirical analysis of Hausman et al. (2013) whose starting point is 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. The measures ECI_i and PCI^k discussed in Section 3.4 can be viewed as the result of an iterative process that further accounts 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.

[44]Appendix B.7 provides the counterparts of Figure 2 and Table 1 for these alternative measures of capability and complexity.



(a) Capability Measures (N_{it}) **(b)** Complexity Measures (n_t^k)

Figure 8: Alternative Measures of Capability and Complexity

Notes: Figure 8 compares our alternative measures of capability $N_{i,t}$ and complexity n_t^k from the logit estimation of equation (22), as described in Section 3.1, to our baseline linear probability model measures of $N_{i,t}$ and n_t^k 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.

baseline complexity measure, with the low PCI index sectors of Hausman et al. (2013) also facing less competition on average despite the index's original motivation as a measure of ubiquity (see footnote 43).

Pushed to the Top or Held at the Bottom? 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 17 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 sectors i produces but few other countries do). Our results are reported in Appendix B.8. Not surprisingly, 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 $\beta = -0.390$ in our preferred two-instrument specification (Table B.5, Column 5).[45]

More complex sectors now face less foreign competition by construction. But since a more complex product mix now generates negative dynamic spillovers, we reach the same qualitative conclusion as in Section 5: pervasive dynamic losses, as illustrated in Figure 9.[46] Opening up to trade still moves countries away from the sectors that are capability-enhancing, leading 85% 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%. This reflects capability changes between trade and autarky that are much smaller in the logit case, as can be seen from Figure C.5 in Appendix C.5.2.[47] The largest losses, however, remain concentrated among a few developing countries, as illustrated in Figure C.6 in Appendix C.5.2, with the correlation between dynamic gains and GDP per capita unchanged around 0.34.

6.2 Other Issues

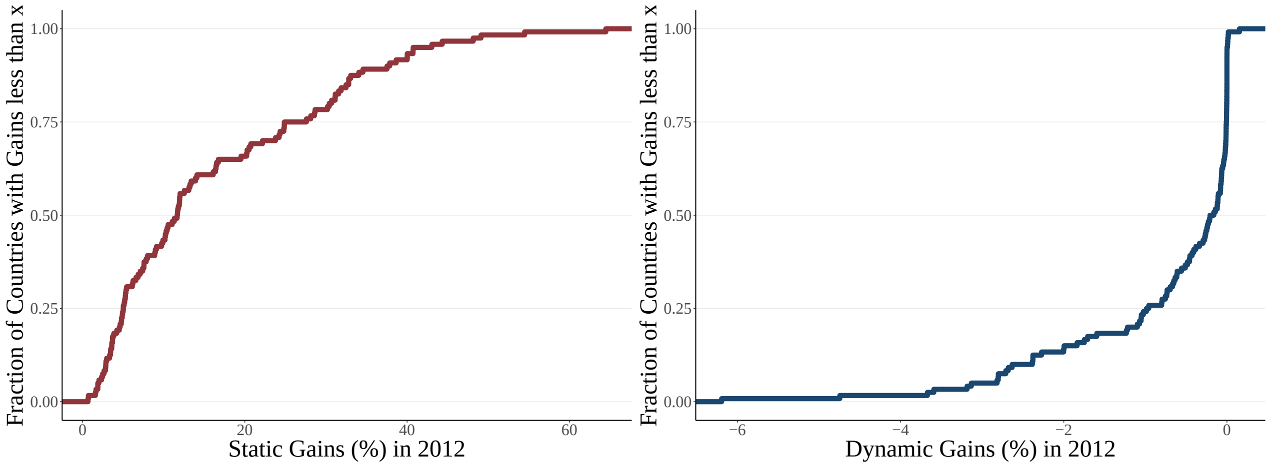
We conclude our robustness analysis by exploring the extent to which other assumptions about the nature of foreign competition and the absence of input-output linkages might have affected our conclusions about the dynamic consequences of international trade. Unless stated otherwise, the calibrated parameters are those described in Section 5.1.

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.

[45] Appendix B.8 also repeats the same set of sensitivity exercises examined in Section 4.4 but now using $N_{i,t}$ and n_t^k recovered via the logit specification (equation 22).

[46] Counterfactual autarkic equilibria are constructed in the exact same way as in the baseline analysis of Section 5.2, except for the fact that $G_{i,t}$ satisfies (22) instead of (15). That is, we follow the procedure described in Appendix C.3 but setting $\pi_{ij,t}^k(N_{i,t}) \equiv \frac{\exp(N_{i,t}-n_t^k)}{1+\exp(N_{i,t}-n_t^k)}$ instead of $\pi_{ij,t}^k(N_{i,t}) \equiv \delta_{ij,t} + \gamma_{j,t}^k + N_{i,t} n_t^k$.

[47] Although our point estimates of β are of similar magnitudes in the linear and logit cases (0.288 and -0.390, respectively), the estimated range of capability is much broader in the logit case. As a result, moving from the 25th to the 75th percentile (the IQR) of the average complexity $S_{i,t}$ in a particular year of our sample results in a change equal to 0.77 IQRs of capability, on average, for the linear model. A similar movement in the logit model changes capability by 0.049 IQRs, in line with the smaller dynamic welfare losses obtained in the logit case.



(a) Distribution of the static gains from trade **(b)** Distribution of the dynamic gains from trade

Figure 9: Welfare Consequences of International Trade Redux

Notes: Figure 9 is the counterpart of Figure 5 when capability and complexity measures are estimated using the logit model described in equation (22). Estimates of dynamic spillovers are from Table B.5, Column 3. Since static gains are unaffected by these considerations, Figures 5a and 9a are identical.

To assess whether this channel is quantitatively important, we recompute the counterfactual autarkic equilibria of Section 5.2 under the assumption that σ^k may vary across sectors. We use the 4-digit estimates from Broda and Weinstein (2006) for the period 1990-2001. Figure C.7 in Appendix C.5.3 shows that this has little effects on our main conclusions. Quantitative magnitudes are similar to our baseline analysis, with an an average dynamic loss equal to 12% and a median loss of 2.4%. The reason is that elasticities of substitution and complexity are only weakly correlated across sectors, as can be seen from 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.

We now formally explore this possibility by introducing input-output linkages as in Caliendo and Parro (2015). Compared to the model previously used in our counterfactual analysis, 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 aggregate 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.

Figure C.9 in Appendix C.5.4 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 5: all countries now experience dynamic losses, with the average and median dynamic loss equal to 13.2% and 2.5%, respectively.

7 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.

In summary, there appear to be "good" sectors, but in contrast to the standard ladder metaphor, "good" sectors are those in which more, not less, countries produce and export. 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 Existence and Uniqueness of a Competitive Equilibrium

Let $\mathbf{N}_t \equiv \{N_{i,t}\}$ denote the state of the world technology at date t; let $\mathbf{A}_t^k \equiv \{A_{i,t}^k\}$ denote the vector of productivity in sector k at date t; and let $G_t^w(\mathbf{a}|n_t^k = n, \mathbf{N}_t = \mathbf{N}) \equiv \prod_i G_{i,t}(a_i|n_t^k = n, N_{i,t} = N_i)$ denote the probability that $\mathbf{A}_t^k \leq \mathbf{a}$ conditional on $n_t^k = n$ and $\mathbf{N}_t = \mathbf{N}$.

By equations (6)-(11), the equilibrium wages $\{w_{i,t}\}$ solve

$$L_{i,t} = \int_n \int_{\mathbf{a}} \sum_j \frac{(a_{ij})^{\sigma-1}(w_{i,t})^{-\sigma}}{(\sum_l (w_{l,t}/a_{lj})^{1-\sigma})^{\frac{\epsilon-\sigma}{1-\sigma}}} \frac{w_{j,t}L_{j,t}dG_t^w(\mathbf{a}|n,\mathbf{N}_t)dF_t(n)}{\int_{n'}\int_{a'}(\sum_l (w_{l,t}/a'_{lj})^{1-\sigma})^{\frac{1-\epsilon}{1-\sigma}} dG_t^w(\mathbf{a}'|n',\mathbf{N}_t)dF_t(n')}. \quad \text{(A.1)}$$

for each i and t. Below we first establish the existence and uniqueness of $\{w_{i,t}\}$ that solve (A.1). The existence and uniqueness of $\{p_{ij,t}^k\}$, $\{c_{ij,t}^k\}$, and $\{\ell_{ij,t}^k\}$ directly follow from equations 6-(10). We conclude by characterizing the smoothness conditions on F_t, G_t^w, and $\{H_{i,t}\}$ required for the existence and uniqueness of $\{N_{i,t}\}$ that solve (4).

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

$$z_{i,t}(\mathbf{w}_t) \equiv \int_n \int_{\mathbf{a}} \sum_j \frac{(a_{ij})^{\sigma-1}(w_{i,t})^{-\sigma}}{(\sum_l (w_{l,t}/a_{lj})^{1-\sigma})^{\frac{\epsilon-\sigma}{1-\sigma}}} \frac{w_{j,t}L_{j,t}dG_t^w(\mathbf{a}|n,\mathbf{N}_t)dF_t(n)}{\int_{n'}\int_{a'}(\sum_l (w_{l,t}/a'_{lj})^{1-\sigma})^{\frac{1-\epsilon}{1-\sigma}} dG_t^w(\mathbf{a}'|n',\mathbf{N}_t)dF_t(n')} - L_{i,t},$$

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.1).

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

$$\begin{aligned} L_{i,t}(\mathbf{w}_t) &\equiv \frac{1}{w_{i,t}} \int_n \int_{\mathbf{a}} \sum_j \frac{(w_{i,t}/a_{ij})^{1-\sigma}}{(\sum_l (w_{l,t}/a_{lj})^{1-\sigma})^{\frac{\epsilon-\sigma}{1-\sigma}}} \frac{w_{j,t}L_{j,t}dG_t^w(\mathbf{a}|n,\mathbf{N}_t)dF_t(n)}{\int_{n'}\int_{a'}(\sum_l (w_{l,t}/a'_{lj})^{1-\sigma})^{\frac{1-\epsilon}{1-\sigma}} dG_t^w(\mathbf{a}'|n',\mathbf{N}_t)dF_t(n')} \\ &= \frac{1}{w_{i,t}} \int_n \int_{\mathbf{a}} \sum_j \lambda_{ij,t}^n(\mathbf{w}_t)\Lambda_{j,t}^n(\mathbf{w}_t) w_{j,t}L_{j,t}dG_t(\mathbf{a}|n,\mathbf{N}_t)dF_t(n), \end{aligned}$$

with

$$\lambda_{ij,t}(\mathbf{a};\mathbf{w}_t) \equiv \frac{(w_{i,t}/a_{ij})^{1-\sigma}}{\sum_l (w_{l,t}/a_{lj})^{1-\sigma}},$$

$$\Lambda_{j,t}(\mathbf{a};\mathbf{w}_t) \equiv \frac{\left(\sum_l (w_{l,t}/a_{lj})^{1-\sigma}\right)^{\frac{1-\epsilon}{1-\sigma}}}{\int_{n'}\int_{\mathbf{a}'}\left(\sum_l (w_{l,t}/a'_{lj})^{1-\sigma}\right)^{\frac{1-\epsilon}{1-\sigma}} dG_t^w(\mathbf{a}'|n',\mathbf{N}_t)dF_t(n')}.$$

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

$$\begin{aligned}\frac{\partial \ln L_{i,t}(\mathbf{w}_t)}{\partial \ln w_{l,t}} = \frac{1}{w_{i,t}L_{i,t}} \int_n \int_{\mathbf{a}} \Bigg(& \lambda_{il,t}(\mathbf{a};\mathbf{w}_t)\Lambda_{l,t}(\mathbf{a};\mathbf{w}_t) w_{l,t} L_{l,t} \\ & + \sum_j \lambda_{ij,t}(\mathbf{a};\mathbf{w}_t)\Lambda_{j,t}(\mathbf{a};\mathbf{w}_t) w_{j,t} L_{j,t} \big[(\sigma-\epsilon)\lambda_{lj,t}(\mathbf{a};\mathbf{w}_t) \\ & + (\epsilon-1)\int_{n'}\int_{\mathbf{a}'} \lambda_{lj,t}(\mathbf{a}';\mathbf{w}_t)\Lambda_j(\mathbf{a}';\mathbf{w}_t) dG_t^w(\mathbf{a}'|n',\mathbf{N}_t)dF_t(n') \big] \Bigg) dG_t^w(\mathbf{a}|n,\mathbf{N}_t)dF_t(n),\end{aligned}$$

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 $F_{i,t}^{\ell}(\cdot;\mathbf{N}_t)$ denote the associated equilibrium distribution of employment across sectors of different complexity,

$$F_{i,t}^{\ell}(n;\mathbf{N}_t) = \frac{\int_{n' \leq n}\int_{\mathbf{a}}\sum_j \frac{(w_{i,t}(\mathbf{N}_t)/a_{ij})^{1-\sigma}}{\left(\sum_l (w_{l,t}(\mathbf{N}_t)/a_{lj})^{1-\sigma}\right)^{\frac{\epsilon-\sigma}{1-\sigma}}} \frac{w_{j,t}(\mathbf{N}_t) L_{j,t} dG_t^w(\mathbf{a}|n',\mathbf{N}_t)dF_t(n')}{\int_{n''}\int_{\mathbf{a}'}\left(\sum_l (w_{l,t}(\mathbf{N}_t)/a'_{lj})^{1-\sigma}\right)^{\frac{1-\epsilon}{1-\sigma}} dG_t^w(\mathbf{a}'|n'',\mathbf{N}_t)dF_t(n'')}}{\int_{n'}\int_{\mathbf{a}}\sum_j \frac{(w_{i,t}(\mathbf{N}_t)/a_{ij})^{1-\sigma}}{\left(\sum_l (w_{l,t}(\mathbf{N}_t)/a_{lj})^{1-\sigma}\right)^{\frac{\epsilon-\sigma}{1-\sigma}}} \frac{w_{j,t}(\mathbf{N}_t) L_{j,t} dG_t^w(\mathbf{a}|n',\mathbf{N}_t)dF_t(n')}{\int_{n''}\int_{\mathbf{a}'}\left(\sum_l (w_{l,t}(\mathbf{N}_t)/a'_{lj})^{1-\sigma}\right)^{\frac{1-\epsilon}{1-\sigma}} dG_t^w(\mathbf{a}'|n'',\mathbf{N}_t)dF_t(n'')}} \quad \text{for all } n. \tag{A.2}$$

By equations (4) and (5), the equilibrium capability vector $\mathbf{N}_t$ solves the following ODE,

$$\dot{\mathbf{N}} = V(\mathbf{N},t), \tag{A.3}$$

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

$$V_i(\mathbf{N},t) \equiv H_{i,t}(N_i, F_{i,t}^{\ell}(\cdot;\mathbf{N})). \tag{A.4}$$

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.3) for $t \in [0,T]$ with initial value $\mathbf{N}_0$ provided that F_t, G_t^w and $\{H_{i,t}\}$ are such that V is Lipschitz-continuous with respect to $\mathbf{N}$ and continuous with respect to t.

A.2 Comparative Statics

A.2.1 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 $N_{i,t}^A$ 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 $N_{i,0}^A = N_{i,0}$. To show that $N_{i,t}^A \leq N_{i,t}$ for all $t \geq 0$, it is therefore sufficient to show that if $N_{i,t_0}^A = N_{i,t_0}$ at any date $t_0 \geq 0$, then $\dot{N}_{i,t_0} \geq \dot{N}_{i,t_0}^A$. By equation (4), under the assumption that $H_{i,t}$ is increasing in $F_{i,t}^{\ell}$, this is equivalent to show that if $N_{i,t_0}^A = N_{i,t_0}$, then F_{i,t_0}^{ℓ} stochastically dominates $F_{i,t_0}^{\ell,A}$ in terms of the Monotone Likelihood Ratio Property (MLRP).

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

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

The same density in the trade equilibrium is

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

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

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

This implies

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

Hence, F_{i,t_0}^{ℓ} dominates the distribution of employment in country i under autarky, $F_{i,t_0}^{\ell,A}$, in terms of MLRP. It follows that $\dot{N}_{i,t_0}^A \leq \dot{N}_{i,t_0}$ and, in turn, that $N_{i,t}^A \leq N_{i,t}$ for all $t \geq 0$.

Change in Aggregate Consumption. Let $C_{i,t}^A$ and $C_{i,t}$ denote aggregate consumption in country i at date t in the autarky and trade equilibrium, respectively, and let $\bar{C}_{i,t}^A$ 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 $\bar{C}^A_{i,t} \leq C_{i,t}$. Since $N^A_{i,t} \leq N_{i,t}$ for all t, we must also have $C^A_{i,t} \leq \bar{C}^A_{i,t}$. Combining the two previous observations, we get $C^A_{i,t} \leq C_{i,t}$ for all $t \geq 0$.

A.2.2 Proof of Proposition 2

Let N^A_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 $N^A_{i,t} \leq N_i$ for all t. This implies $C^A_{i,t} \leq \bar{C}^A_i$, where $\bar{C}^A_i$ 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

$$\underline{GT}_i = 1 - \frac{\bar{C}^A_i}{C_i}.$$

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

$$\overline{GT}_i = 1 - \frac{\underline{C}^A_i}{C_i}.$$

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

$$C_i = w_i L_i / P_i, \tag{A.5}$$

$$\bar{C}^A_i = \bar{w}^A_i L_i / \bar{P}^A_i. \tag{A.6}$$

By equation (9), we also have

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

Using the fact that $e_i(n) = (P_i(n)/P_i)^{1-\epsilon}$, $\bar{P}^A_i(n) = \bar{w}^A_i / A_{ii}$ 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

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

Combining this expression with equations (A.5) and (A.6), 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 $\overline{GT}_i = 1 - \frac{\underline{C}_i^A}{C_i}$. As before, budget balance in every period implies

$$\underline{C}_i^A = \underline{w}_i^A L_i / \underline{P}_i^A,$$

whereas equations (6) and (9) imply

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

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

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

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 $N_i^A = H_i^{-1}(0, F)$. Substituting for N_i and N_i^As, we finally obtain

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

B Online Appendix: Empirics

B.1 Sample of Countries

Table B.1: Sample of Countries

Country Name	Years in Sample	Max Exports 5-yr Avg ($B)	Country Name	Years in Sample	Max Exports 5-yr Avg ($B)	Country Name	Years in Sample	Max Exports 5-yr Avg ($B)
Afghanistan	53	0.79	Ghana	53	9.67	Nigeria	53	92.07
Albania	53	1.89	Gibraltar	51	0.19	North Korea	53	2.82
Algeria	53	52.35	Greece	53	20.23	Norway	53	120.40
Angola	53	58.92	Greenland	47	0.80	Oman	53	39.25
Argentina	53	71.70	Guatemala	53	9.70	Pakistan	53	22.92
Australia	53	239.80	Guinea	53	2.14	Panama	53	6.09
Austria	53	143.00	Guinea-Bissau	53	0.25	Papua New Guinea	53	7.19
Bahamas	53	5.18	Guyana	53	1.36	Paraguay	53	5.95
Bahrain	53	6.03	Haiti	53	0.94	Peru	53	37.78
Bangladesh	43	26.46	Honduras	53	7.75	Philippines	53	69.80
Barbados	53	0.66	Hong Kong	53	77.39	Poland	53	160.40
Belgium-Luxembourg	53	316.10	Hungary	53	89.43	Portugal	53	51.90
Belize	50	1.13	Iceland	53	4.69	Qatar	53	94.11
Benin	53	1.03	India	53	215.60	Republic of the Cong	53	10.13
Bermuda	53	0.80	Indonesia	53	184.50	Romania	53	53.81
Bolivia	53	9.16	Iran	53	93.76	Rwanda	52	0.35
Brazil	53	229.60	Iraq	53	72.40	Saint Kitts and Nevis	51	0.40
Bulgaria	53	21.89	Ireland	53	155.50	Saudi Arabia	53	291.40
Burkina Faso	53	1.42	Israel	53	56.84	Senegal	53	1.69
Burma	53	10.98	Italy	53	438.40	Seychelles	46	0.46
Burundi	53	0.26	Jamaica	53	2.63	Sierra Leone	53	1.11
Cambodia	53	8.93	Japan	53	723.90	Singapore	53	169.20
Cameroon	53	4.72	Jordan	53	5.67	Somalia	53	0.49
Canada	53	413.40	Kenya	53	4.73	South Africa	53	124.10
Central African Repul	53	0.35	Kiribati	53	0.48	South Korea	53	465.40
Chad	53	2.90	Kuwait	53	68.84	Spain	53	246.40
Chile	53	73.64	Laos	53	3.14	Sri Lanka	53	9.47
China	53	2054.00	Lebanon	53	3.18	Sudan	53	9.91
Colombia	53	51.28	Liberia	53	2.90	Suriname	53	1.97
Costa Rica	53	31.16	Libya	53	41.53	Sweden	53	145.50
Cote d'Ivoire	53	9.32	Macau	52	3.81	Switzerland	53	293.00
Cuba	53	5.03	Madagascar	53	1.81	Syria	53	6.53
Cyprus	53	3.29	Malawi	52	1.05	Tanzania	53	3.98
Democratic Republic	53	6.92	Malaysia	53	236.40	Thailand	53	207.70
Denmark	53	87.86	Mali	53	1.95	Togo	53	1.70
Djibouti	53	0.18	Malta	53	4.05	Trinidad and Tobago	53	14.37
Dominican Republic	53	7.24	Mauritania	53	2.95	Tunisia	53	15.38
Ecuador	53	23.62	Mauritius	53	2.35	Turkey	53	119.60
Egypt	53	27.31	Mexico	53	345.90	Uganda	53	1.39
El Salvador	53	4.76	Mongolia	53	4.14	United Arab Emirates	49	178.60
Equatorial Guinea	53	10.99	Morocco	53	20.97	United Kingdom	53	399.00
Ethiopia	53	2.15	Mozambique	53	4.08	United States	53	1260.00
Falkland Islands	45	0.19	Nepal	53	0.79	Uruguay	53	9.19
Fiji	53	0.79	Netherland Antilles a	53	9.03	Venezuela	53	59.20
Finland	53	75.61	Netherlands	53	393.20	Vietnam	53	116.60
France	53	519.90	New Caledonia	53	1.44	Yemen	53	8.17
Gabon	53	9.73	New Zealand	53	35.41	Zambia	53	6.85
Gambia	53	0.25	Nicaragua	53	4.60	Zimbabwe	52	2.47
Germany	53	1227.00	Niger	53	0.72			

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

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 3.1, 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,

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

where $\zeta_{i,t}^k$ 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:

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

where we have applied the law of large numbers across J destination countries to eliminate the u_{ij}^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

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

where we have applied the law of large numbers across K sectors to eliminate the $(\zeta_{i,t}^k - \zeta_{i_0,t}^k)$ 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 $\zeta_{i,t}^{k_0} - \zeta_{US,t}^{k_0}$ 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. $\sum_{k_0}\omega_t^{k_0}(\xi_{i,t}^{k_0}-\xi_{US,t}^{k_0})\to_{K\to\infty}0$. This implies

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

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 $a_t\equiv1/(\sum_k\frac{1}{K}n_t^k-\sum_k\omega_t^k n_t^k)$ 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

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

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 $(\sum_i\frac{1}{I}N_{i,t}-\sum_{i_0}\omega_{i_0,t}N_{i_0,t})\neq0$ and $\sum_{i_0}\omega_{i_0,t}(\xi_{i_0,t}^k-\xi_{i_0,t}^{ME})\to_{I\to\infty}0$ implies

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

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 $c_t\equiv1/(\sum_i\frac{1}{I}N_{i,t}-\sum_i\omega_{i,t}N_{i,t})$ 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 $\sum_k\frac{1}{K}n_t^k-\sum_k\omega_t^k n_t^k\neq0$ and $\sum_k\omega_t^k(\xi_{i,t}^k-\xi_{US,t}^k)\to_{K\to\infty}0$ and $\omega_{i,t}$ is such that $\frac{1}{I}N_{i,t}-\sum_i\omega_{i,t}N_{i,t}\neq0$ and $\sum_i\omega_{i,t}(\xi_{i,t}^k-\xi_{i,t}^{MED})\to_{I\to\infty}0$, 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 $\omega_{i_0,t}$.

Measuring capability and complexity across time. For the purposes of estimating dynamic spillovers in Section 4.3, i.e. estimating β and ϕ in equation (17), and later quantifying the dynamic gains from trade in Section 5, 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 (17), 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 (17) 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

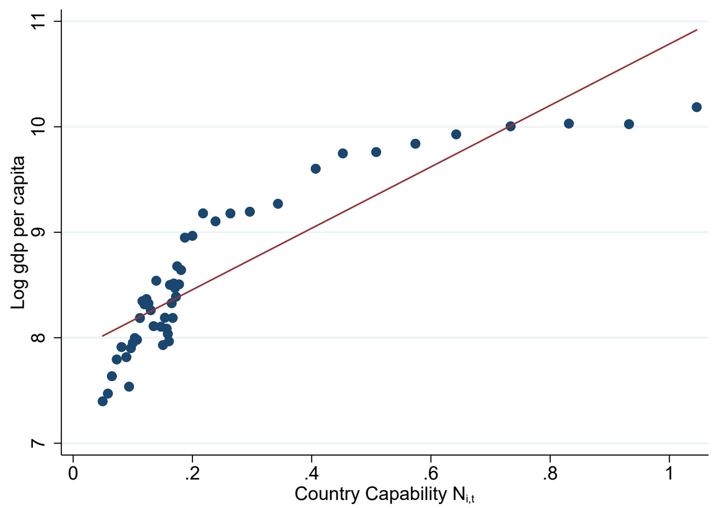


Figure B.1: GDP per capita vs. Capability (within years)

Notes: Figure B.1 is the binned scatter plot associated with a regression of log GDP per capita on both capabilities, recovered from the linear probability model estimation of equation (16) as described in Section 3.1, and year fixed effects.

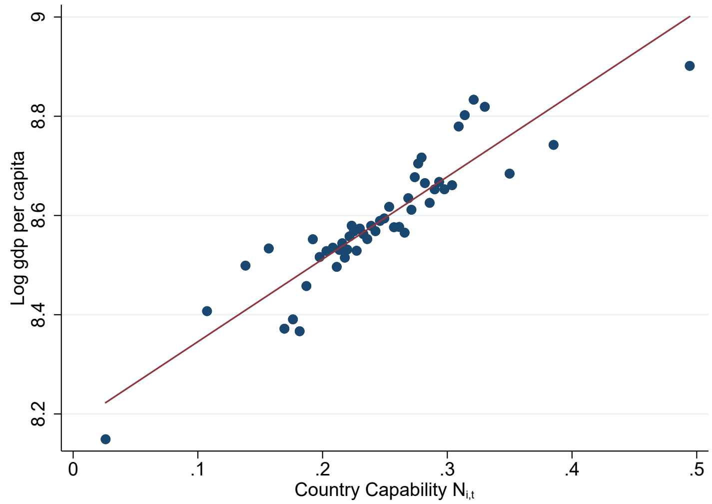


Figure B.2: GDP per capita vs. Capability (within years and countries)

Notes: Figure B.2 is the binned scatter plot associated with a regression of log GDP per capita on capabilities, recovered from the linear probability model estimation of equation (16) as described in Section 3.1, year fixed effects and country fixed effects.

B.4 Construction of Instrumental Variables

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

$$(A^k_{ij,t})'_c = \begin{cases} e^{\alpha} A^k_{ij,t_c-1} & \text{if } i=c \text{ and } j \neq c, \\ A^k_{ij,t_c-1} & \text{otherwise.} \end{cases}$$

with $\alpha > 0$. We then compute, up to a first-order approximation, the counterfactual change in country i's average complexity, $(\Delta S_i)_c$, that would have been observed in any period $t \geq t_c$ if the entry of country c was the only shock occurring from period t_c 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 $S_{i,t}$.

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

$$(\Delta S_i)_c = \sum_k n^k_{t_c-1}(\Delta\omega^k_{i,t})_c,$$

with $(\Delta\omega^k_{i,t})_c \equiv (\omega^k_{i,t})'_c - \omega^k_{i,t_c-1}$. Up to a first-order approximation, we also have

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

with $\rho^k_{ij,t_c-1} = \ell^k_{ij,t_c-1}/[\sum_{j'} \ell^k_{ij',t_c-1}]$ the share of employment in country i and sector k associated with destination j and the log-changes in prices $\Delta\ln(P^k_{j,t})_c \equiv \ln(P^k_{j,t})'_c - \ln P^k_{j,t_c-1}$ and $\Delta\ln(P_{j,t})_c \equiv \ln(P_{j,t_c})' - \ln P_{j,t_c-1}$ given by

$$\begin{aligned}
\Delta\ln(P^k_{j,t})_c &= -\alpha\lambda^k_{cj,t_c-1}, \text{ for all } j \neq c, \\
\Delta\ln(P_{j,t})_c &= -\alpha\lambda_{cj,t_c-1}, \text{ for all } j \neq c,
\end{aligned}$$

with $\lambda^k_{cj,t}$ the share of country j's expenditure on good k allocated to country c at date t, $e^k_{j,t}$ the share of expenditure of country j on sector k, and $\lambda_{cj,t} = \sum_k e^k_{j,t}\lambda^k_{cj,t}$ the total share of expenditure on goods from country c in destination j. Regrouping terms, this leads to

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

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

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

where $Z^I_{i,t}$ and $Z^{II}_{i,t}$ are such that

$$\begin{aligned}
Z^I_{i,t} &= \sum_{c\neq i} 1[t \geq t_c] \sum_k n^k_{t_c-1} \times \omega^k_{i,t_c-1}(\sum_{j\neq c}\rho^k_{ij,t_c-1}\lambda^k_{cj,t_c-1} - \sum_{k'}\omega^{k'}_{i,t_c-1}\sum_{j\neq c}\rho^{k'}_{ij,t_c-1}\lambda^{k'}_{cj,t_c-1}), \\
Z^{II}_{i,t} &= \sum_{c\neq i} 1[t \geq t_c] \sum_k n^k_{t_c-1} \times \omega^k_{i,t_c-1}(\sum_{j\neq c}\rho^k_{ij,t_c-1}\lambda_{cj,t_c-1} - \sum_{k'}\omega^{k'}_{i,t_c-1}\sum_{j\neq c}\rho^{k'}_{ij,t_c-1}\lambda_{cj,t_c-1}).
\end{aligned}$$

These are the two instrumental variables used to estimate equation (17).

B.5 Time Path of $Z^{II}_{i,t}$

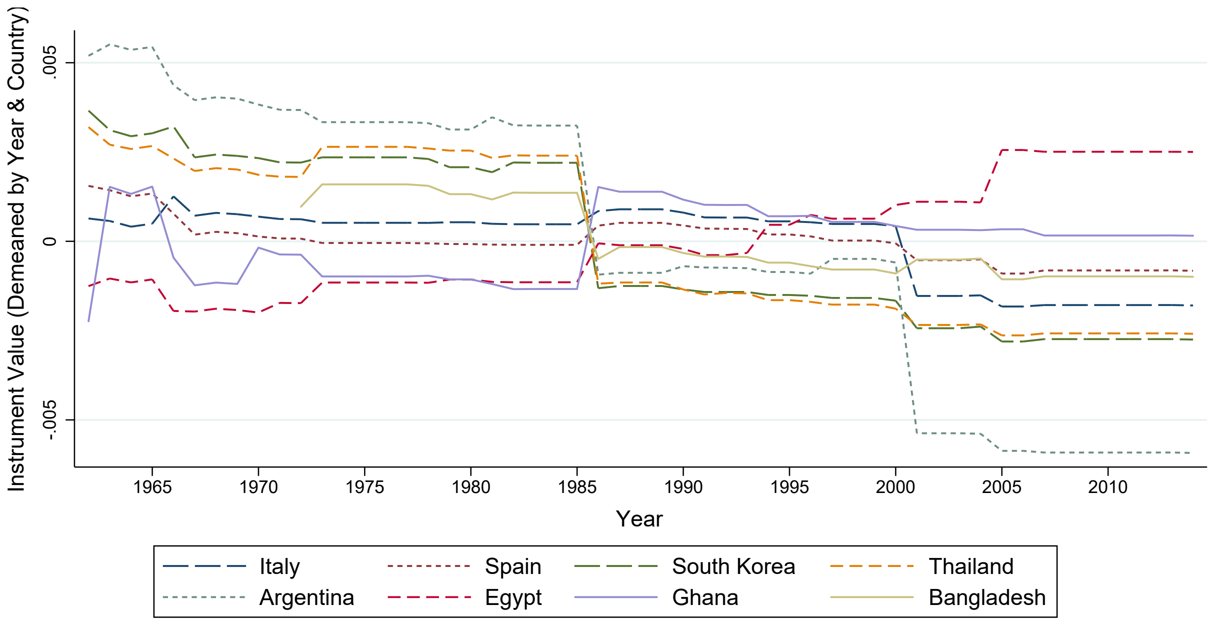


Figure B.3: Time Path of $Z^{II}_{i,t}$

Notes: Figure B.3 plots the value of the instrument $Z^{II}_{i,t}$ 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.

B.6 Estimates of Dynamic Spillovers: Sensitivity

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

	Country Capability $N_{i,t+\Delta}$				
	(1)	(2)	(3)	(4)	(5)
	Baseline	Feenstra Dataset	All Length Panels	No Size Threshold	High Size Threshold
Average Complexity $S_{i,t}$	0.288***	0.298**	0.223***	0.291***	0.414***
	(0.0902)	(0.127)	(0.0732)	(0.0901)	(0.149)
Initial Capability $N_{i,t}$	0.855***	0.929***	0.868***	0.857***	0.805***
	(0.0364)	(0.0416)	(0.0359)	(0.0354)	(0.0532)
Country and year FEs	Yes	Yes	Yes	Yes	Yes
Observations	6,872	6,864	7,905	6,995	5,986
R-squared	0.701	0.721	0.711	0.689	0.648
Clusters	1438	1438	1673	1466	1249
CD F-Stat	36.03	17.52	37.97	34.09	27.05
KP F-Stat	8.445	4.145	9.282	8.475	5.551

Notes: Table B.2 reports estimates of β and ϕ in equation (17) using the baseline measures of complexity n_t^k and capability $N_{i,t}$ from the linear probability model estimation of equation (B.1). All columns use the two-instrument IV strategy. Column 1 reports our baseline estimates (column 3 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. Standard errors clustered at the 5-year-period-country level.

Table B.3: Changes in Capability and Industrial Structure: Sensitivity (II)

	Country Capability $N_{i,t+\Delta}$				$GDP_{i,t+\Delta}$
	(1)	(2)	(3)	(4)	(5)
	Baseline	10-year Lag	1 Obs. per 5-year Cluster	IV $N_{i,t}$	
Average Complexity $S_{i,t}$	0.288***	0.405***	0.205**	0.275***	0.906**
	(0.0902)	(0.144)	(0.0877)	(0.0955)	(0.417)
Initial Capability $N_{i,t}$	0.855***	0.690***	0.876***	0.721***	
	(0.0364)	(0.0651)	(0.0381)	(0.0981)	
GDP per capita $GDP_{i,t}$					0.758***
					(0.0330)
Country and Year FEs	Yes	Yes	Yes	Yes	Yes
Observations	6,872	6,151	1,295	6,195	6,107
R-squared	0.701	0.308	0.751	0.669	0.588
Clusters	1438	723	1295	1303	1269
CD F-Stat	36.03	35.85	7.177	12.98	63.55
KP F-Stat	8.445	8.733	5.094	3.674	16.70

Notes: Table B.3 reports estimates of β and ϕ in equation (17) using the baseline measures of complexity n_t^k and capability $N_{i,t}$ from the linear probability model estimation of equation (B.1). All columns use the two-instrument IV strategy. Column 1 reports our baseline estimates (column 3 of Table 2). Column 2 reports the same estimates using 10-year rather than 5-year lags. Column 3 uses one observation per 5-year cluster. Column 4 instruments initial capability using lagged-values of the WTO shocks $Z_{i,t}^{I}$ and $Z_{i,t}^{II}$. Column 5 uses GDP per capita instead of capability. Standard errors clustered at the 5-year-period-country level.

B.7 Alternative Measures of Capability and Complexity in Section 6.1

B.7.1 Alternative Measures of Capability

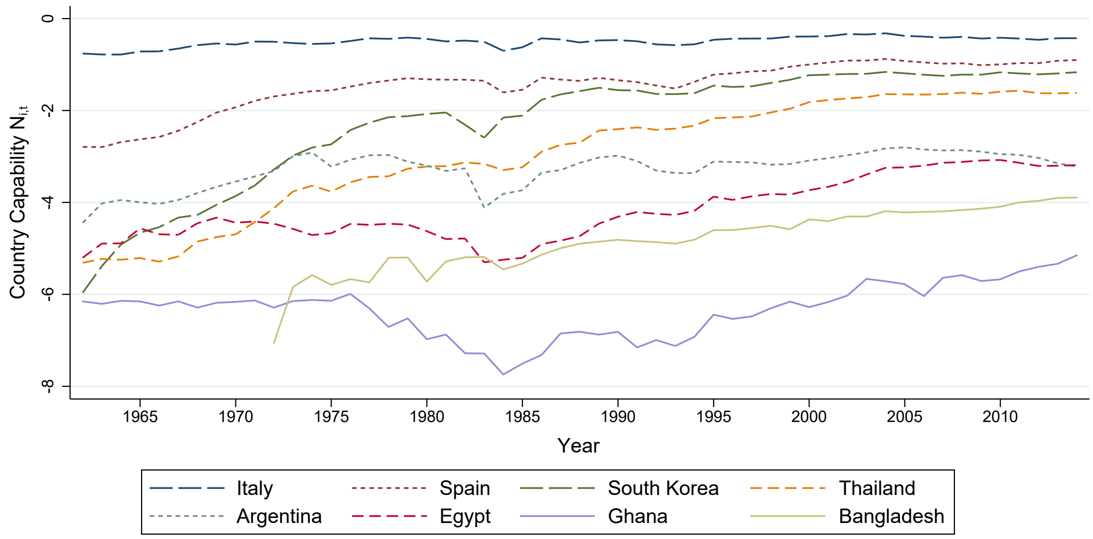


Figure B.4: The Evolution of Capability ($\tilde{N}_{i,t}$)—Alternative Measures

Notes: Figure B.4 reports for a selection of similarly-sized countries the country fixed effects $\tilde{N}_{i,t}$ recovered from the maximum likelihood estimation of equation (22) in a given year t, as described in Section 3.1. Fixed effects are normalized such that $\tilde{N}_{US,t} = 0$ for all t.

B.7.2 Alternative Measures of Complexity

Table B.4: Alternative Complexity ($\tilde{n}_t^k$)

	Sectors with highest n^k (Average Value, 1962-2014)			Sectors with lowest n^k (Average Value, 1962-2014)	
1	Railway Passenger Cars	3.233	1	Medicaments	-1.626
2	Electric Trains	3.230	2	Chemical Products	-1.237
3	Warships	3.193	3	Miscellaneous Non-Electrical Machinery Parts	-1.157
4	Mechanically Propelled Railway	2.894	4	Miscellaneous Electrical Machinery	-1.128
5	High-pressure hydro-electric conduits of steel	2.690	5	Miscellaneous Non-Electrical Machines	-1.067
6	Leather Articles Used in Machinery	2.665	6	Finished Cotton Fabrics	-1.007
7	Rotary Converters	2.557	7	Footwear	-1.001
8	Hats	2.533	8	Medical Instruments	-0.985
9	Aircraft Tires	2.526	9	Electric Wire	-0.969
10	Nuclear Reactors	2.526	10	Miscellaneous Hand Tools	-0.969

Notes: Table B.4 reports the 10 highest and 10 lowest values of the sector fixed effects $\tilde{n}_t^k$ recovered from the maximum likelihood estimation of equation (22) averaged across all years from 1962 to 2014 for products with at least 40 years of data.

B.8 Estimates of Dynamic Spillovers in Section 6.1

B.8.1 Dynamic Spillovers using Alternative Measures of Capability and Complexity

Table B.5: Changes in Capability and Industrial Structure Using Alternative Capability and Complexity Measures

	Average Complexity $S_{i,t}$		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 $Z^I_{i,t}$	-2.945***	-1.064				1.069
(Product-Destination Level)	(0.541)	(0.660)				(0.671)
WTO Entrant Shock $Z^{II}_{i,t}$		-12.03***				-7.700***
(Destination Level)		(2.057)				(2.340)
Average Complexity $S_{i,t}$			0.0412	-0.0474	-0.390**	
			(0.0302)	(0.249)	(0.196)	
Initial Capability $N_{i,t}$			0.595***	0.586***	0.549***	0.585***
			(0.0210)	(0.0320)	(0.0296)	(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	0.723	0.729	0.970	0.405	0.348	0.970
Clusters	1588	1588	1438	1438	1438	1438
CD F-Stat				107.5	119.7	
KP F-Stat				21.65	23.43	

Notes: Columns 1 and 2 of Table 2 report estimates of α_1 and α_2 in equation (18) using alternative complexity measures recovered from the maximum likelihood estimation of equation (22) to construct both average complexity and the instrumental variables. Columns 3–6 report estimates of β and ϕ in equation (17), 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 $S_{i,t}$ 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.

B.8.2 Sensitivity using Alternative Measures of Capability and Complexity

Table B.6: Changes in Capability and Industrial Structure Using Alternative Capability and Complexity Measures: Sensitivity (I)

	Country Capability $N_{i,t+\Delta}$				
	(1)	(2)	(3)	(4)	(5)
	Baseline	Feenstra Dataset	All Length Panels	No Size Threshold	High Size Threshold
Average Complexity $S_{i,t}$	-0.390**	-0.223	-0.488**	-0.398**	-0.458**
	(0.196)	(0.227)	(0.205)	(0.201)	(0.192)
Initial Capability $N_{i,t}$	0.549***	0.567***	0.491***	0.543***	0.546***
	(0.0296)	(0.0291)	(0.0296)	(0.0298)	(0.0345)
Country and year FEs	Yes	Yes	Yes	Yes	Yes
Observations	6,872	6,864	7,905	6,995	5,986
R-squared	0.348	0.383	0.261	0.333	0.371
Clusters	1438	1438	1673	1466	1249
CD F-Stat	119.7	96.88	122.9	113.3	97.36
KP F-Stat	23.43	18.75	24.17	22.98	21.37

Notes: Table B.6 reports estimates of β and ϕ in equation (17) using alternative capability and complexity measures recovered from the maximum likelihood estimation of equation (22). All columns use the two-instrument IV strategy. Column 1 reports our baseline estimates (column 3 of Table B.5). 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 threshold value of total exports required to be included in our sample. Column 5 raises the threshold value of total exports required to be included in our sample from 100 million to 1 billion USD (at 2010 prices). Standard errors clustered at the 5-year-period-country level.

Table B.7: Changes in Capability and Industrial Structure Using Alternative Capability and Complexity Measures: Sensitivity (II)

	Country Capability $N_{i,t+\Delta}$				$GDP_{i,t+\Delta}$
	(1)	(2)	(3)	(4)	(5)
	Baseline	10-year Lag	1 Obs. per 5-year Cluster	IV $N_{i,t}$	
Average Complexity $S_{i,t}$	-0.390**	-0.447	-0.511*	0.213	-0.212***
	(0.196)	(0.280)	(0.302)	(0.215)	(0.0802)
Initial Capability $N_{i,t}$	0.549***	0.283***	0.547***	1.039***	
	(0.0296)	(0.0422)	(0.0469)	(0.202)	
GDP per capita $GDP_{i,t+\Delta}$					0.766***
					(0.0308)
Country and Year FEs	Yes	Yes	Yes	Yes	Yes
Observations	6,872	6,151	1,295	6,195	6,107
R-squared	0.348	0.057	0.284	0.164	0.605
Clusters	1438	723	1295	1303	1269
CD F-Stat	119.7	107.5	20.18	8.123	128.4
KP F-Stat	23.43	21.83	11.73	2.315	26.94

Notes: Table B.7 reports estimates of β and ϕ in equation (17) using alternative capability and complexity measures recovered from the maximum likelihood estimation of equation (22). All columns use the two-instrument IV strategy. Column 1 reports our baseline estimates (column 3 of Table B.5). Column 2 reports the same estimates using 10-year lags. Column 3 uses one observation per 5-year cluster. Column 4 instruments initial capability using lagged-values of the WTO shocks $Z^{I}_{i,t}$ and $Z^{II}_{i,t}$. Column 5 uses GDP per capita instead of capability. 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 5.1, when conducting our counterfactual and welfare analysis, we augment the baseline 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—equations (2)-(5)—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 baseline model of Section 2, the equilibrium consumption of manufacturing goods (previously given by equation 7) 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

$$\sum_j \int \ell^k_{ij,t} dk + L^{NT}_{i,t} = L_{i,t}. \tag{C.7}$$

All other equilibrium conditions—equations 6, 8, 9, 10, and 12—are unchanged.

C.2 Identification of Productivity Draws in Manufacturing Sectors

Let $x^k_{ij,t}$ denote the value of sales by country i to country j in sector k at date t. Equations (6) and (C.3) imply

$$\frac{x^k_{ij,t}}{x^1_{jj,t}} = \frac{(w_{i,t}/A^k_{ij,t})^{1-\sigma}}{(w_{j,t}/A^1_{jj,t})^{1-\sigma}} \frac{(P^k_{j,t})^{\sigma-\epsilon}}{(P^1_{j,t})^{\sigma-\epsilon}}. \tag{C.8}$$

Combined with equation (8), equations (6) and (7) further imply

$$\frac{\sum_i x^k_{ij,t}}{\sum_i x^1_{ij,t}} = \frac{(P^k_{j,t})^{1-\epsilon}}{(P^1_{j,t})^{1-\epsilon}}. \tag{C.9}$$

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

$$\frac{A^k_{ij,t}}{A^1_{jj,t}} = \left(\frac{w_{i,t}}{w_{j,t}}\right) \left(\frac{x^k_{ij,t}}{x^1_{jj,t}}\right)^{\frac{1}{\sigma-1}} \left(\frac{\sum_l x^k_{lj,t}}{\sum_l x^1_{lj,t}}\right)^{\frac{(\sigma-\epsilon)}{(\sigma-1)(\epsilon-1)}}.$$

Under our choice of units of account, $w_{i,t} = 1$ for all i and t. Equation (19) follows.

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

$$E[\pi^k_{i,t}] = 1 - \prod_{j \neq i} \min\{\max\{1 - \pi^k_{ij,t}(N_{i,t}), 0\}, 1\} \equiv \bar{\pi}^k_{i,t}(N_{i,t}), \tag{C.10}$$

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 (15) are between 0 and 1. For the counterfactual dummies $(\pi^k_{i,t})'$ to be consistent with the previous assumptions, we require instead

$$E[(\pi^k_{i,t})'] = 1 - \prod_{j \neq i} \min\{\max\{1 - \pi^k_{ij,t}((N_{i,t})'), 0\}, 1\} = \bar{\pi}^k_{i,t}((N_{i,t})'). \tag{C.11}$$

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

$$(\pi^k_{i,t})' = \begin{cases} \pi^k_{i,t} + (1-\pi^k_{i,t})d^k_{i,t} & \text{if } (N_{i,t})' \geq N_{i,t}, \\ \pi^k_{i,t} + \pi^k_{i,t}(1-d^k_{i,t}) & \text{if } N'_{i,t} < N_{i,t}, \end{cases} \tag{C.12}$$

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.12) 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.12) 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 3, 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	32.38	-27.38	Gambia	52.93	-72.73	Oman	10.31	-4.54
Albania	12.17	-7.24	Germany	2.59	0.00	Pakistan	6.74	-1.67
Algeria	31.60	-11.49	Ghana	24.03	-11.16	Panama	4.62	-0.63
Angola	20.79	-8.58	Greece	5.68	-0.48	Papua New Guinea	39.29	-22.41
Argentina	3.62	-0.37	Greenland	63.58	-60.50	Paraguay	31.60	-20.11
Australia	4.83	-0.08	Guatemala	9.67	-2.42	Peru	13.01	-2.55
Austria	5.74	-0.10	Guyana	29.84	-33.09	Philippines	3.52	-0.52
Bahamas	19.18	-19.08	Honduras	6.32	-3.33	Poland	4.05	-0.11
Bahrain	10.97	-3.72	Hong Kong	9.89	-0.07	Portugal	3.87	-0.14
Bangladesh	6.95	-2.72	Hungary	7.48	-0.19	Qatar	12.24	-3.00
Barbados	12.10	-8.18	Iceland	16.78	-8.05	Romania	3.20	-0.21
Belgium-Luxembourg	3.30	-0.03	India	2.00	-0.09	Rwanda	47.50	-48.10
Belize	31.25	-33.28	Indonesia	3.04	-0.15	Saudi Arabia	14.84	-1.24
Benin	31.88	-28.57	Ireland	3.52	-0.01	Senegal	10.75	-6.55
Bermuda	23.13	-38.58	Israel	1.53	-0.20	Seychelles	22.93	1.05
Bolivia	28.98	-17.50	Italy	1.67	-0.02	Singapore	8.55	-0.04
Brazil	1.83	-0.10	Jamaica	23.75	-16.98	South Africa	3.12	-0.40
Bulgaria	8.45	-0.84	Japan	0.58	0.00	South Korea	1.61	-0.02
Burkina Faso	40.00	-32.71	Jordan	9.36	-4.12	Spain	2.00	-0.02
Burundi	47.89	10.30	Kiribati	29.28	0.02	Sri Lanka	8.20	-2.98
Cambodia	10.37	-0.70	Lebanon	13.14	-4.00	Sudan	41.95	-29.58
Cameroon	27.30	-17.36	Macao	11.23	-2.47	Suriname	37.60	-20.57
Canada	4.34	-0.04	Madagascar	15.25	-13.72	Sweden	4.09	0.00
Central African Republic	14.90	-38.38	Malawi	29.84	-22.09	Switzerland	2.91	0.00
Chile	17.55	-2.55	Malaysia	4.12	-0.10	Tanzania	23.33	-13.33
China	0.63	0.00	Mali	32.83	-4.93	Thailand	6.19	-0.17
Colombia	5.59	-1.05	Malta	8.54	-0.89	Togo	10.91	-12.61
Congo - Brazzaville	36.98	-17.15	Mauritania	43.51	2.31	Trinidad & Tobago	5.82	-2.91
Costa Rica	2.08	-0.28	Mauritius	9.28	-4.68	Tunisia	9.31	-2.31
Côte d'Ivoire	19.41	-10.81	Mexico	3.97	-0.07	Turkey	4.21	-0.16
Cyprus	3.44	-1.01	Morocco	10.75	-2.41	Uganda	22.80	-14.21
Denmark	3.43	0.00	Mozambique	30.50	-21.68	UK	2.78	-0.03
Dominican Republic	10.09	-4.64	Nepal	26.13	-21.31	United Arab Emirate	8.19	-0.05
Ecuador	15.60	-4.85	Netherlands	2.63	-0.06	Uruguay	9.53	-3.87
Egypt	9.29	-1.66	New Caledonia	18.60	-15.18	US	1.47	0.00
El Salvador	6.67	-2.29	New Zealand	6.28	-0.49	Venezuela	27.54	-11.34
Ethiopia	39.69	-27.87	Nicaragua	10.80	-6.90	Vietnam	4.24	-0.40
Fiji	29.01	-29.81	Niger	36.39	-30.69	Yemen	39.08	-23.10
Finland	3.33	-0.21	Nigeria	30.96	-12.52	Zambia	27.03	-16.70
France	2.69	-0.01	Norway	4.79	-0.21	Zimbabwe	18.90	-10.14

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.

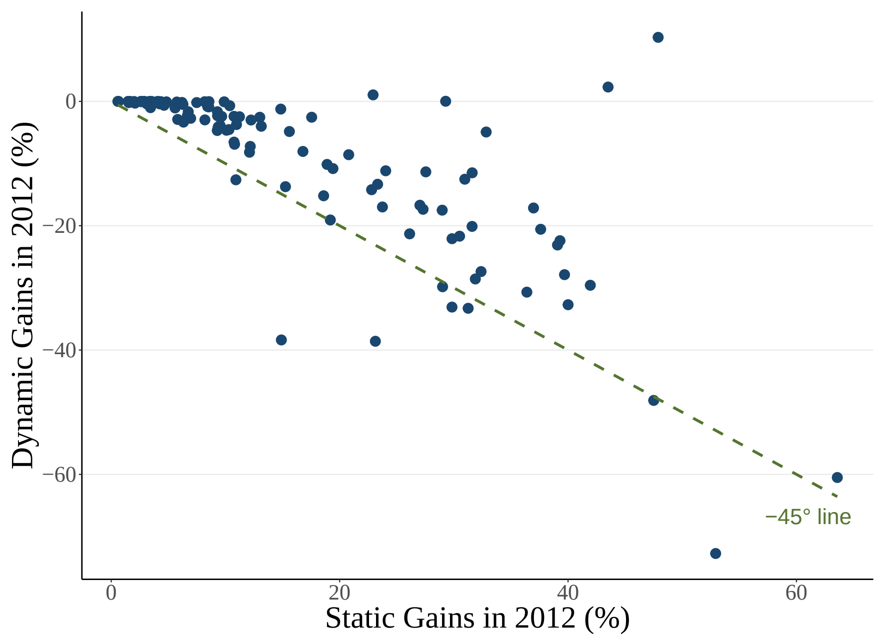


Figure C.1: Dynamic Gains vs. Static Gains from Trade

Notes: Figure C.1 reports reports the dynamic gains from trade, $GT^D_{i,t}$, as described in equation (21), in 2012 against the static gains from trade, $GT^S_{i,t}$, as described in equation (20), in the same year.

C.4.2 Dynamic Gains from Trade versus GDP per Capita

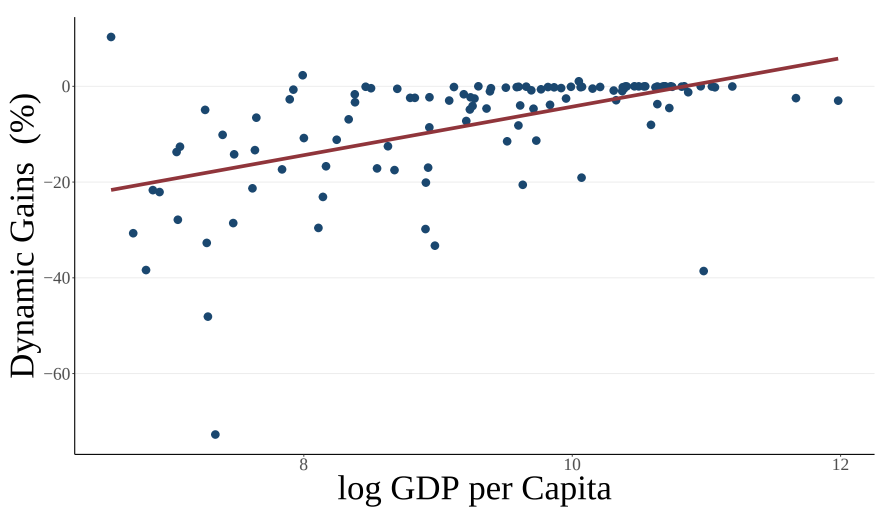
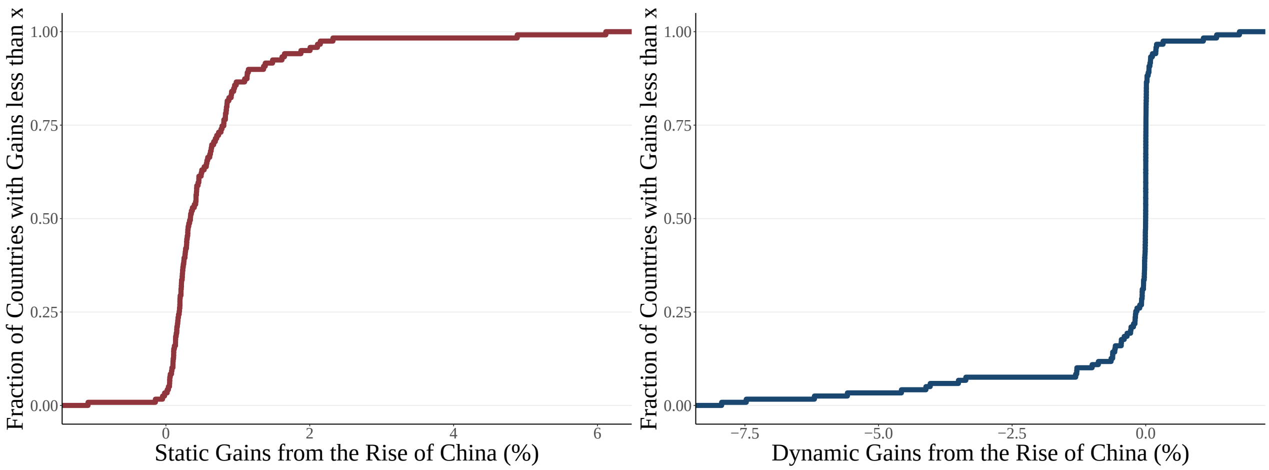


Figure C.2: Dynamic Gains vs. GDP per Capita

Notes: Figure C.2 reports reports the dynamic gains from trade, $GT^D_{i,t}$, as described in equation (21), in 2012 against log GDP per Capita in 2012. The solid line is the line of best fit (slope = 5.06, s.e. = 0.78).

C.4.3 Welfare Consequences of the Rise of China



(a) Distribution of the Static Gains

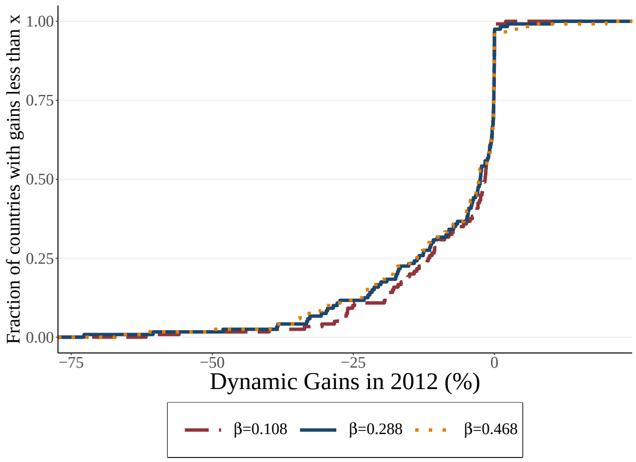
(b) Distribution of the Dynamic Gains

Figure C.3: Welfare Consequences of the Rise of China

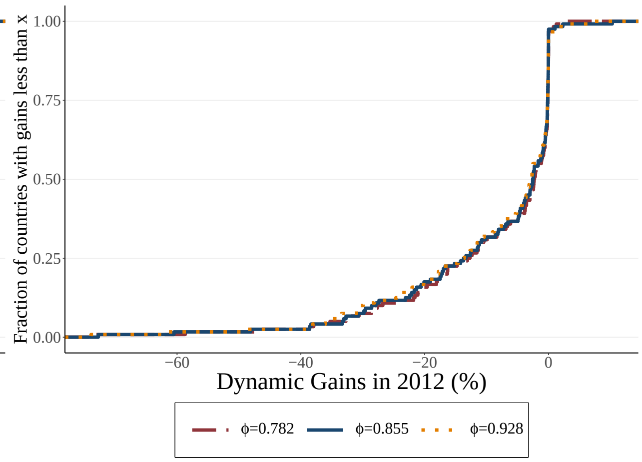
Notes: Figure C.3a reports the distribution of the static gains from China's trade, as described in Section 5.4, in 2012. Figure C.3b reports the distribution of the dynamic gains from trade, $GT^{D}_{i,t}$, as described in Section 5.4, for the same countries and year.

C.5 Robustness

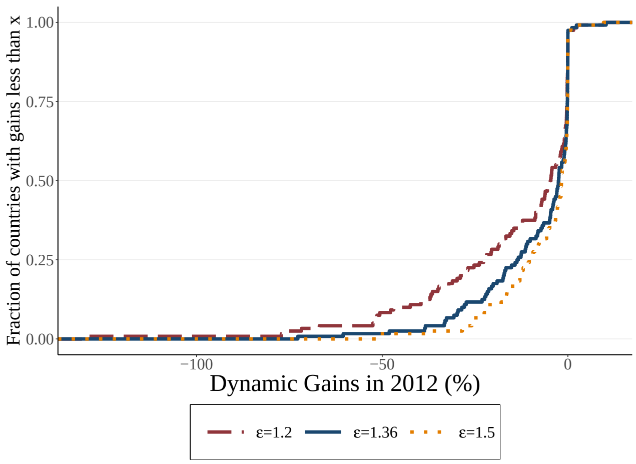
C.5.1 Sensitivity to Alternative Parameter Values



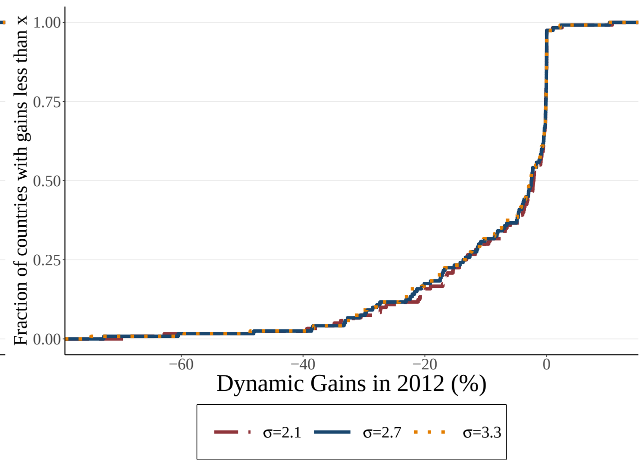
(a) Spillover Parameter, β



(b) Persistence Parameter, ϕ



(c) Upper-Level Elasticity of Substitution, ϵ

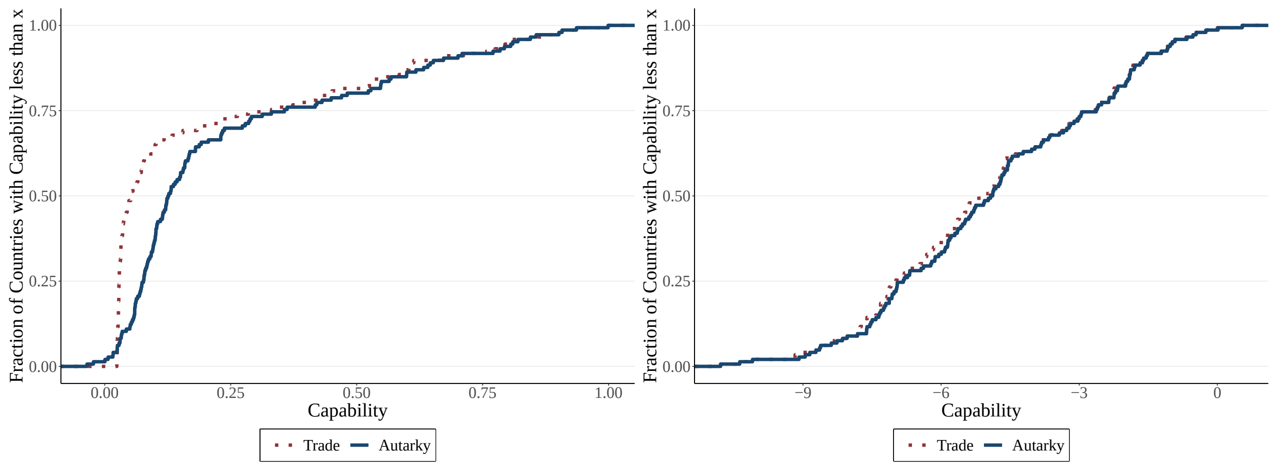


(d) Lower-Level Elasticity of Substitution, σ

Figure C.4: Welfare Consequences of International Trade under Alternative Parameter Values

Notes: Figure C.4a and C.4b are 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. Figure C.4c and C.4d are counterparts of Figure 5b where we vary the upper- and lower-level elasticities of substitution, ϵ and σ, respectively. We consider the parameter values of $\epsilon \in \{1.2, 1.36, 1.5\}$ and $\sigma \in \{2.1, 2.7, 3.3\}$.

C.5.2 Alternative Measures of Capability and Complexity



(a) Distribution of Capability in Baseline Model

(b) Distribution of Capability with Alternative Measures of Capability and Complexity

Figure C.5: Distribution of Capability

Notes: Figure C.5a reports the distribution of capability in the trade and autarkic equilibria in our baseline model. Figure C.5b reports the counterpart of Figure C.5a when capability and complexity are estimated using equation (22).

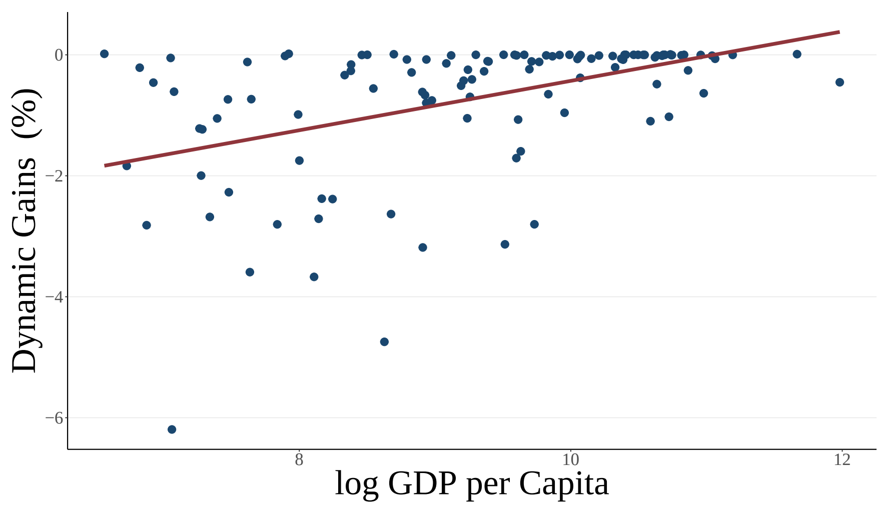
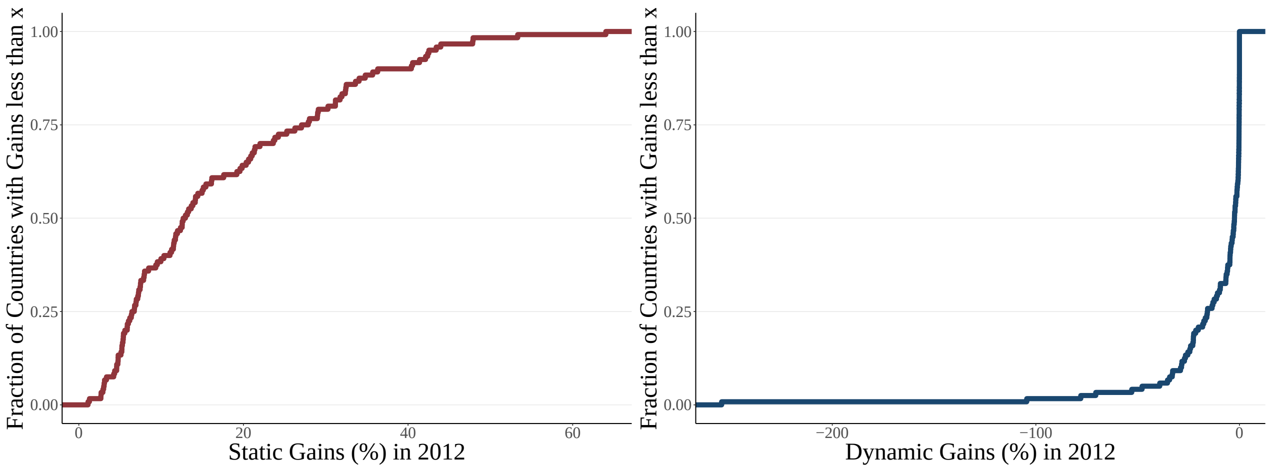


Figure C.6: Dynamic Gains from Trade vs. GDP per Capita

Notes: Figure C.6 is the counterpart of Figure C.2 when capability and complexity are estimated using equation (22). The solid line is the line of best fit (slope = 0.41, s.e. = 0.07).

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 with 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).

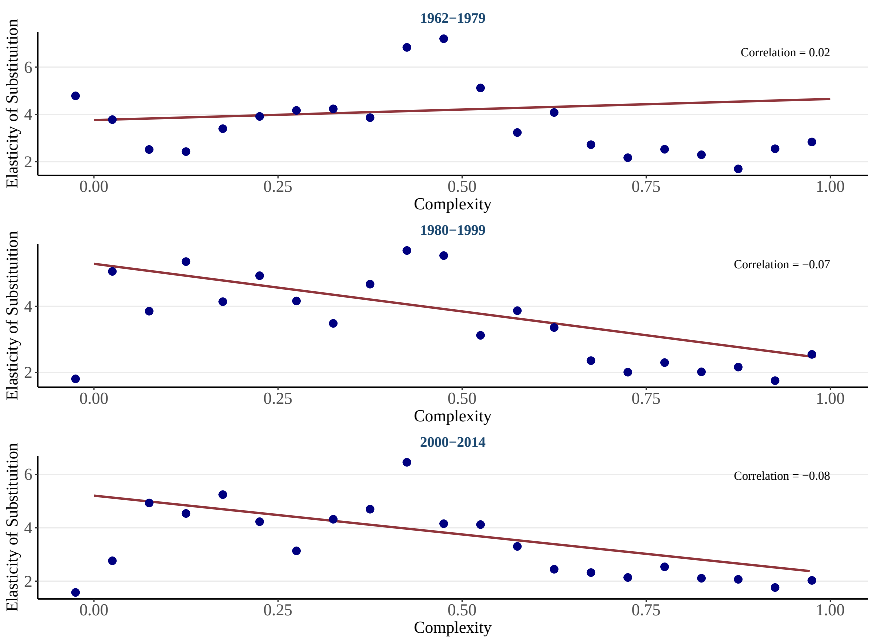


Figure C.8: Elasticity of Substitution and Complexity

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,

$$q_{ij,t}^{k} = A_{ij,t}^{k} (\ell_{ij,t}^{k} / \gamma_{i,t}^{s})^{\gamma_{i,t}^{s}} \prod_{r \in S} (M_{ij,t}^{rk} / \gamma_{i,t}^{rs})^{\gamma_{i,t}^{rs}}, \tag{C.13}$$

$$M_{ij,t}^{rk} = \int_{l \in K_r} (m_{ij,t}^{lk})^{(\epsilon-1)/\epsilon} dl)^{\epsilon/(\epsilon-1)}, \tag{C.14}$$

$$m_{ij,t}^{lk} = (\sum_{o} (m_{oij,t}^{lk})^{(\sigma-1)/\sigma})^{\sigma/(\sigma-1)}, \tag{C.15}$$

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,

$$Q_{i,t}^{NT} = A_{i,t}^{NT} (L_{i,t}^{NT} / \gamma_{i,t}^{NT})^{\gamma_{i,t}^{NT}} \prod_{r \in S} (M_{i,t}^{rNT} / \gamma_{i,t}^{rNT})^{\gamma_{i,t}^{rNT}} \tag{C.16}$$

$$M_{i,t}^{rNT} = \int_{l \in K_r} (m_{i,t}^{lNT})^{(\epsilon-1)/\epsilon} dl)^{\epsilon/(\epsilon-1)}, \tag{C.17}$$

$$m_{i,t}^{lNT} = (\sum_{o} (m_{oi,t}^{lNT})^{(\sigma-1)/\sigma})^{\sigma/(\sigma-1)}. \tag{C.18}$$

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

$$\dot{N}_{i,t} = H_{i,t}(N_{i,t}, F_{i,t}^{q}), \tag{C.19}$$

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

$$F_{i,t}^{q}(n) = \frac{\sum_j \int_{0 \leq n^k \leq n} p_{ij,t}^{k} q_{ij,t}^{k} dk}{\sum_j \int p_{ij,t}^{k} q_{ij,t}^{k} dk} \text{ for all } n \geq 0. \tag{C.20}$$

This guarantees that the empirical analysis of Section (4) 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

$$w_{i,t}\ell^k_{ij,t} = \gamma^s_{i,t} p^k_{ij,t} q^k_{ij,t}, \text{ for all } k \in K_s \text{ and } s \neq NT, \tag{C.21}$$

$$p^l_{oi,t} m^{lk}_{oij,t} = \frac{(p^l_{oi,t})^{1-\sigma}}{\sum_{o'}(p^l_{o'i,t})^{1-\sigma}} \frac{(P^l_{i,t})^{1-\epsilon}}{\sum_{l'\in K_r}(P^{l'}_{i,t})^{1-\epsilon}} \times \gamma^{rs}_{i,t} p^k_{ij,t} q^k_{ij,t}, \text{ for all } l \in K_r,\ k \in K_s, \text{ and } s \neq NT, \tag{C.22}$$

$$w_{i,t} L^{NT}_{ij,t} = \gamma^{NT}_{i,t} P^{NT}_{i,t} Q^{NT}_{i,t}, \tag{C.23}$$

$$p^l_{oi,t} m^{lNT}_{oi,t} = \frac{(p^l_{oi,t})^{1-\sigma}}{\sum_{o'}(p^l_{o'i,t})^{1-\sigma}} \frac{(P^l_{i,t})^{1-\epsilon}}{\sum_{l'\in K_r}(P^{l'}_{i,t})^{1-\epsilon}} \times \gamma^{rNT}_{i,t} P^{NT}_{i,t} Q^{NT}_{i,t}, \text{ for all } l \in K_r,\ k \in K_s, \text{ and } s \neq NT. \tag{C.24}$$

In turn, the zero-profit conditions (previously given by equations 6 and C.5) are now given byX

$$p^k_{ij,t} = [(w_{i,t})^{\gamma^s_{i,t}} \prod_{r\in S} (\mathcal{P}^r_{i,t})^{\gamma^{rs}_{i,t}}] / A^k_{ij,t}, \text{ for all } k \in K_s \text{ and } s \neq NT, \tag{C.25}$$

$$P^{NT}_{i,t} = [(w_{i,t})^{\gamma^{NT}_{i,t}} \prod_{r\in S} (\mathcal{P}^r_{i,t})^{\gamma^{rNT}_{i,t}}] / A^{NT}_{i,t}, \tag{C.26}$$

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

$$\mathcal{P}^r_{i,t} = \left(\int_{k\in K_r} (P^k_{i,t})^{1-\epsilon} dk \right)^{\frac{1}{1-\epsilon}}, \text{ for all } r \neq NT, \tag{C.27}$$

$$P^k_{i,t} = (\sum_j (p^k_{ji,t})^{1-\sigma})^{1/(1-\sigma)}, \text{ for all } k \in K_r \text{ and } r \neq NT, \tag{C.28}$$

$$\mathcal{P}^{NT}_{i,t} = P^{NT}_{i,t}. \tag{C.29}$$

Finally, the good market clearing conditions (previously given by equation 10 and C.6) now requires

$$c^k_{ij,t} + \sum_d \sum_{s\in S} \sum_{l\in K_s} m^{kl}_{ijd,t} = q^k_{ij,t}, \tag{C.30}$$

$$C^{NT}_{i,t} + \sum_d \sum_{s\in S} \sum_{l\in K_s} m^{NTl}_{iid,t} = Q^{NT}_{i,t}, \tag{C.31}$$

with gross-output $q^k_{ij,t}$ and $Q^{NT}_{i,t}$' given by equations (C.13)-(C.15) and (C.16)-(C.18), respectively.

A competitive equilibrium in the environment with input-output linkages corresponds to capabilities, $\{N_{i,t}\}$, wages, $\{w_{i,t}\}$, good prices, $\{p^k_{ij,t}, P^k_{j,t}, \mathcal{P}^s_{j,t}, P_{j,t}\}$, interest rates, $\{r_{i,t}\}$, consumption levels, $\{c^k_{ij,t}, C^k_{j,t}, C^M_{j,t}, C^{NT}_{j,t}, C_{j,t}\}$, input levels, $\{m^{lk}_{oij,t}, m^{lk}_{ij,t}, M^{sk}_{ij,t}, m^{lNT}_{oi,t}, m^{lNT}_{i,t}, M^{sNT}_{i,t}\}$, employment levels, $\{\ell^k_{ij,t}\}$, gross output levels, $\{q^k_{ij,t}, Q^{NT}_{i,t}\}$, and gross output distributions, $\{F^q_{i,t}\}$, such that equations (12), (C.1)-(C.4), C.7, and C.13-C.31 hold.

Calibration of Preferences, Technology, and Labor Endowments. We calibrate preferences in the same way as in the baseline economy of Section 5.1. We set the elasticities of substitution such that $\epsilon = 1.36$ and $\sigma = 2.7$, as described in Table 3, 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.22) and (C.24). 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 5.1, 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.22), (C.25), and (C.28) and using the normalization, $w_{i,t} = w_{j,t} = 1$, we obtain

$$\frac{A_{ij,t}^{k}}{A_{jj,t}^{1}} = \frac{\prod_{r \in S} (\mathcal{P}_{i,t}^{r})^{\gamma_{i,t}^{rs}}}{\prod_{r \in S} (\mathcal{P}_{j,t}^{r})^{\gamma_{j,t}^{r1}}} \left(\frac{x_{ij,t}^{k}}{x_{jj,t}^{1}} \right)^{\frac{1}{\sigma - 1}} \left(\frac{x_{j,t}^{k}}{x_{j,t}^{1}} \right)^{\frac{\sigma - \epsilon}{(\epsilon - 1)(\sigma - 1)}} \left(\frac{X_{j,t}^{1}}{X_{j,t}^{s}} \frac{D_{j,t}^{s}}{D_{j,t}^{1}} \right)^{\frac{1}{\epsilon - 1}}, \tag{C.32}$$

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.

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[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.

Like in Section 5.1, we normalize productivity such that $A^1_{jj,t} = A^{NT}_{j,t} = 1$ both in the autarkic and trade equilibria, for all j and t. This second normalization implies $\mathcal{P}^{NT}_{i,t} = P^{NT}_{i,t} = 1$. Using equations (C.25), (C.27), (C.28), and (C.32), we can then solve for the cost of intermediates, $\prod_{r\in S}(\mathcal{P}^r_{j,t})^{\gamma^{r1}_{j,t}}$ and $\prod_{r\in S}(\mathcal{P}^r_{i,t})^{\gamma^{rs}_{i,t}}$,

$$\prod_{r\in S}(\mathcal{P}^r_{j,t})^{\gamma^{r1}_{i,t}} = \prod_{r\neq NT}\left\{\int_{k\in K_r}\left[\sum_i\left(\frac{x^k_{ij,t}}{x^1_{jj,t}}\right)\left(\frac{x^k_{j,t}}{x^1_{j,t}}\right)^{\frac{\sigma-\epsilon}{\epsilon-1}}\left(\frac{X^1_{j,t}}{X^r_{j,t}}\frac{D^r_{j,t}}{D^1_{j,t}}\right)^{\frac{\sigma-1}{\epsilon-1}}\right]^{\frac{\epsilon-1}{\sigma-1}} dk\right\}^{\frac{\gamma^{r1}_{i,t}}{(1-\epsilon)\gamma^1_{i,t}}}, \tag{C.33}$$

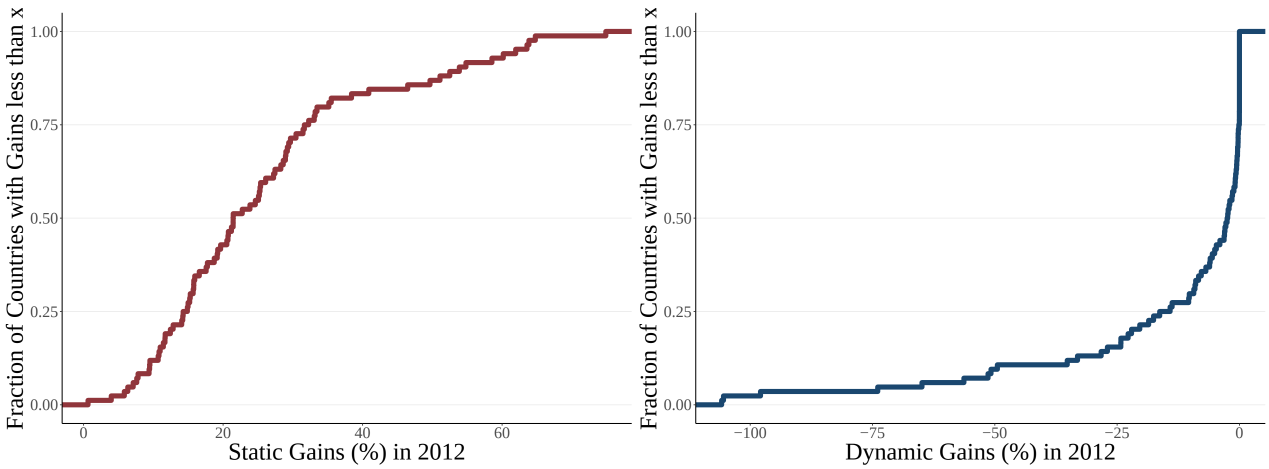
$$\prod_{r\in S}(\mathcal{P}^r_{i,t})^{\gamma^{rs}_{i,t}} = \prod_{r\neq NT}\left\{\int_{k\in K_r}\left[\sum_i\left(\frac{x^k_{ij,t}}{x^1_{jj,t}}\right)\left(\frac{x^k_{j,t}}{x^1_{j,t}}\right)^{\frac{\sigma-\epsilon}{\epsilon-1}}\left(\frac{X^1_{j,t}}{X^r_{j,t}}\frac{D^r_{j,t}}{D^1_{j,t}}\right)^{\frac{\sigma-1}{\epsilon-1}}\right]^{\frac{\epsilon-1}{\sigma-1}}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

From equations (C.32)-(C.34), 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 5.1 and set $\beta = 0.288$ and $\phi = 0.855$, as described in Table 3. The rest of our counterfactual analysis proceeds exactly as in Section 5.2 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 with 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.