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A Portrait of Trade in Value Added over Four Decades*

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Abstract

We combine data on trade, production, and input use to document five facts about changes in the value added content of trade from 1970 to 2009. We find that the ratio of value-added to gross exports fell by roughly 10 percentage points worldwide [Fact 1]. Across sectors, the ratio declined nearly 20 percentage points in manufacturing, but rose in non-manufacturing sectors [Fact 2]. Across countries, declines range from 0 to 25 percentage points, with fast growing countries seeing larger declines [Fact 3]. Across bilateral partners, declines are larger for nearby partners [Fact 4] and partners that adopt regional trade agreements [Fact 5]. What driving forces underlie these changes? Using a multi-sector structural gravity model with input-output linkages, we show that changes in trade frictions play a dominant role in explaining all five facts.

JEL Codes: F1, F4, F6

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Recent decades have seen the emergence of global supply chains. Echoing Feenstra (1998), rising trade integration has coincided with the simultaneous disintegration of production across borders.[1] As inputs pass through these global supply chains, they typically cross borders multiple times. Since the national accounts record gross shipments across the border, not the locations at which value is added at different stages of the production process, conventional trade data obscure how value added – and the primary factors embodied therein – is traded in the global economy. This means that gross trade data alone are not sufficient to isolate the causes or interpret the consequences of the massive changes in the global economy that have occurred in recent decades. We need to pierce the veil of the gross flows to analyze changes in trade in value added directly.

This paper computes and analyzes the value added content of trade over the last four decades (1970-2009). In doing so, we make three contributions. First, we provide long horizon measures of value-added trade for a wide cross section of countries. Second, we document five stylized facts about changes in value-added and gross trade at the world, country, and bilateral level over time. We show that the value added content of trade has declined for the world as a whole, that there is substantial heterogeneity in declines across countries, and that regional trade agreements lower value-added relative to gross trade. Third, we use a trade model with input-output linkages across sectors and countries to quantify the role of international trade frictions in explaining the divergence between value-added and gross trade over time. We show that changes in trade frictions, particularly frictions for manufactured inputs, play a key role in explaining all five stylized facts.

To track value-added trade over time, we combine time series data on trade, production, and input use to construct an annual sequence of global bilateral input-output tables covering forty-two countries back to 1970. These synthetic tables track shipments of final and intermediate goods both within and between countries. Using this framework, we compute value-added exports: the amount of value added from a given source country that is

[1] This theme is reflected in work on vertical specialization, offshoring, and global value chains [Feenstra and Hanson (1999), Yi (2003, 2010), Grossman and Rossi-Hansberg (2008), Antràs (2016)].

consumed in each destination (i.e., embodied in final goods absorbed in that destination) [Johnson and Noguera (2012*a*)]. Value-added exports measure international transactions in a manner consistent with commonly used value-added representations of production and preferences.[2] They differ from gross exports for several distinct reasons: exports are typically produced using imported inputs, some exported inputs return home embodied in imports, and exported inputs often are processed in third countries before being shipped onto their final destination.

This data work builds on and extends an active literature on global input-output accounting and trade in value added.[3] Our data construction effort is distinguished from this related work in that we provide a long historical perspective on the rise of global supply chains, with broad country scope. In this, our work extends the pioneering long run analysis of vertical specialization by Hummels, Ishii and Yi (2001), who measured the import content of exports for ten OECD countries from 1970 to 1990.[4] The data that we compile span a period of major structural changes in the global economy, including the rise of emerging markets, the (re-)integration of Europe, and the spread of regional trade agreements. The long panel dimension of our data is essential to credibly identify the impact of these events.

We summarize the most significant changes in value-added versus gross trade via five stylized facts. The first fact is that the ratio of value-added to gross exports is declining over time, by about ten percentage points over four decades [Fact 1]. Consistent with anecdotal evidence, this decline has accelerated over time: the ratio of value-added to gross exports has fallen roughly three times as fast since 1990 as it did from 1970 to 1990. This global decline masks significant heterogeneity across sectors, countries, and bilateral partners. Across sectors, the ratio of value-added to gross exports has fallen by almost twenty percentage

[2]On the production side, value-added exports are explicitly comparable to GDP. On the demand side, value-added imports equal final expenditure on value added from foreign sources, regardless of whether that value-added is embodied in domestic or imported final goods.

[3]See Daudin, Rifflart and Schweisguth (2011), Johnson and Noguera (2012*a*), Johnson (2014), Timmer et al. (2014), Koopman, Wang and Wei (2014), Los, Timmer and de Vries (2015), and Kee and Tang (2016).

[4]It also complements related data sets, such as the World Input-Output Database, which cover the post-1995 period only.

points within manufacturing, but has risen outside manufacturing [Fact 2]. Across countries, declines in value-added to gross exports range from near zero to over twenty-five percentage points, and fast growing countries have seen larger declines on average [Fact 3].

Across bilateral partners, we show that both bilateral distance and adoption of bilateral trade agreements predict changes in value-added to gross export ratios. In the time series, distance is negatively correlated with changes in the bilateral ratio of value-added to gross exports, so that the largest declines in value-added to export ratios are concentrated among proximate trading partners [Fact 4]. We also find that adoption of regional trade agreements (RTAs) is associated with declines in the ratio of bilateral value-added to gross exports [Fact 5]. For a typical agreement, the ratio of value-added to gross trade falls by five to eleven percent. Further, deep trade agreements (e.g., customs unions or common markets) are associated with larger declines in value-added to export ratios than shallow agreements.[5]

To isolate the driving forces underlying these changes, we interpret the five facts through the lens of the workhorse structural gravity model, augmented to include input-output linkages across sectors and countries.[6] There are two steps in this analysis. First, we use our global input-output data, together with auxiliary data on prices of real value added and final expenditure, to measure changes international trade frictions and sectoral expenditure weights for final goods and inputs. Conditional on prices, the trade frictions influence bilateral sourcing decisions for final goods and intermediate inputs, the final and input expenditure weights govern the allocation of final and inputs expenditure across sectors.

Second, we analyze counterfactual model simulations to evaluate the role of trade frictions in explaining changes in value-added versus gross trade.[7] We show that declines in trade

[5]These findings contribute to an important literature on the impact of RTAs [Freund and Ornelas (2010)]. Despite the fact that many agreements were explicitly adopted to promote integration of supply chains across borders, existing evidence on whether or how they have done so is scarce.

[6]Our model shares many similarities with recent multi-sector Ricardian models, which incorporate trade in both final and intermediate inputs [Caliendo and Parro (2015), Levchenko and Zhang (2016), Eaton et al. (forthcoming)]. Though we rely on Armington rather than Ricardian micro-foundations for trade, the aggregate response of value-added trade to frictions would be similar in both models. In contrast to recent Ricardian models, we allow differences in trade costs for final and intermediate goods to match imports of final and intermediate goods separately within each sector.

[7]Our long horizon analysis complements Eaton et al. (forthcoming), who examine high frequency (business

frictions over time play an important role in explaining all five stylized facts highlighted above. Changes in other driving forces – including changes in productivity, factor supplies, and sectoral expenditure weights – play a comparatively minor role. Among trade frictions, declines in frictions for manufacturing goods, particularly manufactured inputs, are most important for matching the data. We also show that declines in bilateral trade frictions associated with RTA adoption explain changes in bilateral value-added to export ratios. Moreover, the spread of RTAs over time can account for up to 15% of the global decline in ratio of value-added to gross trade.

The paper proceeds as follows. Section 1 outlines the procedure and data we use to measure value-added exports. Section 2 documents five stylized facts about differences between gross and value-added exports. Section 3 presents the model, our quantification procedures, and results on the role of trade frictions versus other forces in accounting for the five facts. We analyze the role of trade frictions in detail in Section 4. Section 5 concludes.

1 Measuring Value-Added Exports Through Time

We begin by laying out the global input-output framework and procedure for computing value-added exports, drawing on Johnson and Noguera (2012*a*). We then briefly discuss how we combine sector-level production, input use, and trade data to implement the calculations, with details provided in the Online Appendix.

1.1 Computing Value-Added Exports

Consider a world with N countries and S sectors at date t. Output in each sector and country is produced using domestic primary factors (capital, labor, etc.) and intermediate inputs, which may be sourced from home or abroad. Output is tradable in all sectors, and it may be used to satisfy final demand (consumption, investment, and government expenditure) or

cycle) variation in trade frictions. Our results on the impact of regional trade agreements also complement Caliendo and Parro (2015), who study North American integration.

used as an intermediate input at home or abroad. The market clearing condition for gross output produced by sector s in country i can be written as:

$$y_{it}(s) = \sum_j f_{ijt}(s) + \sum_j \sum_{s'} m_{ijt}(s, s'), \tag{1}$$

where $y_{it}(s)$ is the value of output in sector s of country i, $f_{ijt}(s)$ is the value of final goods shipped from sector s in country i to country j, and $m_{ijt}(s, s')$ is the value of intermediates from sector s in country i used by sector s' in country j.[8]

These market clearing conditions can be stacked to form the global input-output system. We collect the total value of production in each sector in the $S \times 1$ vector $\mathbf{y}_{it}$ and shipments of final goods from i to country j into $S \times 1$ vectors $\mathbf{f}_{ijt}$. Further, shipments of intermediate inputs from i to country j are $\mathbf{A}_{ijt}\mathbf{y}_{jt}$, where $\mathbf{A}_{ijt}$ is an $S \times S$ matrix with elements $A_{ijt}(s, s') = m_{ijt}(s, s')/y_{jt}(s')$. The $S \times N$ market clearing conditions can then we written concisely as:

$$\mathbf{y}_t = (\mathbf{I} - \mathbf{A}_t)^{-1}\mathbf{f}_t, \tag{2}$$

where $\mathbf{A}_t$ is a block matrix with elements $\mathbf{A}_{ijt}$, $\mathbf{y}_t$ is a block vector with elements $\mathbf{y}_{it}$, and $\mathbf{f}_t$ is a block vector with elements $\sum_j \mathbf{f}_{ijt}$. The matrix $(\mathbf{I} - \mathbf{A}_t)^{-1}$ is the Leontief Inverse of the global input-output matrix: the product of the Leontief Inverse with any vector of final goods returns the value of output from each country and sector that is required to produce those final goods.

To compute value-added exports, we split $\mathbf{f}_t$ into destination specific vectors $\tilde{\mathbf{f}}_{jt}$, where $\tilde{\mathbf{f}}_{jt}$ is the $(SN \times 1)$ vector of final goods absorbed in country j. Then $(\mathbf{I} - \mathbf{A}_t)^{-1}\tilde{\mathbf{f}}_{jt}$ is the vector of output used directly and indirectly to produce final goods absorbed in country j. The $S \times 1$ block elements of $(\mathbf{I} - \mathbf{A}_t)^{-1}\tilde{\mathbf{f}}_{jt}$ – which we now denote $\mathbf{y}_{ijt}$ – record the output from i used to produce final goods absorbed in j.

[8] In the data we use, we observe only the value of cross-border transactions, not quantities shipped. Since markets implicitly clear in quantities, this means we are evaluating the underlying quantity flows at a common set of prices to ensure that revenue for producers equals the value of expenditure across destinations.

If the ratio of value-added to gross output in sector s of source country i is $r_{it}(s) = 1 - \sum_j \sum_{s'} A_{jit}(s', s)$, then the amount of value added from sector s in country i embodied in final goods absorbed in j is: $va_{ijt}(s) \equiv r_{it}(s) y_{ijt}(s)$, where $y_{ijt}(s)$ is an individual element of $\mathbf{y}_{ijt}$ defined above. We refer to $va_{ijt}(s)$ as value-added exports.

1.2 Data

We combine data from the national accounts, commodity trade statistics, and benchmark input-output tables to construct global input-output tables for each year between 1970 and 2009. We include forty-two OECD countries and major emerging markets, which account for around 90% of world GDP. Remaining countries are aggregated into a 'rest of the world' composite.[9] We include four composite sectors: (1) agriculture, hunting, forestry, and fishing; (2) non-manufacturing industrial production; (3) manufacturing; and (4) services.

Starting with macro-data on production and expenditure, we take annual GDP by composite sector and GDP by expenditure category (i.e., final expenditure, exports, and imports) from the UN National Accounts Database. Using the share of goods and services in exports/imports from the IMF Balance of Payments statistics, we split exports/imports in the GDP data into goods (sectors (1)-(3) above) and services.

To measure bilateral trade, we use data from the NBER-UN and CEPII BACI Databases. For goods trade, we measure bilateral final and intermediate goods trade separately for each of the three goods sectors. To do this, we assign disaggregated commodity codes in the trade data to either final or intermediate use, based on the mapping from commodities to national accounts end uses defined in the Broad Economic Categories (BEC) system. We then aggregate commodities to match the composite sector definitions, using correspondences between commodity and industry classifications. The result is a sector-level data set of cross-country final and intermediate goods shipments from 1970 to the present.

[9] The countries in our sample (listed in the Online Appendix) account for roughly 80% of world GDP and 70-80% of world trade in the 1970-1990 period, rising to over 90% of GDP and 80-90% of world trade after 1990. Due to lack of data, we include the Czech Republic, Estonia, Russia, Slovakia, and Slovenia in the rest of the world during 1970's and 1980's.

We turn to input-output tables for additional information on input use and sector-level final expenditure. We take data for benchmark years from the OECD Input-Output Database and IDE-JETRO Asian Input-Output Tables. Input-output tables are available for all forty-two countries after 1995, for Asian countries from 1985, and ten major industrialized countries (the G7 plus Australia, Denmark, and the Netherlands) from the 1970's.

In combining these data, we face two challenges. First, there are discrepancies across alternative data sources, both due to differences in definitions and measurement error. Second, whereas the national accounts and trade data are annual, the input-output tables are produced for benchmark years only, which are asynchronous across countries. To resolve these issues, we prioritize the national accounts data and adjust the commodity trade data in order to match the levels of aggregate trade in the national accounts. We then use a constrained least squares procedure to simultaneously adjust the input-output data to match the annual production and trade data and extrapolate benchmark data to non-benchmark years.

The result is a sector-level data set containing gross output ($\mathbf{y}_{it}$), value-added to output ratios ($r_{it}(s)$), final demand for domestic and imported goods ($\mathbf{f}_{iit}$ and $\mathbf{f}_{Iit}$), and domestic and imported input use matrices ($\mathbf{A}_{iit}$ and $\mathbf{A}_{Iit}$) for forty-two countries.[10] For goods imports ($s = \{1, 2, 3\}$), we use observed bilateral final and intermediate import shares to split $f_{Iit}(s)$ and $A_{Iit}(s, s')$ across sources. For the services sector, we apply a proportionality assumption; we assume that bilateral import shares for final and intermediate services are the same and equal to the share of each partner in multilateral services imports.

[10]Because we do not have production or input-output data for countries in the rest of the world, we assume that all exports from the forty-two countries in our data to the rest of the world are absorbed there. This assumption has little practical effect on measured value-added exports among countries in the sample [Johnson and Noguera (2012*b*)].

2 Changes in Value-Added vs. Gross Exports

Using the framework and data introduced above, we document five stylized time-series facts regarding changes the ratio of value-added to gross exports over time. We start at the multilateral level, documenting changes at the world, sector, and country level. We then examine how proxies for bilateral trade frictions have shaped changes in bilateral value-added versus gross exports. These serve as focal points in the model accounting analysis that follows in Section 3.

2.1 World, Sector, and Country Changes

We start at the global level, plotting the ratio of value-added exports to gross exports for the world as a whole in Figure 1. The ratio of value-added to gross exports declines by 0.08 including the ROW and 0.09 excluding the ROW from 1970-2009. Excluding the 2009 trade collapse, the value-added to export ratio declines by 0.11 including the ROW and by 0.13 excluding the ROW.[11] This decline is spread unevenly over time. During the 1970-1989 interval, there is only a small net decline value added relative to gross exports, on the order of a few percentage points. In contrast, value added relative to gross exports fall rapidly, by 8.5 (9.5 excluding the ROW) percentage points from 1990-2008. The decline in the value-added to export ratio is roughly three times as fast during the 1990-2008 period as during the pre-1990 period.

To drill down, we disaggregate these global trends along two dimensions, into changes in value-added to export ratios at the sector level and across countries. We plot sector-level changes in Figure 2. The headline result is that manufacturing is the only sector in which the value-added to export ratio is falling over time. The ratio is increasing for agriculture and services and stable in non-manufacturing industrial production.[12]

[11]Bems, Johnson and Yi (2010) point to the composition of changes in final expenditure during the 2009 recession to explain why value added rose relative to gross trade. When spending on final goods from sectors with high degrees of vertical specialization (e.g., durable goods) falls, then the ratio of value-added to gross exports rises.

[12]Note that the sector-level value-added to export ratio is not bounded by one. The reason is that each

In Figure 3, we plot changes in value-added to export ratios at the country level. Panel (a) of Figure 3 contains cumulative changes in the ratio of value-added to gross exports from 1970-2008 at the country level. Nearly all countries experienced declines in the ratio of value-added to gross exports, but the magnitude of the decline is heterogeneous across countries. Most experience declines larger than 10 percentage points, though some large and prominent countries (e.g., Japan, the UK, and Brazil) have smaller declines. Among countries with large declines, one sees many emerging markets, but also some important advanced economies (e.g., Germany).

To organize this cross-country variation, we plot the average annual change in the ratio of value-added to gross exports against the average annual growth rate in real GDP in Panel (b) of Figure 3. The correlation is negative and statistically significant at the 1% level. Cumulated over four decades, the point estimate implies that a country at the 90^{th} percentile of the growth distribution (5.8% per year) has a decline in the ratio of roughly 0.21 while a country at the 10^{th} percentile (2.2% per year) has a decline of 0.11. Because emerging markets on average have higher growth than advanced countries, this also reinforces the observation above that gross exports have risen more than value-added exports on average for these countries.

2.2 Bilateral Trade Frictions

Shifting our focus to bilateral country pairs, we describe how changes in bilateral value-added versus gross exports are shaped by bilateral trade frictions. We focus on two common proxies for bilateral frictions: distance and regional trade agreements.

The Differential Burden of Distance We are interested in two main questions. First, how do gross exports (x_{ijt}), value-added exports (va_{ijt}), and value-added to export ratios

sector can export value added directly, embodied in gross exports from the sector, or it can export value added indirectly, embodied in gross exports from other sectors. For example, non-manufacturing inputs are used in production of manufactured goods, and hence non-manufacturing value added is indirectly exported embodied in manufactures.

($VAX_{ijt} \equiv \frac{va_{ijt}}{x_{ijt}}$) respond to bilateral distance? Second, how have these responses changed over time?

To answer these questions, we estimate gravity-style regressions for each of the three variables of interest:

$$\log(y_{ijt}) = \phi^y_{it} + \phi^y_{jt} + \beta^y_t \log(dist_{ij}) + \varepsilon_{ijt}, \tag{3}$$

where $y_{ijt} \in \{x_{ijt}, va_{ijt}, VAX_{ijt}\}$), $\{\phi^y_{it}, \phi^y_{jt}\}$ are importer-year and exporter-year fixed effects and β^y_t is the time-varying coefficient on bilateral distance ($dist_{ij}$) for outcome y. For interpretation, it is useful to note that $\beta^{VAX} = \beta^{va} - \beta^x$ holds by construction, since $\log(VAX_{ijt}) = \log(va_{ijt}) - \log(x_{ijt})$.

The distance coefficients estimated in Equation (3) are plotted in Figure 4.[13] Looking at the left panel, the ratio of value-added to gross exports is higher for more distant markets. This is reflected in the separate distance coefficients for gross versus value-added exports in the right panel. While distance depresses both, gross exports fall more strongly with distance than do value-added exports – i.e., the absolute value of the distance coefficient on gross exports is larger than the coefficient on value-added exports in all years. Further, this differential impact of distance is strengthening over time. The distance coefficient for the value-added to export ratio has risen from under 0.1 to 0.2. The reason is that distance coefficient for gross exports has risen (in absolute value) over time, from roughly 0.9 to 1.1.[14]

[13]Very small bilateral gross trade flows are often lead to extreme value-added to export ratios, which distort the point estimates and muddy inference. These outliers are mostly for emerging markets with low quality data during the 1970-1985 period. We remove them by dropping bilateral flows less than one million dollars and value-added to gross export ratios greater than ten.

[14]In the Online Appendix, we show that changes in these coefficients are robust to adding additional gravity controls (e.g., indicators for common language, border, and colonial origin) and country-pair fixed effects. Further, distance stands out among gravity variables in terms of its ability to explain changes in the value-added to export ratio.

Regional Trade Agreements We now examine how value-added and gross exports respond to the adoption of regional trade agreements.[15]

To demonstrate the main result visually, we take an event study approach. We compare the evolution of the value-added to export ratio for the treatment group of bilateral country pairs that form new RTA's during our sample to outcomes for a pair-specific control group in a window surrounding adoption of the RTA. For country pair (i, j) that forms an RTA, the control series is the bilateral value-added to export ratio for countries i and j vis-à-vis the set of countries with whom both i and j never form an RTA.[16]

We plot the resulting treatment and control series in Figure 5. Prior to RTA adoption, value-added to export ratios are quite similar across the treatment and control groups. There is then a strong divergence between the two, coinciding with adoption of the RTA: for pairs that adopt an RTA, the value-added to export ratio drops sharply around the adoption date and then continues to fall for roughly a decade thereafter. This divergence is prima facie evidence that trade agreements have different effects on gross versus value-added trade.

To formalize these results and control for confounding factors, we turn to panel regressions of the form:

$$\log(y_{ijt}) = \phi^y_{it} + \phi^y_{jt} + \phi^y_{ij} + \beta^y TradeAgreement_{ijt} + \varepsilon^y_{ijt}, \tag{4}$$

where $TradeAgreement_{ijt}$ is a collection of indicators for whether i and j are in a particular trade agreement at time t and ϕ^y_{ij} is a country-pair fixed effect.[17] We consider several different specifications for $TradeAgreement_{ijt}$. The first uses a single indicator for whether countries

[15] We use data on economic integration agreements assembled by Scott Baier and Jeffrey Bergstrand, covering the 1960-2009 period [September 2015 Revision; http://www.nd.edu/~jbergstr/]. Our RTA indicator takes the value one if a country pair has a free trade agreement or stronger.

[16] Formally, define $T_t(i,j) = \frac{va_{ijt}+va_{jit}}{x_{ijt}+x_{jit}}$ to be the bilateral value-added to export ratio for (i,j) pairs in the treatment group. Further, let $K(i,j)$ denote the set of countries with whom both i and j never form an RTA, and define $C_t(i,j) = \sum_{c \in K(i,j)} \frac{(va_{cjt}+va_{jct})+(va_{cit}+va_{ict})}{(x_{cjt}+x_{jct})+(x_{cit}+x_{ict})}$ to be the value-added to export ratio for trade between i and j with the control group. If $t = 0$ is the year of RTA adoption, then we compute $T_t(i,j)$ and $C_t(i,j)$ for $t = [-20, 20]$ for each pair and take an unweighted average of each series across all pairs.

[17] As discussed by Baier and Bergstrand (2007), the pair fixed effect accounts for endogenous adoption of agreements based on time-invariant characteristics of the bilateral pair. In some specifications, we also add a pair-specific linear trend ($\delta^y_{ij}t$), which controls for endogenous adoption based on trending characteristics. These controls also absorb pair-specific levels and trends in unmeasured trade costs.

have an RTA in force, the second distinguishes "shallow" from "deep" agreements, and the third allows for phase-in effects.[18] We estimate this equation using data at five-year intervals from 1970 to 2009 (the 2005-2009 interval is four years).

Table 1 reports the estimation results. We find that adoption of trade agreements lowers value-added relative to gross exports among countries in those agreements. Using the simple binary RTA indicator (RTA_{ijt}), the ratio falls by about 5% following adoption of an agreement. In columns 3 and 4, we split out the effects of different agreements. While signing a preferential agreement has no impact on the ratio of value-added to gross exports, adoption of an FTA lowers the ratio of value-added to gross exports. Further, "deeper" CUCMEU agreements are associated with larger declines than FTAs. Following adoption of a CUCMEU, the ratio declines between 8-12%, whereas adoption of a FTA is associated with a drop of 4-5%. The response of gross and value-added trade flows to RTA adoption are reported in Panels B and C. Consistent with the changes in value-added to export ratios, we find that gross exports rise more following the adoption of RTAs than do value-added exports, with larger differences for "deep" agreements.

To quantify adjustment dynamics, we report the coefficients on RTA indicators for specific periods post-RTA adoption in columns 5 and 6 of Table 1. Consistent with the dynamics in Figure 5, the impact of RTA adoption appears to grow over time.[19] Upon adoption of the RTA, the ratio of value-added to gross exports falls by 3-5% and then continue to fall over the duration of the agreement. The total effect levels off at around 9-11%. Value added and gross exports follow similar adjustment dynamics, with value-added exports rising between 28-39% and gross exports rising between 37-50% in the long run.

[18] In terms of depth, we distinguish preferential trade agreements (PTA), free trade agreements (FTA), and customs unions, common markets, and economic unions (CUCMEU). To allow for phase-in effects, we define a set of indicator variables: $RTA_{ijt}(1)$ takes the value 1 in the RTA adoption year, $RTA_{ijt}(2)$ equals 1 in the 5th year, $RTA_{ijt}(3)$ equals 1 in the tenth year, and $RTA_{ijt}(4)$ equals 1 one for years 15 onward.

[19] Adjustment dynamics may arise for several reasons. First, trade agreements are typically phased in, so impact of the agreement may grows over time. Second, it may take time for trade flows to respond to those changes. Third, countries with weaker agreements may adopt stronger agreements at a later date, so the depth of liberalization evolves over time within pairs.

2.3 Summing Up: Five Stylized Facts

To sum up, we have documented five stylized facts. The first is that the ratio of world value-added to gross exports has fallen over time, by roughly ten percentage points and mostly post-1990. The second is that the ratio of value-added to gross exports has fallen for manufacturing, but actually risen outside of manufacturing. The third fact is that changes have been heterogeneous across countries, with fast growing countries seeing larger declines in the ratio of their value-added to gross exports. The fourth and fifth facts concern bilateral changes: declines in value-added to export ratios have been larger for proximate partners and country pairs that adopted regional trade agreements.

3 What Driving Forces Account for the Facts?

In this section, we ask: what driving forces account for the five stylized facts identified in Section 2? Are they products of distinct driving forces, or do common driving forces account for multiple facts simultaneously? These questions are difficult to answer with data alone. Many features of the global economy have changed over time, and these changes are linked together: any given candidate driving force (e.g., changes in productivity, endowments, trade frictions, etc.) leads to changes in multiple aspects of the input-output system. Therefore, we need a structural equilibrium framework to disentangle competing explanations for the stylized facts.

We develop an Armington-style model with cross-sector and cross-country input-output linkages suited to this task. The analysis then proceeds in two steps. First, we use the model as a measurement device. While we are able to collect data on some driving forces (e.g., changes in factor inputs and productivity across countries), it is difficult to directly measure others. Specifically, trade costs are difficult to measure in a comprehensive, consistent way through time [Anderson and van Wincoop (2004)]. Changes in preferences and production technologies needed to match final and input expenditure across sectors are also unobserved.

Therefore, we combine the model and data to infer them.[20]

Second, we apply the model in a series of counterfactuals to assign responsibility to particular driving forces for changes in value-added to gross exports in the data. To preview the main result, we demonstrate that changes in trade frictions provide a unifying explanation for all five stylized facts. Following up on this result, we use the model to study the role of particular components of trade frictions in greater detail in Section 4.

3.1 Framework

This section lays out the core elements of the model. Details regarding the model and its solution are collected in the Online Appendix.

3.1.1 Economic Environment

Each country combines domestic factors with purchased intermediate inputs to produce a unique, Armington differentiated good in each sector. Denoting the quantity of the good produced by country i in sector s as $Q_{it}(s)$, the production function takes the form:

$$Q_{it}(s) = \left[\lambda_i^V(s)^{1-\sigma} V_{it}(s)^{\sigma} + (1-\lambda_i^V(s))^{1-\sigma} X_{it}(s)\right]^{1/\sigma}, \quad (5)$$

$$V_{it}(s) = Z_{it}(s) K_{it}(s)^{\alpha} L_{it}(s)^{1-\alpha}, \quad (6)$$

$$X_{it}(s) = \left[\sum_{s'} \lambda_{it}^X(s', s)^{1-\sigma} X_{it}(s', s)^{\sigma}\right]^{1/\sigma}, \quad (7)$$

$$X_{it}(s', s) = \left[\sum_{j} X_{jit}(s', s)^{\kappa}\right]^{1/\kappa}, \quad (8)$$

[20]Our approach to measuring trade frictions is closely related to "ratio-type estimation" in gravity models [Head and Mayer (2014)]. Our approach to measuring changes in preferences and production technologies is closely related to methods used to infer changes in product quality in the trade literature and wedges in the business cycle accounting literature.

where the λ's denote CES share parameters.[21] In words, gross output is produced by combining real value added $V_{it}(s)$ and a composite intermediate input $X_{it}(s)$. Real value added is a Cobb-Douglas composite of capital $K_{it}(s)$ and labor $L_{it}(s)$, combined with productivity $Z_{it}(s)$. The composite input is formed by combining composite inputs purchased from different sectors, where $X_{it}(s', s)$ is the quantity of a composite input from sector s' purchased by sector s in country i. $X_{it}(s', s)$ is itself a composite of inputs sourced from different countries, where $X_{jit}(s', s)$ is the quantity of inputs from country j embodied in $X_{it}(s', s)$. Gross output is used as both a final and intermediate good. We assume that there are iceberg frictions associated with purchasing inputs and final goods. These frictions apply to both domestic and imported goods, and they differ by sectors (or sector-pairs) and end use. The market clearing condition for gross output is:

$$Q_{it}(s) = \sum_{s'} \sum_{j} \tau^{X}_{ijt}(s, s') X_{ijt}(s, s') + \sum_{j} \tau^{F}_{ijt}(s) F_{ijt}(s), \tag{9}$$

where the indexing on trade costs (the τ's) is the same as for goods flows.

A composite final good in each country is produced by aggregating final goods purchases:

$$F_{it} = \left[\sum_{s} \lambda^{F}_{it}(s)^{1-\rho} F_{it}(s)^{\rho} \right]^{1/\rho} \quad \text{with} \quad F_{it}(s) = \left[\sum_{j} F_{jit}(s)^{\kappa} \right]^{1/\kappa}, \tag{10}$$

where $F_{it}(s)$ is the quantity of a sector-level composite goods and $F_{jit}(s)$ is the quantity of final goods from sector s purchased by country i from country j.

This composite final good is used for both consumption (C_{it}) and investment (I_{it}), with $F_{it} = C_{it} + I_{it}$. As is standard, investment determines the aggregate capital stock: $K_{i,t+1} = I_{it} + (1 - \delta_{it}) K_{it}$, where I_{it} is real investment and δ_{it} is the depreciation rate. We assume

[21] We impose constant share parameters $\lambda^{V}_{i}(s)$ in Equation (5) because we do not have the gross output price data necessary to infer changes in $\lambda^{V}_{i}(s)$. Because we omit CES weight parameters in Equation (8) and (10), we attribute changes in cross-country sourcing (conditional on factory-gate prices) to changes in trade frictions, as is standard in the literature [Head and Mayer (2014)]. Because we solve the model in changes, time-invariant CES weights have no impact on the model equilibrium or interpretation. Time-varying CES weights would be picked up in the trade frictions that we back out of the data.

that each country is endowed with labor L_{it}, which is inelastically supplied to firms. The market clearing conditions for capital and labor are: $K_{it} = \sum_s K_{it}(s)$ and $L_{it} = \sum_s L_{it}(s)$.

To close the model, we assume that real investment is proportional to final expenditure, as in Levchenko and Zhang (2016). That is, $I_{it} = s_{it}F_{it}$, where s_{it} is an exogenous investment share parameter.[22] Together with the representative consumer's budget constraint, this pins down consumption. The budget constraint takes the form $p^F_{it}F_{it} = \sum_s[r_{it}K_{it}(s)+w_{it}L_{it}(s)]+T_{it}$, where p^F_{it} is the price of the final composite, r_{it} and w_{it} are the prices of capital and labor, and T_{it} is a nominal transfer received by agents in country i. We assume T_{it} (i.e., the trade balance) is exogenous.

Following Dekle, Eaton and Kortum (2008), we solve for the model's competitive equilibrium in changes. In doing so, we take changes in trade balances, productivity, labor endowments, and the investment share as given. We define the equilibrium and collect the equilibrium conditions (in levels and changes) in the Online Appendix.

3.1.2 Quantification

To operationalize the model, we need to assign values to model parameters and collect data on exogenous forcing variables. Further, we need to back changes in unknown parameters (e.g., trade frictions, preference/technology parameters) out of the data. We provide an overview of the procedure here, with details in the Online Appendix. As a practical matter, we use a two-sector version of the model and data to simplify the parametrization, computation, and counterfactual analysis. The two sectors are manufacturing (m) and non-manufacturing (n) sectors ($s \in \{m, n\}$).

Parameters and Exogenous Variables The parameter κ governs substitution across countries in final and intermediate input purchases. We set $\kappa = 0.75$ – corresponding to

[22]We discuss this assumption further in the Online Appendix. We back changes in s_{it} out of data and include them among the exogenous forcing variables in the simulations.

an elasticity of substitution of 4 – to match standard estimates of the trade elasticity.[23] The parameter ρ governs the cross-sector elasticity of substitution in final demand, while σ governs substitution between real value added and inputs, as well as across inputs from different sectors. We set $\sigma = \rho = -1$, corresponding to an elasticity of substitution equal to 0.5. This means that manufacturing and non-manufacturing sectors are complements in final demand, and that value added and inputs, and inputs across sectors, are complements on the production side. These assumptions are both supported by existing evidence.[24]

We also need values for the parameters $\{\alpha, \delta_{it}\}$ and the exogenous forcing variables $\{\hat{s}_{it}, \hat{T}_{it}, \hat{Z}_{it}(s), \hat{L}_{it}\}$. We set $\alpha = 0.3$, and we set the remaining values based on our input-output data and the Penn World Tables.

Trade Frictions and Expenditure Weights We introduce the following notation and nomenclature to clarify what aspects of trade frictions and preference/technology parameters we are able to back out of the data.[25] First, we normalize international iceberg frictions relative to domestic frictions: $\omega^X_{jit}(s', s) \equiv \tau^X_{jit}(s', s)/\tau^X_{iit}(s', s)$ and $\omega^F_{jit}(s) \equiv \tau^F_{jit}(s)/\tau^F_{iit}(s)$. Henceforth, we refer to $\omega^X_{jit}(s', s)$ and $\omega^F_{jit}(s)$ as "trade frictions," since they govern substitution across country sources. Given this normalization of the international frictions, we define a second set of "expenditure weights" that combine CES weight parameters and domestic frictions: $\omega^X_{it}(s', s) \equiv \lambda^X_{it}(s', s)^{(\sigma-1)/\sigma}\tau^X_{iit}(s', s)$, $\omega^F_{it}(s) \equiv \lambda^F_{it}(s)^{(\rho-1)/\rho}\tau^F_{iit}(s)$. These expenditure weights govern substitution across sectors in sourcing inputs and final goods.

To compute changes in trade frictions and expenditure weights, we need additional price

[23] This is the mean SITC 3-digit trade elasticity reported in Broda and Weinstein (2006). Note that we implicitly restrict κ to be the same in both sectors. This is consistent with the fact that the mean Broda-Weinstein elasticity estimates for non-manufacturing (SITC 1-4) and manufacturing (SITC 5-8) are both close to 4.

[24] The low final expenditure elasticity is consistent with the fact that both the share of non-manufacturing in final expenditure and the relative price of non-manufacturing output have been rising over time. This observation motivates low elasticities in the structural change literature [Ngai and Pissarides (2007), Herrendorf, Rogerson and Valentinyi (2013)]. Low substitutability in production is consistent with recent estimates by Atalay (2015) and Oberfield and Raval (2015).

[25] If domestic trade frictions are constant, then we could identify changes in the level of international trade frictions and changes in the CES expenditure weights in preferences and technologies. We do not assume that domestic frictions are constant, so we must redefine parameters here.

data, not already included in our global input-output data. We need changes in the price of real value added in each sector $\hat{p}_i^V(s)$, and changes in the price of final expenditure $\hat{p}_i^F$. Drawing on national accounts sources, we set $\hat{p}_i^V(s)$ equal to changes in GDP deflators in the manufacturing and non-manufacturing sectors, and we set $\hat{p}_i^F$ equal to changes in the ratio of nominal to real final expenditure.[26] We use this price data, along with first order conditions and price indexes from the model, to solve for changes in the trade frictions and expenditure weights implied by changes in expenditure shares over time.

The estimates we recover via this procedure are sensible and consistent with related work.[27] Globally, iceberg trade frictions decline by 35% from 1970-2009. There is significant dispersion in the magnitude of the declines across countries, and declines are strongly correlated with changes in openness (as expected). Trade frictions decline both in manufacturing and non-manufacturing sectors, though declines are somewhat larger for manufactures. As we discuss further in Section 4.2, RTA adoption predicts declines in trade frictions at the bilateral level. As for the expenditure weights, changes in final goods expenditure weights are similar across manufacturing and non-manufacturing sectors, while input expenditure weights have tended to pull input expenditure toward non-manufacturing.

3.2 Counterfactuals

We now conduct counterfactuals in the model to assess the role of trade frictions in explaining changes in value-added to export ratios. The first counterfactual holds both trade frictions and expenditure weights constant at their 1970 levels. Following our notation above, $\hat{\omega}_{it}^X(s', s) = \hat{\omega}_{it}^F(s) = \hat{\omega}_{jit}^X(s', s) = \hat{\omega}_{jit}^F(s) = 1$, and the exogenous variables $\{\hat{s}_{it}, \hat{T}_{it}, \hat{Z}_{it}(s), \hat{L}_{it}\}$ evolve as in the data. We treat this simulation as the baseline against which we assess the relative importance of trade versus expenditure weights.

[26] We take price changes and exchange rates (to convert GDP and final expenditure deflators to a common currency) from the UN National Accounts Database, with one exception. For China, we take $\hat{p}_i^V(s)$ from the World Development Indicators, since it is missing for many years in the UN Database.

[27] For example, our estimated changes in trade frictions are comparable to estimates by Jacks, Meissner and Novy (2011). See the Online Appendix for detailed discussion.

The second and third counterfactuals decompose the gap between this baseline and the data into components due to trade frictions versus expenditure weights. The second counterfactual holds expenditure weights constant at their 1970 levels ($\hat{\omega}^X_{it}(s', s) = \hat{\omega}^F_{it}(s) = 1$) and allows trade frictions to evolve as implied by the data. The third counterfactual holds trade frictions constant at their 1970 levels ($\hat{\omega}^X_{jit}(s', s) = \hat{\omega}^F_{jit}(s) = 1$) and allows expenditure weights to evolve as implied by the data.

Figure 6 plots changes in value-added to export ratios for the world as a whole.[28] In the baseline simulation of the model, there is virtually no long run change in the ratio of value-added to gross exports. This means that changes in country size and sectoral output composition, driven by both productivity and factor endowments in the baseline simulation, do not explain the decline in the ratio of value-added to gross exports. Interestingly, these results obtain even though world trade does rise substantially in this counterfactual simulation: the baseline model alone accounts for about 40% of the growth of trade since 1970. The stability of the value-added to export ratio simply means that this gross trade growth is matched by increases in value-added exports. Adding expenditure weights to the model does little to change this result. In contrast, allowing trade frictions to change generates a simulated series that captures the evolution of the ratio of value-added to gross exports well.

Figure 7 plots changes in value-added to export ratios at the sector level. Here again, the baseline simulation performs poorly. It accounts for only a small part of the declining value-added to export ratio in manufacturing, and the ratio in non-manufacturing moves in the wrong direction entirely. Expenditure weights close the gap between simulation and data, but their explanatory power is limited. Where they play a role is in explaining the medium-term dynamics of the manufacturing VAX ratio, capturing the pre-1990 slowdown and post-1990 acceleration in the rate of decline. Trade frictions are important in explaining changes in the VAX ratio for both sectors. They explain changes in the non-manufacturing sector almost completely, and explain more than half of the steady decline in manufacturing.

[28]To match the simulation, the 'true' value-added to export ratios in these figures are computed using a thirty-seven country, two-sector aggregation of the data.

Figure 8 plots changes in value-added to export ratios from 1975-2005 at the country level. As in previous figures, both the baseline simulation and the simulation with changes in expenditure weights struggle to match the data. The baseline simulation under-predicts the magnitude of the declines, particularly for countries with large declines. Expenditure weights generate additional dispersion, but do little to improve the overall fit. Again, changes in trade frictions bring the simulated data in line with actual changes for most countries. The visual impression conferred by the figures is confirmed by more systematic measures of the goodness of fit. The correlations between simulations and data are 0.39 in panels (a) and (b), and 0.69 in panel (c). Mean errors are 0.11, 0.08, and 0.03 for the three simulations (in order).

Turning to bilateral flows, we estimate the same regressions used to describe the stylized facts in Section 2 using simulated data. The left panel of Table 2 includes long difference regressions that focus on the role distance, while the right panel examines the role of RTAs.

Consistent with the discussion above, the baseline simulation fails badly at explaining the distance or RTA results. Input-output and final goods expenditure weights do a little better for the distance effects. However, it looks initially like they help explain declines in the value-added to export ratio surrounding RTAs. This apparent good performance is misleading. Looking at Panels B and C, changes in input-output and final goods expenditure weights lower the simulated bilateral VAX ratio because they lead bilateral value-added exports to fall post-RTA adoption, while gross exports are unchanged – both these results are grossly inconsistent with the data. Changes in trade frictions, instead, do well in matching both the distance and RTA evidence. They predict both the decline in the VAX ratio and the rise in value-added and gross exports post-RTA adoption.

To sum up, we set out to evaluate the role of trade frictions in explaining the data. The counterfactuals point to changes in trade frictions as the most important force underlying all five stylized facts. We therefore shift our attention to examining the role of trade frictions in greater detail.

4 Interpreting the Role of Trade Frictions

To interpret the role of trade frictions in explaining the five facts, we unpack the frictions themselves. First, we distinguish trade frictions by sector (manufacturing vs. non-manufacturing) and end use (final vs. intermediate goods). We simulate the model with each set of frictions independently, and we use these simulations together with accounting relationships to examine the mechanics underlying changes in multilateral value-added to export ratios. Second, we hone in on bilateral frictions to examine the role of policy changes – specifically, RTA adoption – in driving changes in value-added to export ratios.

4.1 Unpacking Trade Frictions

We run four new counterfactual simulations with changes in (1) final non-manufacturing trade frictions, holding other trade frictions fixed ($\hat{\omega}^F_{jit}(m) = \hat{\omega}^X_{jit}(s', s) = 1$), (2) input non-manufacturing trade frictions (with $\hat{\omega}^F_{jit}(s) = \hat{\omega}^X_{jit}(m, s) = 1$), (3) final manufacturing trade frictions (with $\hat{\omega}^F_{jit}(n) = \hat{\omega}^X_{jit}(s', s) = 1$), and (4) input manufacturing trade frictions (with $\hat{\omega}^F_{jit}(s) = \hat{\omega}^X_{jit}(n, s) = 1$). In all these simulations, expenditure weights are held constant at 1970 levels ($\hat{\omega}^X_{it}(s', s) = \hat{\omega}^F_{it}(s)$). These four simulations decompose the Trade Frictions simulation presented previously, so we compare them that simulation in the analysis below.

4.1.1 Results

Along all three dimensions of the multilateral data – for the world, countries, and sectors – trade frictions for manufactures are more important than trade frictions for non-manufacturing output. Further, among manufacturing trade frictions, frictions for inputs are more important than frictions for final goods.

In Figure 9, we plot the four simulations for the world. As is evident, changes in trade frictions for manufacturing goods used as inputs generate a large decline in the simulated value-added to export ratio. While changes in the remaining frictions are less important, the ratio also declines due to changes in frictions for final manufacturing goods (particularly post-1990).

Turning to sectors, we plot value-added to export ratios in the four simulations in Figure 10. Here again, manufacturing trade frictions do the bulk of the work. Frictions on manufactured inputs are most important in accounting for the decline in the manufacturing ratio, though frictions on final manufactures matter as well. For the non-manufacturing sector, final manufacturing frictions are most important, with input-manufacturing frictions also playing a role in explaining the rising value-added to export ratio in this sector.

At the country level, all four simulations generate data that is positively correlated with the composite Trade Frictions simulation, and roughly equally so (the correlations are all near 0.5). However, simulations with changes in non-manufacturing frictions alone underpredict the size of the declines in value-added to export ratios: the mean error is 0.10 in simulation (1) and 0.08 in simulation (2). In contrast, simulations with changes in manufacturing frictions generate significant declines in value-added to export ratios, with a mean error of 0.04 in simulation (3) and -0.006 in simulation (4). From this, we conclude that frictions for manufactured inputs are most important in explaining country-level ratios as well.

4.1.2 Interpretation

To interpret these results, we combine accounting results with the intuitive mechanics of the model. We start by explaining the link between sector-level trends and the world-level results, and then we discuss sector trends themselves in detail. We conclude with a brief discussion of heterogeneity across countries.

Aggregating Sector Trends The world value-added to export ratio can be written as a trade-weighted average of sector-level ratios: $VAX_t = \sum_s \left(\frac{X_t(s)}{X_t}\right) VAX_{it}(s)$. This suggests a simple Between-Within decomposition of changes in VAX_t between year t and year $t-1$

into components due to changes in $VAX_t(s)$ versus sectoral trade shares:

$$\Delta VAX_t = \underbrace{\sum_s \bar{\omega}_t(s)\Delta VAX_t(s)}_{\text{Within}} + \underbrace{\sum_s \overline{VAX}_t(s)\Delta\omega_t(s)}_{\text{Between}}, \tag{11}$$

where Δ denotes time differences, $\bar{\omega}_t(s) \equiv \frac{1}{2}(\omega_t(s) + \omega_{t-1}(s))$ with $\omega_t(s) = \frac{\sum_{i\neq j} x_{ijt}(s)}{\sum_{i\neq j}\sum_s x_{ijt}(s)}$, and $\overline{VAX}_t(s) \equiv \frac{1}{2}(VAX_t(s) + VAX_{t-1}(s))$.

We report this decomposition in actual and simulated data in Table 3. In the data, both the between and within terms are negative, and the within term is larger than the between term. The within term is obviously driven by the decline in the manufacturing value-added to export ratio, which dominates the rise in the non-manufacturing ratio because manufactures account for 60-70% of world trade. The between term is negative because the share of manufacturing rises over the period, and the level of the value-added to export ratio is lower in manufacturing than non-manufacturing. The between term is modest in size because changes in trade shares are small (a few percentage points).

Turning to simulation results, the Trade Frictions counterfactual generates negative within and between effects, consistent with the data. Breaking the trade frictions apart, only the simulation with declines in trade frictions for manufactures used as inputs matches this pattern (and hence the data). All the other trade frictions simulations generate results that point in the wrong direction for explaining the data, in one way or another.[29] Falling input frictions for manufacturing goods lower the value-added to export ratio in manufacturing (as in Figure 10), and this drives the within effect. They also increase the share of manufactures in trade, which accounts for the negative between effect.

[29]Non-manufacturing trade costs generate negative within effects, but (counterfactual) positive between effects. The between effects arise because declines in non-manufacturing trade frictions raise the share of non-manufacturing in trade, and non-manufacturing has a higher value-added to export ratio than manufacturing. Declining trade frictions for final manufactures generate strong negative between effects, but positive within effects. The negative between effect here arises because declines in manufacturing frictions raise the share of manufactures in trade. The positive within effect is a product of the strong rise in VAX ratios for non-manufacturing in response to falling final manufacturing trade frictions.

Sector Trends We now turn our attention to explaining the sector trends themselves. To do this, it is helpful to appeal to the tight (empirical and conceptual) link between value-added to export ratios and the domestic content of exports. Domestic content is the value of exports less the import content of exports, and it measures the amount of domestic value added needed to produce exports [Hummels, Ishii and Yi (2001)]. As an empirical matter, sector-level domestic content is approximately equal to sector-level value-added exports [Johnson and Noguera (2012*a*)]. We therefore use domestic content as a proxy for value-added exports in interpreting sector trends, because domestic content is a mathematically simpler object to interpret.

Formally, domestic content can be written as $DC_{it} = R_{it}(I - A_{Dit})^{-1}X_{it}$, where R_{it} is a matrix with sector-level value-added to output ratios $r_{it}(s)$ along the diagonal, A_{Dit} is the domestic input-output matrix, and X_{it} is the export vector of country i.[30] The domestic content to gross export ratio at the sector level is then: $DC_{it}(s)/X_{it}(s) = w_{it}(s,s) + w_{it}(s,s')(X_{it}(s')/X_{it}(s))$, where the weights $w_{it}(s,s')$ are the elements of $R_{it}(I - A_{Dit})^{-1}$ and indicate how much domestic content from sector s is needed to produce exports from sector sector s'. These weights depend both on cross-sector input linkages – how much output from sector s is used in producing exports in sector s' (via $(I - A_{Dit})^{-1}$) and the imported-input intensity of production in sector s (via R_{it}). Finally, note that this ratio depends directly on export composition, because domestic content is both exported directly via a sector's own exports and indirectly via exports of other sectors. As indirect exports rise, then $DC_{it}(s)/X_{it}(s)$ will rise.

Putting these observations to work, falling frictions on manufactured inputs increase foreign sourcing in the manufacturing sector, and hence drive down $DC_{it}(m)/X_{it}(m)$ in manufacturing. They also simultaneously drive up $DC_{it}(n)/X_{it}(n)$, because they raise the share of manufactures in trade, which in turn raises the level of indirect exports by the non-manufacturing sector. Falling frictions on final manufactures have similar composi-

[30] To interpret this, $(I - A_{Dit})^{-1}X_{it}$ is the amount of domestic gross output needed to produce exports, so multiplying by the value-added to output ratio yields a measure of domestic content in exports.

tional effects, which explains why they too raise the value-added to export ratio in non-manufacturing. These compositional effects also contribute to the decline in the value-added to export ratio in manufacturing, since they lower indirect exports of manufacturing value added, by reducing $(X_{it}(n)/X_{it}(m))$. Together these mechanisms explain the dominant role of manufacturing trade frictions in explaining the trends in sector-level VAX ratios, depicted in Figure 9.

Country-Level Changes Looking at cross-country changes in value-added to export ratios, the same basic within and between forces come into play as in the aggregate. As at the world level, the value-added to export ratio in manufacturing declines in virtually all countries. The large majority of countries also see increases in value-added to export ratios in non-manufacturing. Further, the level of the non-manufacturing ratio is higher than the manufacturing VAX essentially everywhere.

The main difference is that between effects are more important in explaining country-level changes than they are at the world level. The reason is that changes in trade shares are substantially larger at the country-level than in the aggregate, so they play a larger role in the between-within decomposition. Countries with the largest declines in value-added to export ratios tend to have very large, negative between effects (i.e., tend to see large increases in the share of manufacturing exports). Because declines in manufacturing trade frictions increase manufacturing exports, they are important in explaining cross-country variation as well.

4.2 The Role of Regional Trade Agreements

We now turn to assessing the role of regional trade agreements in our results. Our first goal is to confirm that Fact 5 – that RTAs lower bilateral value-added to export ratios – is explained entirely by changes in bilateral trade costs surrounding RTA adoption. Our second goal is to quantify how much of the decline in the world value-added to export ratio is explained by the spread of RTAs over time.

The approach we take is to simulate a counterfactual world in which no new regional trade agreements were adopted between 1970 and 2009, and then we compare this to data. To do this, we need to construct counterfactual trade frictions that capture how trade frictions would have evolved in the absence of post-1970 RTAs. We proceed in two steps (see the Online Appendix for details). In the first step, we model trade frictions as a function of RTAs and other unobserved time-varying importer, exporter, and pair-specific factors. We then estimate the impact of RTA adoption by regressing changes in measured frictions (for each input sector-pair or final goods sector separately) on fixed effects and trade agreement indicators. In the second step, we use the estimated RTA coefficients to adjust the measured trade frictions, removing changes in trade frictions due to RTA adoption.[31]

As expected, our estimates indicate that RTA adoption lowers bilateral trade frictions among adopting countries.[32] To summarize the magnitudes, trade frictions fall by roughly 7-8% after RTA adoption when we measure RTA adoption using a simple binary indicator. When we allow for dynamic phase-in effects, RTAs lower trade frictions by 16-20% in the long run. We view these estimates as lower and upper bounds on plausible RTA-impacts. When we separate agreements, we find an ordering of changes in trade frictions consistent with our previous gravity results: deep trade agreements are associated with larger declines in trade frictions than shallower agreements.

Using these results, we simulate the model with counterfactual trade frictions, removing post-1970 RTAs and allowing all other driving forces (including changes in expenditure weights) to evolve as implied by data. This means that deviations between simulated and true data in this set of results reflect only the removal of RTAs. To frame the analysis, recall that we showed (in Table 2) that changes in trade frictions can account for declines in value-added relative to gross exports following adoption of regional trade agreements (Fact

[31] For pairs that form a new RTA after 1970, trade frictions equal measured values prior to RTA adoption and then are adjusted upward post-RTA as if the RTA were never signed. For all pairs that either never form an RTA or already had an RTA in force in 1970, trade frictions evolve as in the data.

[32] See Table C3 of the Online Appendix for the full set of estimates.

5). We now demonstrate that changes in bilateral frictions attributable to RTA adoption drive this result.

Using the simulated data, we re-estimate the baseline regressions specifications used previously to document RTA effects. Because we have removed changes in trade frictions attributable to RTAs, we expect RTAs to have *no effect* on bilateral value-added to export ratios in these regressions. In fact, that is exactly what we find. In Panel A of Table 4, the RTA-coefficient is numerically close to, and statistically indistinguishable from, zero. This holds regardless of the technique we use to remove RTAs. Further, this result reflects zero impact of regional agreements on both value-added exports (Panel B) and gross exports (Panel C) when RTAs are removed. These results imply that RTA-induced changes in bilateral trade frictions alone drive the differential response of bilateral value-added versus gross trade that we observe in the data post-RTA adoption.

An important remaining question is: does the spread of RTAs also help explain the global decline in the ratio of value-added to gross exports? The answer is that post-1970 RTAs can explain roughly 6-15% of the overall decline. With RTA effects estimated using a binary RTA indicator, the ratio of value-added to gross exports for the world as a whole falls by about 6% less in the counterfactual than in the data. When we split agreements by type, the ratio of value-added to gross exports falls by about 13% less in the counterfactual than in the data. Allowing for phase-in effects, the ratio falls by about 15% less than in the data. These magnitudes are sizable given that only about a third of all country pairs adopt RTAs during the sample period, and many of these post-1990 agreements have yet to reach their peak impact. We conclude that the spread of RTAs has played a significant quantitative role in driving the global decline in value-added relative to gross exports.

5 Conclusion

With the rise of cross-border supply chains, conventional (gross) trade data is an increasingly misleading guide to how value added is traded in the global economy. In this paper, we characterized changes in gross versus value-added trade over four decades. Value-added exports are falling relative to gross exports, implying double counting in gross trade data is more pervasive today than in the past. Importantly, gaps between gross and value-added exports are unevenly distributed across time, sectors, countries, and bilateral partners. These differences imply that shifting from a gross to value-added view of trade changes the relative openness of sectors or countries, and the relative importance of bilateral trade partners for a given country.

Using a structural gravity model, we found that changes in trade frictions play a first-order role in explaining not only global trends, but also differences across countries, sectors, and bilateral partners. We emphasize in particular that regional trade agreements have led to declines in value-added relative to gross trade among adopting partners, such that the spread of RTAs over time can account for 15% of the decline in the world value-added to export ratio over time. In contrast, other major structural changes in the global economy (e.g., the increasing weight of emerging markets in global GDP) play a minimal role. Changes in sector-level patterns of input use and demand are also relatively unimportant, as compared to the role of trade frictions.

Our results have a number of implications for future research. First, the value-added data we provide are immediately useful for parameterizing quantitative models. Because the value-added content is falling over time, shifting from gross to value-added export data in empirical applications is more important now than ever. Second, the large role of trade frictions in explaining changes in gross versus value-added trade calls for re-visiting classic questions about the burden of trade frictions. For example, how do gross trade frictions map into reduced form frictions for trading value added, or how do RTAs induce trade creation vs. diversion in value-added exports? Third, if one knows the factor/task contents employed in producing value added, one can immediately convert value-added exports into bilateral measures of factor/task trade. Therefore, the type of value-added data we provide should be useful in analyzing models of factor/task trade, including the role of factor/task trade in explaining changes in the distribution of income.

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Table 1: Panel Regressions with Regional Trade Agreements

Panel A: Log VAX Ratio							
	By Agreement Type					With Phase-in Effects	
	(A1)	(A2)	(A3)	(A4)		(A5)	(A6)
RTA	-0.046***	-0.054***			RTA(1)	-0.030*	-0.046**
	(0.015)	(0.018)				(0.016)	(0.019)
PTA			-0.004	-0.002	RTA(2)	-0.051***	-0.074***
			(0.015)	(0.018)		(0.018)	(0.023)
FTA			-0.035**	-0.052***	RTA(3)	-0.090***	-0.079***
			(0.017)	(0.020)		(0.021)	(0.029)
CUCMEU			-0.115***	-0.082***	RTA(4)	-0.113***	-0.088**
			(0.020)	(0.024)		(0.021)	(0.036)
R^2	0.74	0.85	0.74	0.85		0.74	0.85

Panel B: Log Value Added Exports							
	By Agreement Type					With Phase-in Effects	
	(B1)	(B2)	(B3)	(B4)		(B5)	(B6)
RTA	0.256***	0.222***			RTA(1)	0.176***	0.193***
	(0.031)	(0.033)				(0.028)	(0.032)
PTA			0.081**	-0.007	RTA(2)	0.292***	0.305***
			(0.036)	(0.039)		(0.036)	(0.047)
FTA			0.253***	0.210***	RTA(3)	0.416***	0.323***
			(0.035)	(0.037)		(0.046)	(0.057)
CUCMEU			0.447***	0.351***	RTA(4)	0.385***	0.284***
			(0.044)	(0.046)		(0.048)	(0.071)
R^2	0.97	0.99	0.97	0.99		0.97	0.99

Panel C: Log Gross Exports							
	By Agreement Type					With Phase-in Effects	
	(C1)	(C2)	(C3)	(C4)		(C5)	(C6)
RTA	0.303***	0.276***			RTA(1)	0.206***	0.239***
	(0.042)	(0.046)				(0.039)	(0.046)
PTA			0.085*	-0.005	RTA(2)	0.344***	0.379***
			(0.045)	(0.052)		(0.049)	(0.064)
FTA			0.288***	0.262***	RTA(3)	0.506***	0.402***
			(0.046)	(0.051)		(0.060)	(0.077)
CUCMEU			0.561***	0.434***	RTA(4)	0.498***	0.373***
			(0.057)	(0.064)		(0.061)	(0.097)
R^2	0.96	0.98	0.96	0.98		0.96	0.98

Pair Trend		X		X			X
Obs.	11158	11158	11158	11158		11158	11158

Note: All regressions include exporter-year, importer-year, and pair fixed effects. Columns 2, 4, and 6 include linear pair-specific trends. Standard errors, clustered by country pair, are in parentheses. Significance levels: * $p < .1$, ** $p < .05$, *** $p < .01$. Sample excludes pair-year observations with bilateral exports smaller than $1 million or VAX ratios larger than ten.

Table 2: Panel Regressions with Distance and Regional Trade Agreements in Simulated Data

Distance

Panel A1: Change in Log VAX Ratio	Data (A1)	Baseline (A2)	Expenditure Weights (A3)	Trade Frictions (A4)
Log Distance	0.092***	-0.006*	0.027**	0.087***
	(0.012)	(0.004)	(0.011)	(0.013)
R^2	0.39	0.57	0.44	0.33

Panel B1: Change in Log Value-Added Exports	Data (B1)	Baseline (B2)	Expenditure Weights (B3)	Trade Frictions (B4)
Log Distance	-0.105***	0.029***	0.073***	-0.107***
	(0.027)	(0.005)	(0.013)	(0.029)
R^2	0.66	0.98	0.89	0.64

Panel C1: Change in Log Gross Exports	Data (C1)	Baseline (C2)	Expenditure Weights (C3)	Trade Frictions (C4)
Log Distance	-0.197***	0.035***	0.046***	-0.195***
	(0.036)	(0.007)	(0.017)	(0.038)
R^2	0.60	0.96	0.82	0.56
Obs.	1171	1171	1171	1171

Regional Trade Agreements

Panel A2: Log VAX Ratio	Data (A5)	Baseline (A6)	Expenditure Weights (A7)	Trade Frictions (A8)
RTA	-0.045***	0.000	-0.076***	-0.033**
	(0.015)	(0.008)	(0.016)	(0.016)
R^2	0.72	0.99	0.98	0.69

Panel B2: Log Value-Added Exports	Data (B5)	Baseline (B6)	Expenditure Weights (B7)	Trade Frictions (B8)
RTA	0.241***	-0.025***	-0.051***	0.263***
	(0.033)	(0.008)	(0.016)	(0.035)
R^2	0.97	0.99	0.99	0.97

Panel C2: Log Gross Exports	Data (C5)	Baseline (C6)	Expenditure Weights (C7)	Trade Frictions (C8)
RTA	0.286***	-0.026**	0.025	0.296***
	(0.044)	(0.012)	(0.022)	(0.046)
R^2	0.96	0.99	0.99	0.96
Obs.	11291	11291	11291	11291

Note: Panels A1, B1, and C1 replicate the specification from Table D3, where the dependent variable is the change in the specified variable. Panels A2, B2, and C2 replicate the specification from column 1 of Table 1. Significance levels: * $p < .1$, ** $p < .05$, *** $p < .01$. Sample excludes pairs with bilateral exports smaller than $1 million or VAX ratios larger than ten in 1975.

Table 3: Between-Within Decomposition of Changes in World Value-Added to Export Ratios

		Between-Within Decomposition	
	$VAX_{2009} - VAX_{1970}$	Between Term	Within Term
Data	-0.10	-0.03	-0.07
Trade Frictions	-0.08	-0.05	-0.04
Final Non-Manufacturing	0.00	0.11	-0.11
Input Non-Manufacturing	-0.02	0.10	-0.12
Final Manufacturing	-0.05	-0.08	0.03
Input Manufacturing	-0.10	-0.05	-0.06

Note: $VAX_{2009} - VAX_{1970}$ is the change in the world value-added to export ratio from 1970 to 2009 for the 37 countries in the simulation sample. The columns labeled Between and Within contain the cumulated year-on-year values for the decomposition reported in Equation (11). The Trade Frictions row reports results for simulated data with changes in all trade frictions (holding final and input expenditure weights constant). Other rows include decompositions in simulated data for changes in the individual trade frictions indicated.

Table 4: Panel Regressions in Simulated Data with Regional Trade Agreements Removed

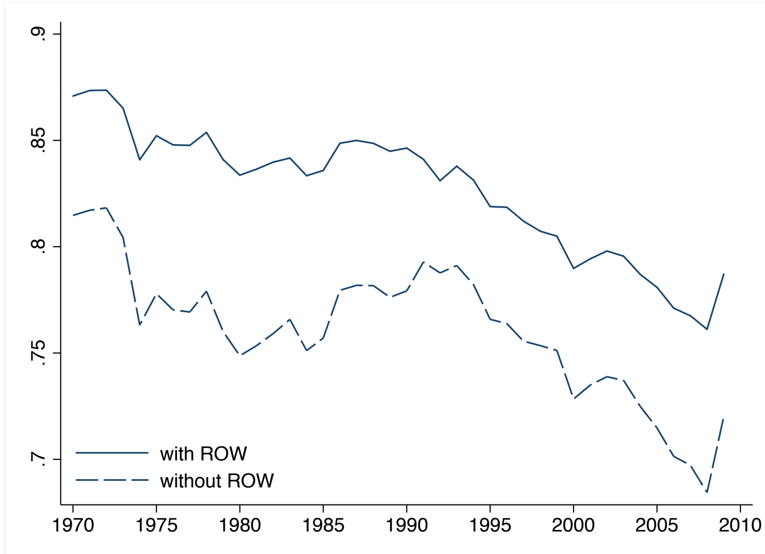
Panel A: Log VAX Ratio				
		Approach to Removing RTAs		
	Data	Binary RTA	Split Agreement Types	with Phase-in
	(A1)	(A2)	(A3)	(A4)
RTA	-0.045***	-0.005	-0.005	0.006
	(0.015)	(0.015)	(0.014)	(0.015)
R^2	0.72	0.72	0.72	0.71

Panel B: Log Value-Added Exports				
		Approach to Removing RTAs		
	Data	Binary RTA	Split Agreement Types	with Phase-in
	(B1)	(B2)	(B3)	(B4)
RTA	0.241***	0.064*	0.034	0.005
	(0.033)	(0.033)	(0.033)	(0.033)
R^2	0.97	0.97	0.97	0.97

Panel C: Log Gross Exports				
		Approach to Removing RTAs		
	Data	Binary RTA	Split Agreement Types	with Phase-in
	(C1)	(C2)	(C3)	(C4)
RTA	0.286***	0.068	0.039	-0.000
	(0.044)	(0.044)	(0.043)	(0.044)
R^2	0.96	0.96	0.96	0.96
Obs.	11291	11291	11291	11291

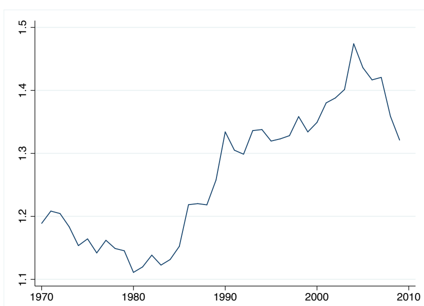
Note: Colums 2-4 report regression results for counterfactual simulated data in which the estimated impact of RTAs has been removed from measured trade frictions, as described in the Online Appendix. All regressions include exporter-year, importer-year, and pair fixed effects. The sample matches that used in Table 1. Standard errors, clustered by country pair, are in parentheses. Significance levels: * $p < .1$, ** $p < .05$, *** $p < .01$.

Figure 1: Ratio of Value-Added to Gross Exports for the World

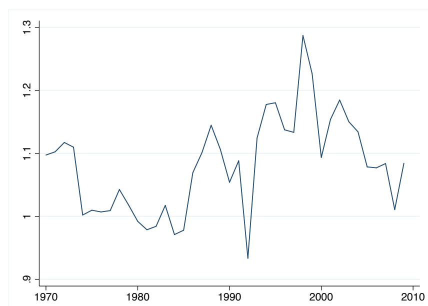


Note: The world value-added to export ratio is $VAX_t \equiv (\sum_{i \neq j} \sum_s va_{ijt}(s))/(\sum_{i \neq j} \sum_s x_{ijt}(s))$. The solid line includes shipments to/from the rest of the world, and the dashed line excludes them.

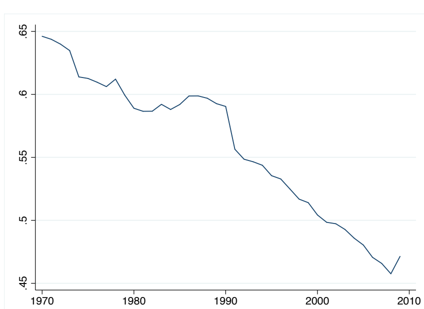
Figure 2: Ratio of Value-Added to Gross Exports for the World, by Sector



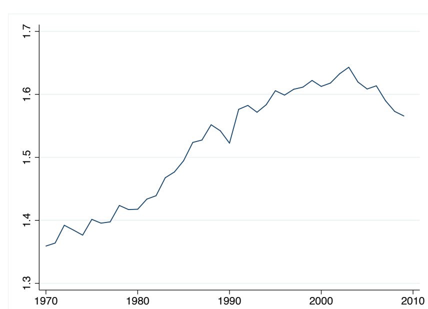
(a) Agriculture, Forestry, and Fishing



(b) Non-Manuf. Industrial Production



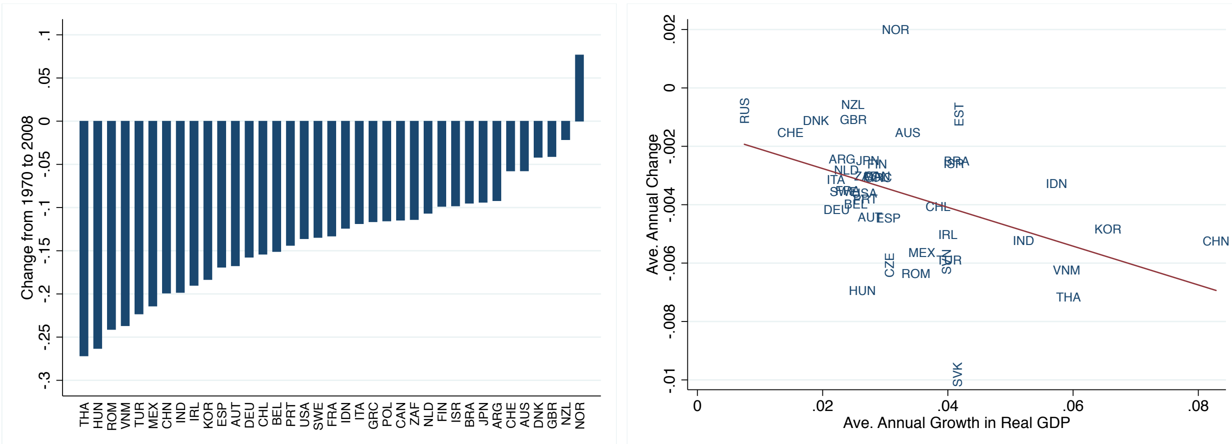
(c) Manufacturing



(d) Services

Note: The sector-level value-added to export ratio is $VAX_t(s) \equiv (\sum_{i \neq j} va_{ijt}(s))/(\sum_{i \neq j} x_{ijt}(s))$.

Figure 3: Changes in Ratio of Value-Added to Gross Exports, by Country

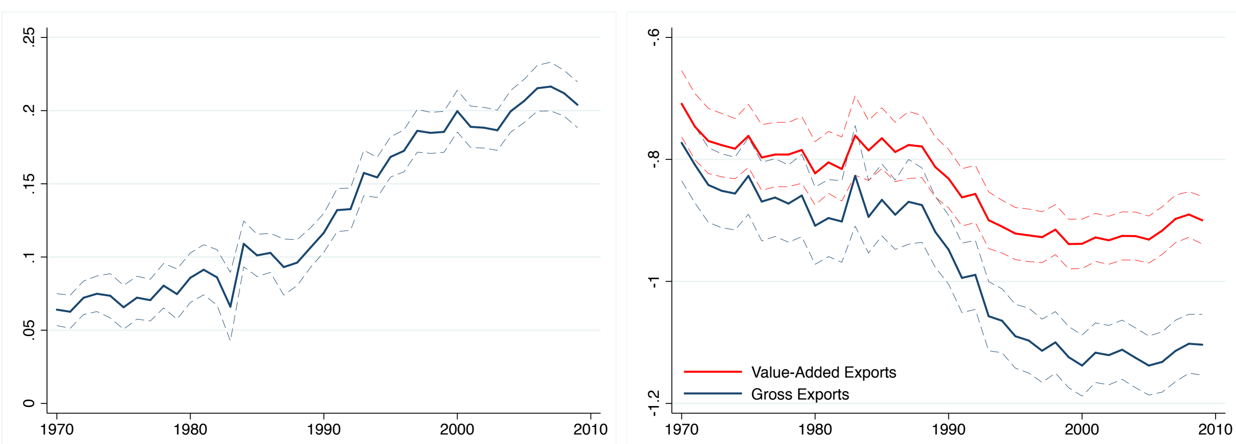


(a) Cumulative Changes (1970-2008)

(b) Average Annual Change vs. Average Annual Real GDP Growth

Note: Real GDP data is from the UN National Accounts Database. Panel (a) includes 37 countries for which we have data back to 1970. All countries are included in Panel (b), and vertical labels denote countries with less than 40 years of data. Red line denotes least squares regression line.

Figure 4: The Elasticity of Value-Added and Gross Exports to Distance

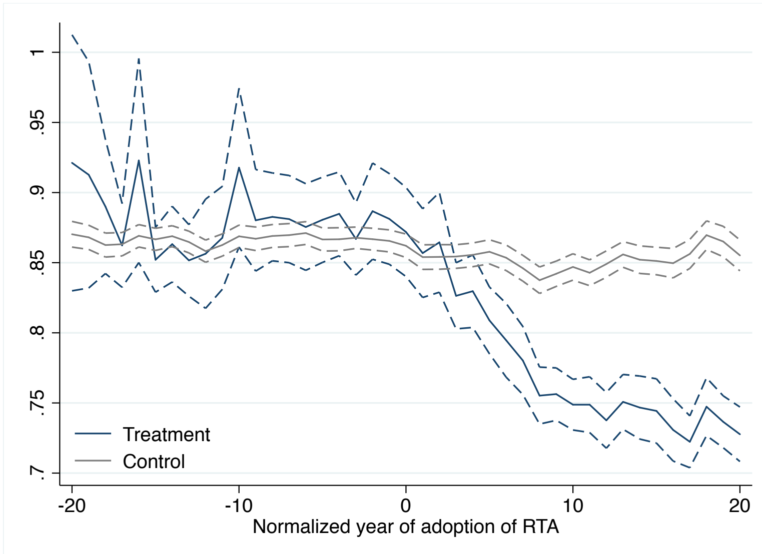


(a) Ratio of Value-Added to Gross Exports

(b) Value-Added and Gross Exports

Note: See Equation (3) for regression specification. Regressions include time-varying source and destination fixed effects. Distance is the simple distance between the most populated cities in the two countries, from the CEPII Gravity Dataset. The middle solid line indicates the point estimate, and upper/lower dashed lines denote 90% confidence intervals. Standard errors are clustered by country pair.

Figure 5: Bilateral Value-Added to Export Ratios around Adoption of Regional Trade Agreements



Note: In each set of lines, the middle line indicates the group mean, and upper/lower dashed lines denote 90% confidence intervals for group means.

Figure 6: Actual and Simulated World Value-Added to Gross Export Ratios

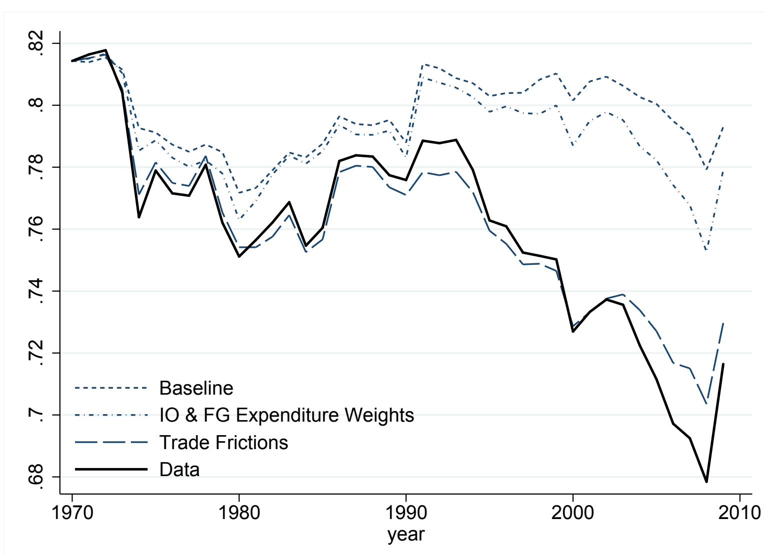
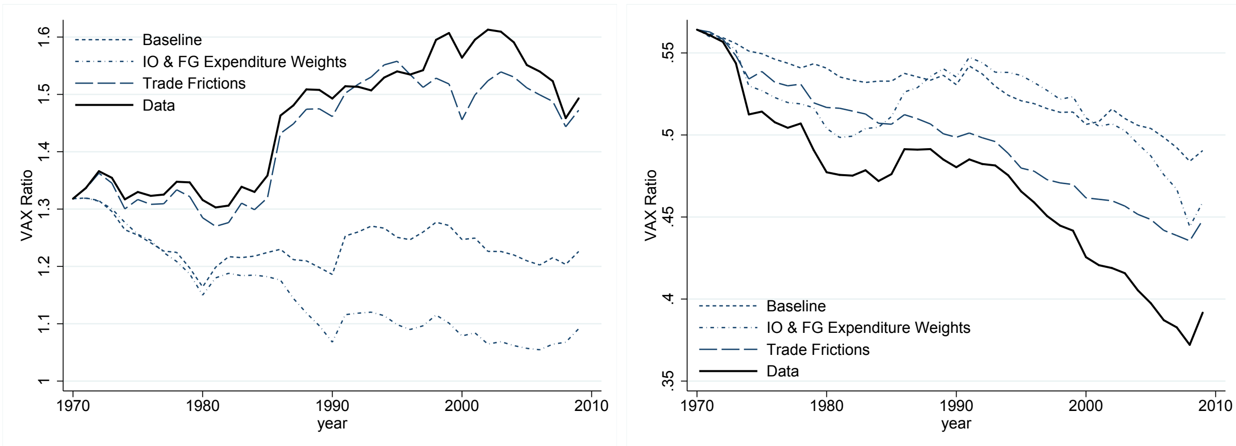


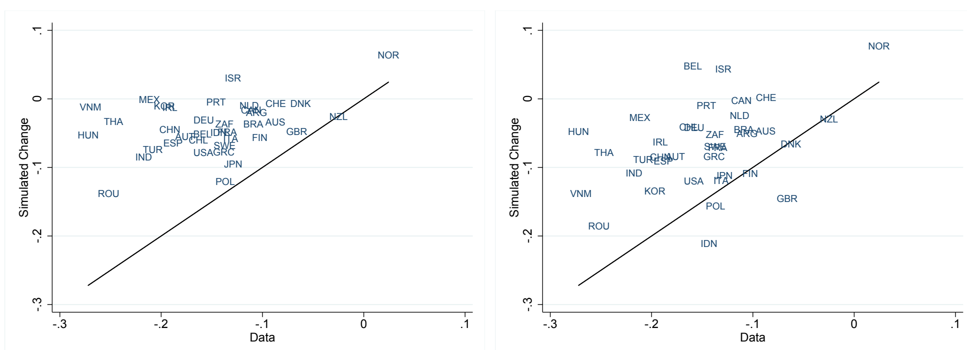
Figure 7: Actual and Simulated World Value-Added to Gross Export Ratios, by Sector



(a) Non-Manufacturing

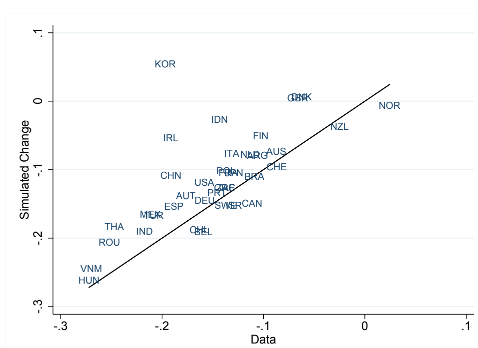
(b) Manufacturing

Figure 8: Actual and Simulated World Value-Added to Gross Export Ratios by Country



(a) Baseline

(b) IO & FG Expenditure Weights



(c) Trade Frictions

Note: Solid black line depicts 45° line.

Figure 9: Simulated World Value-Added to Gross Export Ratios with Changes in Trade Frictions

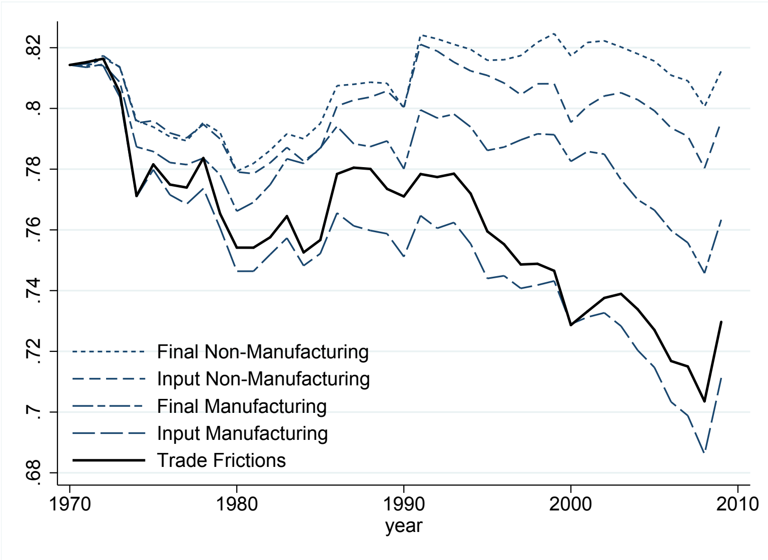
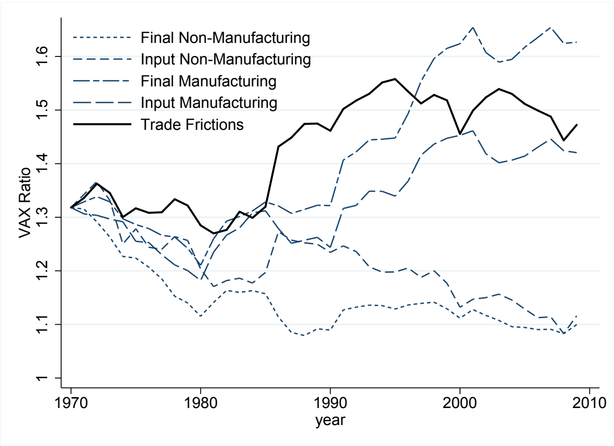
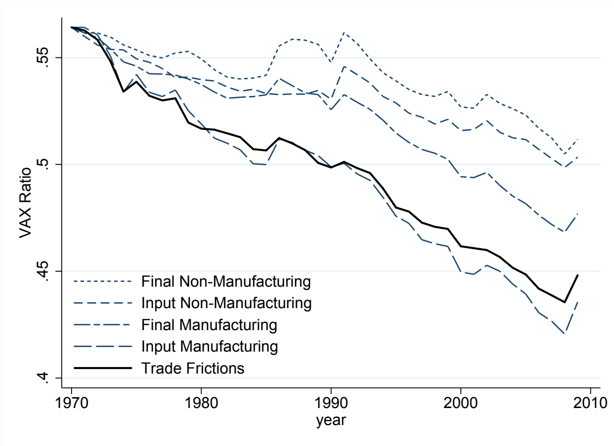


Figure 10: Simulated World Value-Added to Gross Export Ratios with Changes in Trade Frictions, by Sector



(a) Non-Manufacturing



(b) Manufacturing

Online Appendix for "A Portrait of Trade in Value Added over Four Decades"

Robert C. Johnson   Guillermo Noguera

October 2016

A Data Appendix

This appendix describes the data sources and procedures that we use to construct the input-output framework. Further details are available from the authors on request.

A.1 National Accounts Data

To measure macroeconomic aggregates and sector-level production over time, we primarily rely on the United Nations National Accounts Main Aggregates Database [http://unstats.un.org/unsd/snaama]. For all countries other than China, we take aggregate GDP and the expenditure side breakdown of GDP (consumption, investment, government spending, exports, and imports) from the UN data. We use data from the World Development Indicators [http://databank.worldbank.org] for China.[1] We also take sector-level GDP data from these sources for the four composite sectors, and include the sector definitions in Table A2. Finally, we extract goods and services trade shares in total exports and total imports from the IMF Balance of Payments Statistics (BPM5) [http://elibrary-data.imf.org/], and we use these shares to split exports and imports from the expenditure-side GDP data into goods and services.

A.2 Trade Data

We combine bilateral commodity trade statistics with multilateral totals from the national accounts to generate a bilateral trade database that is consistent in level terms with the national accounts. First, we discuss bilateral commodity trade data sources, classification of trade according to final and intermediate use, and correspondences to industry data. Second, we discuss how we harmonize the commodity trade data with national accounts data. Third, we discuss how we deal with missing bilateral services trade data.

For bilateral goods trade, we draw on the NBER-UN Database [http://cid.econ.ucdavis.edu] for 1970-2000 and the CEPII BACI Database [http://www.cepii.fr] for 1995-2009. This data is reported on a commodity-basis. We assign commodities to end uses and industries using existing correspondences from the World Bank [http://wits.worldbank.org]. To assign commodities to end uses, we use correspondences between SITC (Revision 2) 4-digit or HS (1996 Revision) 6-digit commodities and the BEC end use classifications. To assign commodities to industries, we use correspondences between SITC and HS categories and ISIC (Revision 2) industries.[2] We then map ISIC sectors into our four composite sectors.

In general, these correspondences provide a clean mapping from the trade to end use or industry classifications. We are able to match upwards of 95% of trade to industries in most country years, and the match quality for the post-1995 BACI data is nearly perfect. However, there are a few complications that we note here.

[1]Comparing the WDI to the UN data, values for most countries are nearly identical. China is an exception. Upon examination of other sources (e.g., Chinese national accounts), the WDI data appears more accurate.

[2]For a few unassigned commodities, we use a supplemental correspondence between SITC and ISIC classifications developed by Marc Muendler [http://econ.ucsd.edu/muendler/html/resource.html].

First, though most commodities map into unique end use classifications, some do not (e.g., "motor spirits" in the BEC classification is a mixed use commodity). For these mixed use commodities, we assign half the value to final use and half to intermediate use.

Second, some trade cannot be assigned using the correspondences. This problem occurs primarily in the NBER-UN data, where there are aggregate categories ending in 'X' (e.g., 04XX) for some countries and years that include trade that could not be disaggregated. Where possible, we map directly from higher levels of aggregation (e.g., SITC 2 digit codes) to sectors/uses. Where necessary, we split unallocated SITC 1-digit residual trade across sectors/uses using the world-level allocation shares for these categories.

Having formed a complete bilateral goods trade dataset, we need to harmonize the levels of bilateral trade with aggregate exports and imports in the national accounts. The procedure we use is as follows. First, we harmonize levels for aggregate bilateral goods trade with national accounts totals.[3] Second, we use the share of each sector and end use in bilateral trade from the commodity trade data to allocate the harmonized bilateral goods trade to sectors and end uses. This yields a sector-level bilateral final and intermediate goods trade dataset that aggregates to match the national accounts.

Next, we turn to bilateral services trade. Unfortunately, bilateral services trade data has not been collected with the same scope and rigor as goods trade data; Data on bilateral services trade is incomplete today, and virtually nonexistent going back in time. Therefore we impute these flows using multilateral data on services trade along with bilateral trade shares for goods. This procedure is sensible, given the strong correlation between goods and services trade shares in modern data. We run a constrained least squares program that finds the bilateral services flows that minimize deviations between imputed services trade shares and target shares (based on goods trade), subject to the constraint that the sum of the bilateral flows be equal to multilateral exports and imports for each country.[4]

A.3 Input-Output Tables

We obtain input-output tables from the OECD Input-Output Database (1995 and 2011 editions) [http://www.oecd.org/sti/inputoutput/] and the IDE-JETRO Asian Input-Output Tables [http://www.ide.go.jp/]. Benchmark tables are available for countries and years listed in Table A1. The mapping between sectors in the input-output data and our

[3]In this step, we take bilateral trade shares from the commodity trade data and multiply them with the level of goods exports and imports reported in the national accounts. This procedure yields two conflicting estimates for each bilateral trade flow, one 'exporter report' from multiplying the trade share times reported multilateral exports in a given source country and a corresponding 'importer report' from multiplying the trade share times reported multilateral imports in a given destination. To reconcile the flows, we average the flows to form a single bilateral flow and then add or subtract the residual (e.g., the exporter report minus the reconciled trade flow) from trade flows with the rest of the world. This procedure occasionally results in negative values for trade with the rest of the world, concentrated in particular countries and years where either trade or national accounts data are suspect (e.g., for Argentina in the early 1970's). We adjust the data to eliminate these zeros using a constrained least squares procedure that penalizes changes in trade shares among the 42 countries in our sample. The necessarily adjustments are trivially small.

[4]The target shares are constructed by multiplying goods trade shares with multilateral services trade from the national accounts. As in the goods data, this yields conflicting exporter and importer reports, and we set the reconciled flow equal to the average report, as in the previous footnote.

four composite sectors are included in Table A2.[5]

In the input-output tables, there are accounting variables that we did not explicitly define in our framework, such as statistical discrepancies, other adjustments, non-comparable imports, and net taxes.[6] In general, these tend to be small or exactly zero (due to how data is reported from national authorities to the OECD). We drop net taxes, and therefore define value added as output (the row sum of the tables) less inputs used (the column sum of the domestic and import input-output tables).[7] We allocate other adjustments and non-comparable exports and imports to the services sector, based on the fact that non-comparable imports in the U.S. input-output accounts are entirely services. Finally, values in the input-output tables are reported in national currency in the OECD input-output tables. We convert these to U.S. dollars using end-of-year exchange rates from the IMF's International Financial Statistics (AE series) and OECDStat. Values in the IDE-JETRO tables are reported in U.S. dollars.

Because the input-output and national accounts data are taken from separate sources, they are not identical. On top of this, input-output tables are available only for selected benchmark years, which differ across countries. To reconcile data sources and extrapolate from benchmark to non-benchmark years, we adjust the benchmark input-output data to match the time-varying national accounts and trade data using a constrained least squares procedure. In doing so, we give priority to matching the national accounts and trade data, both because they are available in all years and measured consistently through time (likely with less error). The objective is to minimize the weighted squared distance between the adjusted data and input-output data for benchmark years (or interpolations thereof), subject to a set of accounting identities. We pause here to spell out this procedure.

To define notation, let I_{Di} and I_{Ii} be 4×4 matrices of domestic and imported inputs, with elements $I_{Di}(s,s')$ and $I_{Ii}(s,s')$, let f_{Di} and f_{Ii} be 4×1 vectors of domestic and imported final demand, and let y_i be a 4×1 vector of sector-level output. Further, the 4×1 vector of exports is x_i. Note we suppress year notation here for convenience.

In the national accounts and trade data, we observe the following objects, denoted with bars to indicate data. We observe sector-level value added in a 1×4 vector $\bar{va}_i$ and (scaler) aggregate final demand $\bar{f}_i$. We also observe sector-level exports $\bar{x}_i$. On the import side, we observe imports by sector and end use for goods – $\bar{f}_{Ii}(s)$ and $\bar{I}_{Ii}(s)$ for $s=1,2,3$ – and services imports $\bar{m}_{it}(4)$.

Sector-level input use for domestic and imported intermediates (I_{Di}, I_{Ii}), sector-level domestic and imported final goods absorption $(f_{Di}, f_{Ii}(4))$, and sector-level gross output $(y_i(s))$ are treated as unknowns. We observe 'target' values for each of these unknowns, based on the value of these variables in the input-output tables for benchmark years, and linear

[5]The original OECD data covers 35 sectors for years before 1990 and 48 sectors for years after 1995, though not all countries report data at this level of disaggregation. The IDE-JETRO tables contain 24 sectors. Aggregation enables us to link these tables.

[6]Further, in the pre-1995 data, a few countries have negative entries in their import tables, due to treatment of transport margins, recycled products, and measurement error. We eliminate these using a procedure similar to that which we use to merge the IO tables with the production and trade data below, so omit details here for brevity.

[7]Recall that we adjust this data to match national accounts value added by sector. The only way value added from the input-output tables is used is to create value-added to output ratios, which are the basis for generating target values for gross output in the harmonization procedure described below.

interpolations between benchmark years.[8] We construct target sector output by dividing value added from the national accounts by the value added to output ratio in the input-output tables. We also construct target sector final expenditure by multiplying final demand in the national accounts by sector shares from input-output tables.

In each year, we solve for values for these 'unknown' variables that: (a) minimize differences between the adjusted data and raw data observed in benchmark years (or interpolations thereof between benchmark years); and (b) satisfy adding up constraints. We constrain the solution to match sector-level GDP, exports and imports of final and intermediate goods for each of the three goods sectors, exports and imports of services, and aggregate final expenditure. These constraints provide a lot of discipline in extrapolating the benchmark data. For example, we exactly match the time series for sector-level intermediate goods imports in all countries, which is the key determinant of vertical specialization.

With target values denoted by stars, then we solve:

$$\min \sum_i \sum_s \sum_{s'} \left[\left(\frac{I_{Di}(s,s') - I^*_{Di}(s,s')}{I^*_{Di}(s,s')} \right)^2 + \left(\frac{I_{Ii}(s,s') - I^*_{Ii}(s,s')}{I^*_{Ii}(s,s')} \right)^2 \right]$$
$$+ \sum_i \sum_s \left[\left(\frac{f_{Di}(s) - f^*_{Di}(s)}{f^*_{Di}(s)} \right)^2 + \left(\frac{y_i(s) - y^*_i(s)}{y^*_i(s)} \right)^2 \right] + \sum_i \left(\frac{f_{Ii}(4) - f^*_{Ii}(4)}{f^*_{Ii}(4)} \right)^2$$

subject to the following constraints:

$$y_{it}(s) = \bar{va}_{it}(s) + \sum_{s'} \left[I_{Iit}(s', s) + I_{Dit}(s', s) \right],$$
$$y_{it}(s) = f_{Dit}(s) + \sum_{s'} I_{Dit}(s, s') + \bar{x}_{it}(s),$$
$$\bar{m}_{it}(4) = f_{Iit}(4) + \sum_{s'} I_{Iit}(4, s'),$$
$$\bar{I}_{Iit}(s) = \sum_{s'} I_{Iit}(s, s') \quad \text{for } s = 1, 2, 3.$$

Note that in our data, $\bar{m}_{it}(s) = \bar{f}_{Iit}(s) + \sum_{s'} I_{Iit}(s, s')$ for $s = 1, 2, 3$ holds by construction. Further, the constraints imposed above imply that final expenditure adds up by construction: $\bar{f}_i = \sum_{s=1}^{3} \bar{f}_{Ii}(s) + f_{Ii}(4) + \sum_{s=1}^{4} f_{Di}(s)$. Therefore, we do not explicitly write these as constraints in the program above, though these adding up conditions are also satisfied.

The solution to this program provides annual domestic and imported intermediate input use and final demand values for the 42 countries between 1970 and 2009. Upon inspection, input-output data adjustments are generally small and plausible.

[8] For years outside the range of years bracketed by benchmarks, we set the initial values equal to the closest benchmark year. This is likely a conservative assumption, as it minimizes changes in input-output tables over time.

Table A1: Input-Output Data Coverage

Country	Code	early 70s	mid 70s	early 80s	mid 80s	early 90s	mid 90s	early 00s	mid 00s
Argentina	ARG	.	.	.	.	.	1997	.	.
Australia	AUS	1968	1974	.	1986	1989	1994/95	2001/02	2004/05
Austria	AUT	.	.	.	.	.	1995	2000	2005
Belgium	BEL	.	.	.	.	.	1995	2000	2005
Brazil	BRA	.	.	.	.	.	1995	2000	2005
Canada	CAN	1971	1976	1981	1986	1990	1995	2000	2005
Chile	CHL	.	.	.	.	.	1996	.	2003
China	CHN	.	.	.	*1985*	*1990*	1995	2000	2005
Czech Republic	CZE	.	.	.	.	.	.	2000	2005
Denmark	DNK	1972	1977	1980	1985	1990	1995	2000	2005
Estonia	EST	.	.	.	.	.	1997	2000	2005
Finland	FIN	.	.	.	.	.	1995	2000	2005
France	FRA	1972	1977	1980	1985	1990	1995	2000	2005
Germany	DEU	.	.	1978	1986	1988, 1990	1995	2000	2005
Greece	GRC	.	.	.	.	.	1995	2000	2005
Hungary	HUN	.	.	.	.	.	1998	2000	2005
India	IND	.	.	.	.	.	1993/94	1998/99	2003/04
Indonesia	IDN	.	.	.	*1985*	*1990*	1995	2000	2005
Ireland	IRL	.	.	.	.	.	1998	2000	2005
Israel	ISR	.	.	.	.	.	1995	.	2004
Italy	ITA	.	.	.	1985	.	1995	2000	2005
Japan	JPN	1970	1975	1980	1985	1990	1995	2000	2005
Korea	KOR	.	.	.	*1985*	*1990*	*1995*	2000	2005
Mexico	MEX	.	.	.	.	.	.	.	2003
Netherlands	NLD	1972	1977	1981	1986	.	1995	2000	2005
New Zealand	NZL	.	.	.	.	.	1995/96	2002/03	.
Norway	NOR	.	.	.	.	.	1995	2000	2005
Poland	POL	.	.	.	.	.	1995	2000	2005
Portugal	PRT	.	.	.	.	.	1995	2000	2005
Romania	ROU	.	.	.	.	.	.	2000	2005
Russia	RUS	.	.	.	.	.	1995	2000	.
Slovak Republic	SVK	.	.	.	.	.	1995	2000	2005
Slovenia	SVN	.	.	.	.	.	1996	2000	2005
South Africa	ZAF	.	.	.	.	.	1993	2000	2005
Spain	ESP	.	.	.	.	.	1995	2000	2005
Sweden	SWE	.	.	.	.	.	1995	2000	2005
Switzerland	CHE	.	.	.	.	.	.	2001	.
Thailand	THA	.	.	.	*1985*	*1990*	*1995*	*2000*	2005
Turkey	TUR	.	.	.	.	.	1996	1998	2002
United Kingdom	GBR	1968	.	1979	1984	1990	1995	2000	2005
United States	USA	1972	1977	1982	1985	1990	1995	2000	2005
Vietnam	VNM	.	.	.	.	.	.	2000	.

Note: Regular font indicates table is from the OECD Input-Output Database. Italics indicate table is from the IDE-JETRO Asian Input-Output Tables.

Table A2: Sector Aggregation and Definitions

Sector	Name	ISIC Rev. 2	ISIC Rev. 3.1	1995 OECD codes	2011 OECD codes	Asian IO codes
1	Agriculture, hunting, forestry and fishing	1	A,B	1	1	1 to 5
2	Non-manufacturing industrial production	2,4,5	C,E,F	2,25,26	2, 3, 26 to 30	6,7,20,21
3	Manufactures	3	D	3 to 24, 35	4 to 25	8 to 19
4	Services	6 to 9	G to Q	27 to 34	31 to 48	23, 24

B Model Appendix

This appendix describes the equilibrium of the model presented in Section 3.1. We also discuss how we take the model to data, including how we use the model to recover trade frictions and expenditure weights from data, how we compute productivity and the investment share shock, and other technical details.

B.1 Equilibrium in Levels

Using the notation defined in Section 3.1.2, the we characterize the equilibrium as follows.

Representative producers in each sector choose $\{L_{it}(s), K_{it}(s), X_{jit}(s', s)\}$ to maximize profits, given by $p_{it}(s)Q_{it}(s) - w_{it}L_{it}(s) - r_{it}K_{it}(s) - \sum_j \sum_{s'}(1 + \tau^X_{jit}(s', s))p_{jt}(s')X_{jit}(s', s)$, taking prices $\{p_{it}(s), w_{it}, r_{it}\}$ as given and subject to the production function defined in Equations (5)-(8). The first order conditions for production can be written as:

$$\pi^V_{it}(s) = \lambda^V_i(s)\left(\frac{p^V_{it}(s)}{p_{it}(s)}\right)^{\sigma/(\sigma-1)} \tag{B1}$$

$$\pi^X_{it}(s', s) = (1 - \lambda^V_i(s))\left(\frac{\omega^X_{it}(s', s)p^X_{it}(s', s)}{p_{it}(s)}\right)^{\sigma/(\sigma-1)} \tag{B2}$$

$$\pi^X_{jit}(s', s) = \left(\frac{\omega^X_{jit}(s', s)p_{jt}(s')}{p^X_{it}(s', s)}\right)^{\kappa/(\kappa-1)} \tag{B3}$$

$$r_{it}K_{it}(s) = \alpha p^V_{it}(s)V_{it}(s) \tag{B4}$$

$$w_{it}L_{it}(s) = (1 - \alpha)p^V_{it}(s)V_{it}(s), \tag{B5}$$

where $\pi^V_{it}(s) \equiv p^V_{it}(s)V_{it}(s)/p_{it}(s)Q_{it}(s)$, $\pi^X_{it}(s', s) \equiv p^X_{it}(s', s)X_{it}(s', s)/p_{it}(s)Q_{it}(s)$, $\pi^X_{jit}(s', s) \equiv \tau^X_{jit}(s', s)p_{jt}(s')X_{jit}(s', s)/p^X_{it}(s', s)X_{it}(s', s)$, and the composite prices $\{p^X_{it}(s', s), p^V_{it}(s)\}$ are given by:

$$p^X_{it}(s', s) = \left[\sum_j \left(\omega^X_{jit}(s', s)p_{jt}(s')\right)^{\kappa/(\kappa-1)}\right]^{(\kappa-1)/\kappa} \tag{B6}$$

$$p^V_{it}(s) = \frac{(r_{it}/\alpha)^{\alpha}(w_{it}/(1-\alpha))^{1-\alpha}}{Z_{it}(s)}. \tag{B7}$$

Further, the price of gross output can be written as:

$$p_{it}(s) = \left[\lambda^V_{it}(s)p^V_{it}(s)^{\sigma/(\sigma-1)} + (1 - \lambda^V_i(s))\sum_{s'}\left(\omega^X_{it}(s', s)p^X_{it}(s', s)\right)^{\sigma/(\sigma-1)}\right]^{(\sigma-1)/\sigma} \tag{B8}$$

Representative final goods producers maximize $p^F_{it}F_{it} - \sum_j \sum_s(1 + \tau^F_{jit}(s))p_{jt}(s)F_{ji}(s)$, taking prices $\{p^F_{it}, p_{jt}(s)\}$ as given and subject to the final goods production function in

Equation (10). The first order conditions are:

$$\pi_{it}^F(s) = \left(\frac{\omega_{it}^F(s)p_{it}^F(s)}{p_{it}^F}\right)^{\rho/(\rho-1)} \tag{B9}$$

$$\pi_{jit}^F(s) = \left(\frac{\omega_{jit}^F(s)p_{jt}(s)}{p_{it}^F(s)}\right)^{\kappa/(\kappa-1)}, \tag{B10}$$

where $\pi_{it}^F(s) \equiv p_{it}^F(s)F_{it}(s)/p_{it}^F F_{it}$, $\pi_{jit}^F(s) \equiv \tau_{jit}^F(s)p_{jt}(s)F_{jit}(s)/p_{it}^F(s)F_{it}(s)$, and the composite prices $\{p_{it}^F(s)\}$ are given by:

$$p_{it}^F(s) = \left[\sum_j \left(\omega_{jit}^F(s)p_{jt}(s)\right)^{\kappa/(\kappa-1)}\right]^{(\kappa-1)/\kappa}. \tag{B11}$$

Further, the price of the composite final goods can be written as:

$$p_{it}^F = \left[\sum_s \left(\omega_{it}^F(s)p_{it}^F(s)\right)^{\rho/(\rho-1)}\right]^{(\rho-1)/\rho}. \tag{B12}$$

The remaining market clearing and equilibrium conditions are:

$$p_{it}(s)Q_{it}(s) = \sum_{s'}\sum_j \pi_{ijt}^X(s,s')\pi_{jt}^X(s,s')p_{jt}(s)Q_{jt}(s) + \sum_j \pi_{ijt}^F(s)\pi_{jt}^F(s)p_{jt}^F F_{jt} \tag{B13}$$

$$K_{it} = \sum_s K_{it}(s) \tag{B14}$$

$$L_{it} = \sum_s L_{it}(s) \tag{B15}$$

$$p_{it}^F F_{it} = \sum_s [r_{it}K_{it}(s) + w_{it}L_{it}(s)] + T_{it} \tag{B16}$$

$$F_{it} = C_{it} + I_{it} \tag{B17}$$

$$K_{i,t+1} = I_{it} + (1-\delta_{it})K_{it} \tag{B18}$$

$$I_{it} = s_{it}F_{it}. \tag{B19}$$

B.2 Equilibrium in Changes

Following Dekle, Eaton and Kortum (2008), we define and solve the model equilibrium in changes. By way of notation, let $\hat{x}_t \equiv \frac{x_{t+1}}{x_t}$. Then we can re-write the first-order conditions for production and demand as:

$$\hat{\pi}_{it}^{V}(s) = \left(\frac{\hat{p}_{it}^{V}(s)}{\hat{p}_{it}(s)}\right)^{\sigma/(\sigma-1)} \tag{B20}$$

$$\hat{\pi}_{it}^{X}(s', s) = \left(\frac{\hat{\omega}_{it}^{X}(s', s)\hat{p}_{it}^{X}(s', s)}{\hat{p}_{it}(s)}\right)^{\sigma/(\sigma-1)} \tag{B21}$$

$$\hat{\pi}_{jit}^{X}(s', s) = \left(\frac{\hat{\omega}_{jit}^{X}(s', s)\hat{p}_{jt}(s')}{\hat{p}_{it}^{X}(s', s)}\right)^{\kappa/(\kappa-1)} \tag{B22}$$

$$\hat{r}_{it}\hat{K}_{it}(s) = \hat{p}_{it}^{V}(s)\hat{V}_{it}(s) \tag{B23}$$

$$\hat{w}_{it}\hat{L}_{it}(s) = \hat{p}_{it}^{V}(s)\hat{V}_{it}(s) \tag{B24}$$

$$\hat{\pi}_{it}^{F}(s) = \left(\frac{\hat{\omega}_{it}^{F}(s)\hat{p}_{it}^{F}(s)}{\hat{p}_{it}^{F}}\right)^{\rho/(\rho-1)} \tag{B25}$$

$$\hat{\pi}_{jit}^{F}(s) = \left(\frac{\hat{\omega}_{jit}^{F}(s)\hat{p}_{jt}(s)}{\hat{p}_{ti}^{F}(s)}\right)^{\kappa/(\kappa-1)}. \tag{B26}$$

Changes in price indexes take the form:

$$\hat{p}_{it}(s) = \left[\pi_{it}^{V}(s)\hat{p}_{it}^{V}(s)^{\sigma/(\sigma-1)} + \sum_{s'} \pi_{it}^{X}(s', s)\left(\hat{\omega}_{it}^{X}(s', s)\hat{p}_{it}^{X}(s', s)\right)^{\sigma/(\sigma-1)}\right]^{(\sigma-1)/\sigma} \tag{B27}$$

$$\hat{p}_{it}^{X}(s', s) = \left[\sum_{j} \pi_{jit}^{X}(s', s)\left(\hat{\omega}_{jit}^{X}(s', s)\hat{p}_{jt}(s')\right)^{\kappa/(\kappa-1)}\right]^{(\kappa-1)/\kappa} \tag{B28}$$

$$\hat{p}_{it}^{V}(s) = \frac{(\hat{r}_{it})^{\alpha}(\hat{w}_{it})^{1-\alpha}}{\hat{Z}_{it}(s)} \tag{B29}$$

$$\hat{p}_{it}^{F} = \left[\sum_{s} \pi_{it}^{F}(s)\left(\hat{\omega}_{it}^{F}(s)\hat{p}_{it}^{F}(s)\right)^{\rho/(\rho-1)}\right]^{(\rho-1)/\rho} \tag{B30}$$

$$\hat{p}_{it}^{F}(s) = \left[\sum_{j} \pi_{jit}^{F}(s)\left(\hat{\omega}_{jit}^{F}(s)\hat{p}_{jt}(s)\right)^{\kappa/(\kappa-1)}\right]^{(\kappa-1)/\kappa} \tag{B31}$$

Other market clearing and equilibrium conditions are re-written as:

$$\begin{aligned} p_{it}(s)Q_{it}(s)\hat{p}_{i}(s)\hat{Q}_{i}(s) = {} & \sum_{j} \pi_{ijt}^{F}(s)\pi_{jt}^{F}(s)p_{jt}^{F}F_{jt}\hat{\pi}_{ij}^{F}(s)\hat{\pi}_{j}^{F}(s)\hat{p}_{j}^{F}\hat{F}_{j} \\ & + \sum_{s'}\sum_{j} \pi_{ijt}^{X}(s, s')\pi_{jt}^{X}(s, s')p_{jt}(s')Q_{jt}(s')\hat{\pi}_{ij}^{X}(s, s')\hat{\pi}_{j}^{X}(s, s')\hat{p}_{j}(s')\hat{Q}_{j}(s'). \end{aligned} \tag{B32}$$

$$K_{it}\hat{K}_{it} = \sum_s K_{it}(s)\hat{K}_{it}(s) \quad \text{(B33)}$$

$$L_{it}\hat{L}_{it} = \sum_s L_{it}(s)\hat{L}_{it}(s) \quad \text{(B34)}$$

$$p^F_{it}F_{it}\hat{p}^F_i\hat{F}_i = \sum_s p^V_{it}V_{it}(s)\hat{p}^V_{it}\hat{V}_{it}(s) + T_{it}\hat{T}_i \quad \text{(B35)}$$

$$\hat{F}_{it} = \pi^C_{it}\hat{C}_{it} + \pi^I_{it}\hat{I}_{it} \quad \text{(B36)}$$

$$\hat{K}_{i,t+1} = \frac{\hat{I}_{it}}{\hat{K}_{it}}\left[\hat{K}_{it} - (1-\delta_{it})\right] + (1-\delta_{i,t+1}) \quad \text{(B37)}$$

$$\hat{I}_{it} = \hat{s}_{it}\hat{F}_{it}, \quad \text{(B38)}$$

where $\pi^C_{it} = \frac{p^F_{it}C_{it}}{p^F_{it}F_{it}}$ and $\pi^I_{it} = \frac{p^F_{it}I_{it}}{p^F_{it}F_{it}}$ are the value shares of consumption (private + government) and investment in final expenditure. In the capital accumulation equation, note that $\hat{K}_{it}$ is predetermined at date t (i.e., not a function of $\hat{I}_{it}$), and so can be treated as given when solving for equilibrium changes between dates t and $t+1$.

To parameterize the model, we need values for expenditure shares $\{\pi^V_{it}(s), \pi^X_{it}(s',s), \pi^X_{jit}(s',s), \pi^F_{it}(s), \pi^F_{jit}(s), \pi^C_{it}, \pi^I_{it}\}$ and expenditure levels $\{p_{it}(s)Q_{it}(s), p^V_{it}(s)V_{it}(s), p^F_{it}F_{it}, T_{it}\}$. We take these from data when we compute trade frictions and expenditure weights. In counterfactual simulations, these are set to the initial period (1970) value to compute changes between 1970-1971 and then set to counterfactual values thereafter. In addition to the elasticities (discussed in the main text), we also need depreciation rates $\{\delta_{it}\}$. We also take these from data, as discussed below.

Equilibrium Definition Given an initial condition $\{\hat{K}_{i1}\}$, changes in expenditure weights $\hat{\Omega} \equiv \{\hat{\omega}^X_{jit}(s',s), \hat{\omega}^X_{it}(s',s), \hat{\omega}^F_{jit}(s), \hat{\omega}^F_{it}(s)\}$, and changes in trade balances, productivity, labor endowments, and the investment share $\{\hat{T}_{it}, \hat{Z}_{it}(s), \hat{L}_{it}, \hat{s}_{it}\}$, an equilibrium is a set of changes in quantities $\{\hat{Q}_{it}(s), \hat{F}_{it}(s), \hat{F}_{it}, \hat{V}_{it}(s), \hat{K}_{it}(s), \hat{L}_{it}(s), \hat{C}_{it}, \hat{I}_{it}, \hat{K}_{i,t+1}\}$, shares $\{\hat{\pi}^V_{it}(s), \hat{\pi}^X_{it}(s',s), \hat{\pi}^X_{jit}(s',s), \hat{\pi}^F_{it}(s), \hat{\pi}^F_{jit}(s)\}$, and prices $\{\hat{p}^V_{it}(s), \hat{p}_{it}(s), \hat{\bar{p}}^X_{it}(s',s), \hat{p}^F_{it}, \hat{\bar{p}}^F_{it}(s), \hat{r}_{it}, \hat{w}_{it}\}$ that satisfy Equations (B20)-(B38). Reflecting Walras Law, one price change should be normalized to 1 and a corresponding equilibrium condition should be dropped in solving for the equilibrium.[9]

B.3 Computing Trade Frictions and Expenditure Weights

Using the equilibrium conditions above, along with data on prices $\{\hat{p}^V_{it}(s), \hat{p}^F_{it}\}$ and expenditure shares $\{\hat{\pi}^V_{it}(s), \hat{\pi}^X_{it}(s',s), \hat{\pi}^X_{jit}(s',s), \hat{\pi}^F_{it}(s), \hat{\pi}^F_{jit}(s)\}$, we solve for $\hat{\Omega}$ in the following sequence:

1. We use Equation (B20) to solve for gross output prices $\hat{p}_{it}(s)$.

2. We use Equation (B22) to solve for input trade frictions $\hat{\omega}^X_{jit}(s',s)$.

[9] Because we focus on nominal values for value-added and gross trade, all results in the paper can be interpreted without needing to know the country/sector of normalization.

3. We use Equation (B28) to construct input prices $\hat{p}^X_{it}(s', s)$.

4. We use Equation (B21) to solve for input expenditure weights $\hat{\omega}^X_{it}(s', s)$.

5. We use Equation (B26) to solve for final goods trade frictions $\hat{\omega}^F_{jit}(s)$.

6. We use Equation (B31) to construct final goods prices $\hat{p}^F_{it}(s)$.

7. We use Equation (B25) to solve for final expenditure weights $\hat{\omega}^F_{it}(s)$.

B.4 Parameters and Exogenous Variables for Counterfactuals

In addition to $\hat{\Omega}$, we need values for the remaining exogenous variables $\{\hat{T}_{it}, \hat{Z}_{it}(s), \hat{L}_{it}, \hat{s}_{it}\}$ to compute counterfactuals. We also need depreciation rates $\{\delta_{it}\}$ to track the capital stock over time. We set $\{\hat{T}_{it}\}$ equal to trade balances observed in our global input-output data, described in Section 1.2. The remaining data are based on the Penn World Tables (Version 8.1).[10] We set $\{\hat{L}_{it}\}$ equal to changes in "effective labor," defined as the product of human capital per worker (the PWT human capital index) times the number of workers (number of persons engaged).

Turning to capital accumulation, we use the Penn World Tables capital stock series and country-specific, time-varying depreciation rates δ_{it} to back out changes in real investment $\hat{I}_{it}$ using Equation (B37).[11] Combined with data on real expenditure, we then compute $\hat{s}_{it} = \frac{\hat{I}_{it}}{\hat{F}_{it}}$.

Lastly, we need to estimate productivity changes $\hat{Z}_{it}(s)$ to conduct counterfactuals. To do so, we allocate changes in aggregate capital and labor series from the Penn World Tables using the model. Using Equations (B4) and (B5), it is straightforward to show that $K_{it}(s) = \left(\frac{GDP_{it}(s)}{GDP_{it}}\right) K_{it}$ and $L_{it}(s) = \left(\frac{GDP_{it}(s)}{GDP_{it}}\right) L_{it}$, where $GDP_{it}(s) = p^V_{it}(s)V_{it}(s)$. This gives us data series for changes in capital and labor by sector $\{\hat{K}_{it}(s), \hat{L}_{it}(s)\}$. Combining these with data on real GDP changes $\hat{V}_{it}(s)$, we recover $\hat{Z}_{it}(s) = \frac{\hat{V}_{it}(s)}{(\hat{K}_{it}(s))^{\alpha}(\hat{L}_{it}(s))^{1-\alpha}}$.

B.5 Additional Details

In computing trade frictions, expenditure weights, and counterfactuals, we confront a few additional complications.

[10]See http://www.rug.nl/research/ggdc/data/pwt/pwt-8.1.

[11]Because the Penn World Tables capital stock series is built using an investment-specific deflator, this real investment series allows for investment-specific technical change, which is embedded in $\hat{s}_{it}$. In making the assumption that $\hat{s}_{it}$ is exogenous, we are making two underlying assumptions: both the nominal share of investment in final expenditure and the rate of investment-specific technical are exogenous. This is substantively the same as in Levchenko and Zhang (2016). While Levchenko and Zhang take the (nominal) savings rate as exogenous, this is equivalent to taking the nominal investment share as given since their baseline model has balanced trade. They also use the Penn World Tables capital stock to compute real investment, as we do.

Rest of the World As noted in Section 1.2, we possess input-output data for 42 individual countries and collect remaining countries in a composite rest-of-the-world region. In the model accounting exercise, we focus on the 37 countries that have complete time series data from 1970-2009, and add the remaining 5 Eastern European countries to the rest-of-the-world composite. Because we do not have input-output and price data for this rest-of-the-world composite, we need to make two additional assumptions.

First, we assume that changes in gross exports from each country to the rest of the world ($\widehat{EX}_{i,ROW,t}(s)$) are exogenous. This means that the gross output market clearing condition can be re-written as:

$$\begin{aligned} p_{it}(s)Q_{it}(s)\hat{p}_{it}(s)\hat{Q}_{it}(s) = & \sum_{j \neq ROW} \pi^F_{ijt}(s)\pi^F_{jt}(s)p^F_{jt}F_{jt}\hat{\pi}^F_{ijt}(s)\hat{\pi}^F_{jt}(s)\hat{p}^F_{jt}\hat{F}_{jt} \\ & + \sum_{s'} \sum_{j \neq ROW} \pi^X_{ijt}(s,s')\pi^X_{jt}(s,s')p_{it}(s')Q_{it}(s')\hat{\pi}^X_{ijt}(s,s')\hat{\pi}^X_{jt}(s,s')\hat{p}_{jt}(s')\hat{Q}_{jt}(s') \\ & + EX_{i,ROW,t}(s)\widehat{EX}_{i,ROW,t}(s), \end{aligned}$$

where $EX_{i,ROW,t}(s)$ is exports from i to the rest-of-the-world region in sector s. This replaces Equation (B32) in the numerical solution procedure.

Second, we assume that gross output prices for imports from the rest of the world ($\hat{p}_{ROW,t}(s)$) are exogenous. Normalizing $\hat{p}_{ROW,t}(s) = 1$, this second assumption implies that trade frictions $\{\hat{\tau}^X_{ROW,it}(s,s'), \hat{\tau}^F_{ROW,it}(s)\}$ measure both changes in frictions and unobserved price changes.

In all simulations, we feed realized values for $\widehat{EX}_{i,ROW,t}(s)$ and $\{\hat{\tau}^X_{ROW,it}(s,s'), \hat{\tau}^F_{ROW,it}(s)\}$ into the model. Therefore, these nuisance parameters do not play a significant role in explaining differences in simulated data across alternative counterfactual scenarios.

Zeros In the input-output and trade data, there are a small number of zero entries (or near zeros), almost exclusively in the bilateral trade data and mostly concentrated in first half of the sample period. These create technical problems in computing trade frictions and solving the model. If a particular value is zero in the initial period, then $\hat{x}_t$ is undefined. Alternatively, if a particular value is positive in the initial period and then zero in period $t+1$, CES preferences imply that trade frictions fall from infinity to a finite value. Since these occurrences are rare, we deal with them by adopting an approximation. We take any value in the bilateral final and and intermediate goods shipments data that is less than \$1000 and set it equal to \$1000, and then recompute other objects in the data (e.g., gross output) as necessary to satisfy adding up conditions. This approximation plays no role in understanding model results.

C Model Accounting Appendix

This appendix documents how trade frictions and expenditure weights change over time. It also describes how we estimate the response of trade frictions to adoption of regional trade agreements and construct the counterfactual trade cost series used in Section 4.2.

C.1 Changes in Trade Frictions

In our framework, changes in trade frictions vary across bilateral pairs at the sector (or sector-pair) level. To summarize them, we aggregate the frictions in to composite indexes. These indexes can be constructed for any time horizon. In our analysis below, we focus on long horizon changes in trade frictions, from 1970 to 2009.[12] Therefore, the hat-notation in this section can be interpreted as denoting the ratio of frictions in 2009 relative to 1970, and trade weights are based on 1970 values.

For each importer and sector, we aggregate bilateral frictions via CES indexes:

$$\hat{\omega}^F_{(-i)i}(s) \equiv \left[\sum_{j\neq i}\left(\frac{\pi^F_{ji}(s)}{\pi^F_{(-i)i}(s)}\right)\hat{\omega}^F_{ji}(s)^{\kappa/(\kappa-1)}\right]^{(\kappa-1)/\kappa} \tag{C1}$$

$$\hat{\omega}^X_{-(i)i}(s',s) \equiv \left[\sum_{j\neq i}\left(\frac{\pi^X_{ji}(s',s)}{\pi^X_{(-i)i}(s',s)}\right)\left(\hat{\omega}^X_{ji}(s',s)\right)^{\kappa/(\kappa-1)}\right]^{(\kappa-1)/\kappa}, \tag{C2}$$

where $\pi^F_{(-i)i}(s) = \sum_{j\neq i}\pi^F_{ji}(s)$ and $\pi^X_{(-i)i}(s',s) = \sum_{j\neq i}\pi^X_{ji}(s',s)$. These indexes aggregate the trade frictions in a way that summarizes their impact on CES import price indexes.[13]

To build country-level indexes, we take imported-weighted averages of these indexes across sectors:

$$\hat{\omega}_{(-i)i} \equiv \sum_s\sum_{j\neq i} w^F_i(s)\hat{\omega}^F_{(-i)i}(s) + \sum_s\sum_{s'}\sum_{j\neq i} w^X_i(s',s)\hat{\omega}^X_{-(i)i}(s',s),$$

where the weights are $w^F_i(s) \equiv \frac{\pi^F_{ji}(s)\pi^F_i(s)p^F_i F_i}{IM_i}$ and $w^X_i(s',s) \equiv \frac{\pi^X_{ji}(s,s')\pi^X_i(s,s')p_i(s')Q_i(s')}{IM_i}$, with $IM_i = \sum_{j\neq i}\pi^F_{ji}(s)\pi^F_i(s)p^F_i F_{it} + \sum_{s'}\sum_{j\neq i}\pi^X_{ji}(s,s')\pi^X_i(s,s')p_i(s')Q_i(s')$.

To aggregate trade frictions across countries, we take trade-weighted averages of these country-level indexes:

$$\hat{\omega} \equiv \sum_i\left(\frac{IM_{it}}{IM_t}\right)\hat{\omega}_{(-i)i}. \tag{C3}$$

For the world as a whole, our estimates imply that iceberg frictions fall by 35% from 1970 to 2009 (i.e., $\hat{\omega} = 0.65$). To benchmark this figure, Jacks, Meissner and Novy (2011)

[12] Note that 2009 includes the Great Recession and Trade Collapse. Excluding the trade collapse has little effect on measured trade frictions, consistent with Eaton et al. (forthcoming).

[13] To clarify this point, one can use the final goods price index (Equation (B31)) to define the following import price index: $\hat{p}^F_{(-i)it}(s) \equiv \left[\sum_{j\neq i}\left(\frac{\pi^F_{jit}(s)}{\pi^F_{(-i)it}(s)}\right)\left(\hat{\omega}^F_{ji}(s)\hat{p}_j(s)\right)^{\kappa/(\kappa-1)}\right]^{(\kappa-1)/\kappa}$. A price index for imported inputs can be defined similarly. The trade frictions indexes are analogs to these import price indexes.

estimate that the ad valorem tariff equivalent of iceberg trade frictions declined by 26% from 1970 to 2000 for 12 industrial countries.[14] For reasonable values of iceberg costs in 1970, this translates into a decline in iceberg frictions on the order of 17%.[15] For comparison, our estimates imply that iceberg frictions fell by 23% over the 1970-2000 interval, close to the Jacks et al. estimate.[16] Comparing this to our estimate over the entire 1970-2008 interval, iceberg trade costs continued to fall (rapidly) during the 2000's.

Disaggregating this global result, we present disaggregated trade friction indexes by country and sector in Table C1. There is significant dispersion in estimated trade cost declines across countries. The summary statistic $\hat{\omega}_{(-i)i}$ is included in the last column of Table C1. The quartiles of the distribution are $\{0.51, 0.64, 0.79\}$. An important feature of these changes is that they line up with changes in openness in a sensible way. To illustrate this, Figure C1 plots the log ratio of trade frictions against the log ratio of openness. Turning to the sector level indexes $\hat{\omega}^F_{(-i)i}(s)$ and $\hat{\omega}^X_{-(i)i}(s', s)$ in the body of the table, trade frictions decline in 184 out of 222 (83%) of cases. Looking at the medians in the bottom row, declines are somewhat larger for manufactures (sector 2) than for non-manufactures (sector 1), particularly for final goods.

C.2 Changes in Expenditure Weights

Table C2 presents changes in input and final goods expenditure weights over time. These are the cumulated values of $\hat{\omega}^F_i(s)$ and $\hat{\omega}^X_i(s', s)$ from 1970-2008.[17]

Three general points are worth making. First, the changes in final goods expenditure weights are broadly similar across sectors. This holds despite the fact that the share of services in final expenditure is rising. The reason is that this rise in the services share is largely accounted for in the model by the complementarity between manufactures and non-

[14] In the main body of the paper, Jacks et al. use country-level GDP data to measure production (and hence domestic trade). In Appendix B of their paper, they use data on gross output for goods producing sectors instead. Our approach to measuring frictions is closer to this second gross output method, and so we use it as our benchmark.

[15] Let $\tau = (1 + t)$ be the iceberg friction and let t is the ad valorem tariff equivalent. Jacks et al. report $\frac{t_{2000}}{t_{1970}} = 0.74$. To compare this to our figure, we need to convert this into a ratio of iceberg frictions: $\frac{1+t_{2000}}{1+t_{1970}}$. This requires taking a stand on the level of trade frictions in 1970. A reasonable guess is that trade frictions were 200% in 1970, since Anderson and van Wincoop (2004) report ad valorem trade costs totaled 170% based on evidence from the 1990's and early 2000's. Given this prior, then the Jacks et al. tariff equivalent estimates implies that the ratio of iceberg frictions in 2000 relative to 1970 would be 0.83.

[16] There are many technical reasons why the estimates should not match exactly, and it is not the purpose of this paper to conduct a fine-grained comparison of them. Nonetheless, it is useful to highlight a few basic issues. First, we use a lower trade elasticity than do Jacks et al. (4 versus 8). Second, our sample includes emerging markets, where declines in frictions have been larger. Both these tend to raise our estimates relative to Jacks et al. On the other hand, we include services trade, where the Jacks et al. estimate covers goods trade only. This tends to attenuate measured changes in aggregate trade frictions, since frictions in services have fallen more slowly than in manufactures (see Table C1). All together, we conclude that our estimates are in the ballpark of what is currently known about changes in trade costs.

[17] Here we exclude data for 2009, during the Great Recession and Trade Collapse. The reason is that there are sharp changes in demand composition during the recession, which are picked up in the measured expenditure weights. For example, the final expenditure weight on manufacturing is substantially lower in 2009, reflecting the collapse in demand for manufactures (despite minimal price changes) observed in the data. Discarding these recession-induced changes gives us a clearer picture of secular trends.

manufactures in preferences. Second, on the input side, increases in expenditure weights for the use of non-manufactures as inputs have tended to pull input expenditure toward non-manufactures over time. This reflects structural change in IO tables, not accounted for by relative price changes. In contrast, manufactures have become more intensively used in services (indicated in the 2,1 column) for reasons not accounted for by relative prices. Third, at the individual and country and sector level, there is a good bit of heterogeneity in how these expenditure weights evolve. We implicitly assess whether these structural shifts and heterogeneity matter via the counterfactuals.

C.3 Trade Frictions and RTA Adoption

To estimate how trade frictions change with RTA adoption, we model the trade frictions in levels as:

$$\begin{aligned} \omega^X_{ijt}(s,s') &= \Phi^X_{ij}(s,s')\Phi^X_{it}(s,s')\Phi^X_{jt}(s,s')c^X_{ijt}(s,s'), \\ \omega^F_{ijt}(s) &= \Phi^F_{ij}(s)\Phi^F_{it}(s)\Phi^F_{jt}(s)c^F_{ijt}(s), \end{aligned} \tag{C4}$$

where the first component is a time-invariant pair effect, the second and third components are source and destination time-varying effects, and the fourth component is a bilateral, time-varying effect. We then parameterize the bilateral, time-varying component as:

$$\begin{aligned} \log(c^X_{ijt}(s,s')) &= \beta^X(s,s')TradeAgreement_{ijt} + \epsilon^X_{ijt}(s,s'), \\ \log(c^F_{ijt}(s)) &= \beta^F(s)TradeAgreement_{ijt} + \epsilon^F_{ijt}(s), \end{aligned} \tag{C5}$$

where $TradeAgreement_{ijt}$ is a vector of indicators for whether i and j are in a particular trade agreement at time t, and $\beta^X(s,s')$ and $\beta^F(s)$ are then estimated trade agreement effects for each type of trade and sector-pairing.

Taking logs and first-differences across adjacent time periods (five year intervals), we arrive at the following reduced form estimating equations:

$$\begin{aligned} \Delta\log(\omega^X_{ijt}(s,s')) &= \Delta\phi^X_{it}(s,s') + \Delta\phi^X_{jt}(s,s') + \beta^X(s,s')\Delta TradeAgreement_{ijt} + \Delta\epsilon^X_{ijt}(s,s'), \\ \Delta\log(\omega^F_{ijt}(s)) &= \Delta\phi^F_{it}(s) + \Delta\phi^F_{jt}(s) + \beta^F(s)\Delta TradeAgreement_{ijt} + \Delta\epsilon^F_{ijt}(s), \end{aligned} \tag{C6}$$

where $\phi \equiv \log(\Phi)$. Note that the time-invariant, pair-specific components of the trade frictions are differenced away. Further, we can control for the time-varying source and destination components of trade costs with source-year and destination-year fixed effects.

Following the discussion in Section 2.2, we estimate these regressions using several alternative specifications for $TradeAgreement_{ijt}$. We report coefficient estimates for the same specifications used in Figure C6.

Using the point estimates on trade agreement indicators from estimating Equation (C6), we adjust measured trade frictions $\hat{\omega}^X_{ijt}(s,s')$ and $\hat{\omega}^F_{ijt}(s)$ to remove changes due to adoption of trade agreements. The exact procedure we use is as follows.

We first cumulate changes in the trade frictions to define a series that defines changes since 1970. Let $\hat{v}^X_{ijt}(s,s') \equiv \omega^X_{ijt}(s,s')/\omega^X_{ij1970}(s,s')$ and $\hat{v}^F_{ijt}(s) \equiv \omega^F_{ijt}(s)/\omega^F_{ij1970}(s)$ denote the ratio of trade frictions in year t relative to 1970. Then we compute bilateral adjustment factors $\exp\left(\beta^X(s,s')\Delta_{1970}TradeAgreement_{ijt}\right)$ and $\exp\left(\beta^F(s)\Delta_{1970}TradeAgreement_{ijt}\right)$, where Δ_{1970} indicates a long difference from year t to 1970. These adjustment factors take the value one in years that a pair has the same agreement it had in 1970 (i.e., when $\Delta_{1970}TradeAgreement_{ijt} = 0$). They take on the values $\exp\left(\beta^X(s,s')\right)$ or $\exp\left(\beta^F(s)\right)$ when ij has an agreement in year t that it did not have in 1970.[18] The counterfactual changes in trade frictions are then given by:

$$\begin{aligned}
\hat{\tilde{v}}^X_{ijt}(s,s') &\equiv \frac{\hat{v}^X_{ijt}(s,s')}{\exp\left(\beta^X(s,s')\Delta_{1970}TradeAgreement_{ijt}\right)}, \\
\hat{\tilde{v}}^F_{ijt}(s) &\equiv \frac{\hat{v}^F_{ijt}(s)}{\exp\left(\beta^F(s)\Delta_{1970}TradeAgreement_{ijt}\right)},
\end{aligned} \tag{C7}$$

where the tilde denotes counterfactual values. Since the estimates of $\beta^X(s,s')$ and $\beta^F(s)$ are negative in all cases, this adjustment raises counterfactual trade frictions relative to the baseline series. We convert these counterfactual cumulative changes in trade frictions into counterfactual year-on-year changes by taking ratios of cumulative changes in adjacent years: $\hat{\tilde{\omega}}^X_{ijt}(s,s') \equiv \hat{\tilde{v}}^X_{ij,t+1}(s,s')/\hat{\tilde{v}}^X_{ijt}(s,s')$ and $\hat{\tilde{\omega}}^F_{ijt}(s) \equiv \hat{\tilde{v}}^F_{ij,t+1}(s)/\hat{\tilde{v}}^F_{ijt}(s)$. We feed $\hat{\tilde{\omega}}^X_{ijt}(s,s')$ and $\hat{\tilde{\omega}}^F_{ijt}(s)$ into the model to generate the counterfactuals in Section 4.2.

[18]In this adjustment, we use the same set of trade agreement indicators as we use in running the regression, with changes in agreement status recorded at 5 year intervals.

Table C1: Changes in Trade Frictions

	Final Goods		Inputs				Trade-Weighted
	n	m	n,n	n,m	m,n	m,m	Average
ARG	0.31	0.22	0.33	0.35	0.34	0.27	0.28
AUS	0.88	0.59	0.90	0.65	0.73	0.87	0.76
AUT	1.06	0.50	0.96	1.00	0.70	0.58	0.69
BEL	0.56	0.36	0.51	0.54	0.54	0.60	0.52
BRA	0.98	1.30	0.89	1.19	1.51	1.29	1.23
CAN	0.55	0.60	0.70	0.55	0.81	0.81	0.69
CHE	0.97	0.96	0.93	1.04	1.16	1.18	1.05
CHL	0.45	0.51	0.39	0.36	0.55	0.68	0.52
CHN	0.21	0.10	0.21	0.25	0.19	0.20	0.20
DEU	0.47	0.55	0.65	0.69	0.67	0.64	0.62
DNK	0.58	0.44	1.16	1.47	0.78	0.76	0.82
ESP	1.08	0.62	1.19	1.17	1.02	0.82	0.91
FIN	1.18	0.36	0.81	0.72	0.40	0.41	0.53
FRA	0.64	0.51	0.87	0.88	0.69	0.72	0.69
GBR	0.61	0.26	1.34	1.31	0.23	0.31	0.64
GRC	0.61	0.48	0.37	0.59	0.58	0.51	0.52
HUN	0.58	0.44	0.52	0.36	0.68	0.68	0.59
IDN	1.28	0.32	1.29	1.02	0.35	0.46	0.58
IND	0.03	0.21	0.27	0.27	0.24	0.22	0.24
IRL	2.05	0.48	1.39	0.67	1.01	1.01	0.94
ISR	0.62	0.40	0.57	0.62	0.39	0.46	0.49
ITA	0.69	0.52	1.09	1.23	0.97	0.67	0.83
JPN	0.76	0.43	1.31	1.32	0.52	0.59	0.97
KOR	0.96	0.25	1.32	1.67	0.39	0.40	0.78
MEX	0.64	0.62	0.55	0.59	0.72	0.63	0.63
NLD	1.42	0.00	1.15	1.79	0.65	1.09	0.87
NOR	0.63	1.05	0.84	1.02	1.19	1.09	1.01
NZL	0.85	0.55	0.77	0.76	0.76	0.85	0.73
POL	0.31	0.10	0.44	0.47	0.15	0.12	0.21
PRT	0.70	0.66	0.84	0.73	0.95	0.86	0.78
ROU	0.21	0.17	0.16	0.09	0.24	0.01	0.21
SWE	0.39	0.33	0.45	0.40	0.42	0.37	0.38
THA	0.26	0.65	0.59	0.55	0.88	0.60	0.64
TUR	0.40	0.47	0.50	0.73	0.59	0.64	0.57
USA	0.70	0.31	0.47	0.55	0.31	0.34	0.42
VNM	0.33	0.33	0.33	0.35	0.45	0.48	0.40
ZAF	0.75	0.76	0.70	0.70	0.80	0.86	0.79
Median	0.63	0.47	0.70	0.69	0.65	0.63	

Note: Trade frictions indexes cumulated values of $\hat{\omega}^F_{(-i)i}(s)$ and $\hat{\omega}^X_{-(i)i}(s',s)$ for 1970-2009. The last column includes a trade-weighted average of frictions for each importing country, defined by $\hat{\omega}_i$ in the text. In column labels, the pair (s',s) denotes shipments from sector s' to sector s. Sector abbreviations are manufacturing (m) and non-manufacturing (n).

Table C2: Changes in Expenditure Weights

	Final Goods		Inputs			
	n	m	n,n	n,m	m,n	m,m
ARG	1.16	0.62	1.28	2.91	0.44	0.90
AUS	0.87	0.35	1.97	2.51	0.49	0.57
AUT	0.92	1.16	2.03	1.75	0.45	1.41
BEL	0.94	1.74	1.52	3.57	0.15	1.37
BRA	1.42	0.53	1.28	3.28	0.46	0.76
CAN	0.96	0.54	1.08	1.35	0.58	1.46
CHE	0.86	1.09	1.11	1.39	0.66	1.09
CHL	0.76	0.99	1.53	2.17	0.48	1.44
CHN	0.60	0.62	2.52	0.75	2.48	1.47
DEU	1.25	0.46	2.25	2.01	0.21	1.11
DNK	0.78	0.92	3.62	0.75	0.41	1.08
ESP	0.95	0.49	2.16	1.30	0.54	1.10
FIN	0.78	2.28	1.88	1.00	1.20	0.68
FRA	1.05	0.33	2.05	1.62	0.49	1.32
GBR	0.96	0.54	4.90	0.92	0.57	0.66
GRC	1.29	1.08	1.41	1.40	0.69	0.95
HUN	1.28	1.41	1.51	1.71	0.38	2.13
IDN	0.43	2.52	3.88	0.07	29.53	1.95
IND	0.67	0.96	1.42	1.14	3.36	1.32
IRL	0.62	1.05	2.19	1.13	2.00	0.40
ISR	1.16	0.72	1.62	1.59	0.32	0.76
ITA	0.93	0.60	2.21	0.98	0.80	1.25
JPN	1.47	0.58	1.57	0.91	0.55	0.81
KOR	0.69	1.88	2.99	0.11	7.33	1.49
MEX	0.99	0.94	1.13	0.95	1.04	2.60
NLD	0.67	2.11	5.00	1.43	0.29	1.42
NOR	1.22	0.41	1.06	1.96	0.22	0.93
NZL	0.99	1.07	1.38	0.99	0.51	0.93
POL	1.15	1.99	1.06	0.57	0.94	1.40
PRT	0.91	0.54	1.83	1.15	0.44	1.38
ROU	1.32	0.44	1.43	4.60	0.36	1.13
SWE	0.97	1.58	1.40	1.89	0.69	0.98
THA	0.68	2.09	1.54	0.55	1.31	3.10
TUR	0.65	0.88	1.76	1.18	1.04	2.79
USA	0.84	0.55	1.93	1.32	1.29	0.76
VNM	0.61	1.92	0.62	0.68	3.91	1.74
ZAF	0.78	0.50	1.83	1.83	0.67	0.90
Median	0.93	0.92	1.62	1.32	0.57	1.13

Note: Expenditure weights are cumulated values for $\hat{\omega}_i^F(s)$ and $\hat{\omega}_i^X(s', s)$ for 1970-2008. In column labels, the pair (s',s) denotes shipments from sector s' to sector s. Sector abbreviations are manufacturing (m) and non-manufacturing (n).

Table C3: Panel Regressions of Changes in Trade Frictions with Regional Trade Agreements

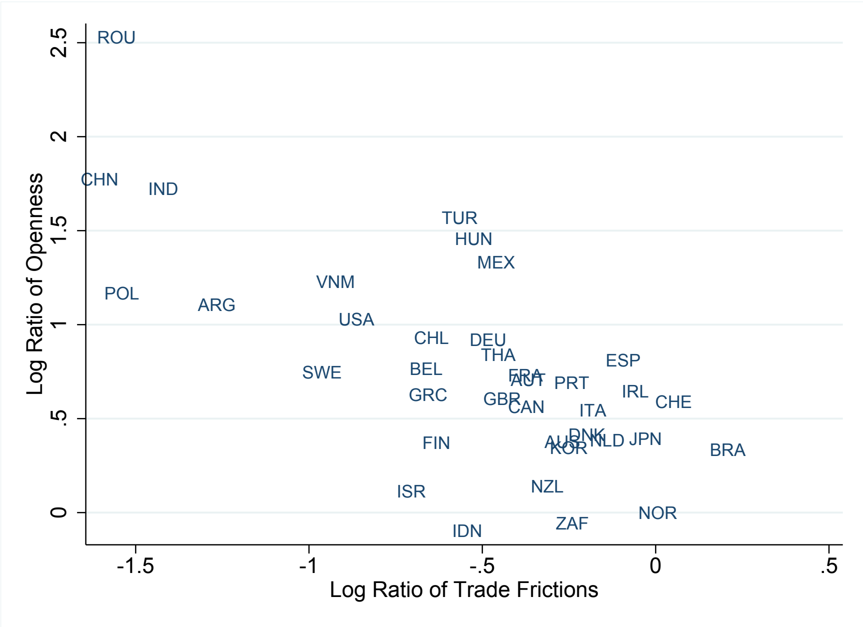
Panel A: Binary RTA Variable						
	Inputs				Final Goods	
	n,n	n,m	m,n	m,m	n	m
	(A1)	(A2)	(A3)	(A4)	(A5)	(A6)
RTA	-0.070***	-0.041*	-0.081***	-0.074***	-0.087***	-0.076***
	(0.024)	(0.024)	(0.023)	(0.024)	(0.025)	(0.025)
R^2	0.53	0.50	0.45	0.44	0.53	0.53

Panel B: By Agreement Type						
	Inputs				Final Goods	
	n,n	n,m	m,n	m,m	n	m
	(B1)	(B2)	(B3)	(B4)	(B5)	(B6)
PTA	-0.046*	-0.017	-0.053*	-0.064**	-0.042	-0.117***
	(0.027)	(0.027)	(0.031)	(0.032)	(0.027)	(0.038)
FTA	-0.072***	-0.034	-0.093***	-0.090***	-0.086***	-0.111***
	(0.027)	(0.028)	(0.029)	(0.030)	(0.029)	(0.031)
CUCMEU	-0.226***	-0.173***	-0.169***	-0.166***	-0.260***	-0.189***
	(0.035)	(0.036)	(0.029)	(0.031)	(0.035)	(0.034)
R^2	0.53	0.50	0.45	0.44	0.53	0.53

Panel C: With Phase-in Effects						
	Inputs				Final Goods	
	n,n	n,m	m,n	m,m	n	m
	(C1)	(C2)	(C3)	(C4)	(C5)	(C6)
RTA(1)	-0.080***	-0.049**	-0.087***	-0.079***	-0.091***	-0.077***
	(0.023)	(0.024)	(0.023)	(0.024)	(0.025)	(0.025)
RTA(2)	-0.147***	-0.101***	-0.096***	-0.089***	-0.095***	-0.064**
	(0.031)	(0.032)	(0.024)	(0.025)	(0.030)	(0.027)
RTA(3)	-0.167***	-0.127***	-0.148***	-0.142***	-0.154***	-0.100***
	(0.035)	(0.036)	(0.028)	(0.029)	(0.035)	(0.032)
RTA(4)	-0.217***	-0.163***	-0.198***	-0.194***	-0.178***	-0.101***
	(0.039)	(0.040)	(0.032)	(0.033)	(0.040)	(0.037)
R^2	0.53	0.50	0.45	0.44	0.53	0.53

Note: In column labels, the ordered pair (s',s) denotes shipments from sector s' to sector s. Sector abbreviations are manufacturing (m) and non-manufacturing (n). All regressions are estimated in first differences, with exporter-year and importer-year fixed effects (pair fixed effects are implicitly differenced away). There are 10,656 observations in each regression. Standard errors, clustered by country pair, are in parentheses. Significance levels: * $p < .1$, ** $p < .05$, *** $p < .01$.

Figure C1: Changes in Trade Frictions and Openness, by Country



Note: Log Ratio of Trade Frictions is measured as $\log(\hat{\omega}_{(-i)i})$. Log Ratio of Openness is measured as $\log\left(\widehat{open}_i\right)$, with $open_{it} = IM_{it}/(Q_{it} - IM_{it})$. Both are measured over 1970-2009.

D Supplemental Results Appendix

This appendix includes supplemental data and decomposition results, which we omitted from the main set of figures for brevity.

Table D1 includes data by sector for the world as a whole, along with the share of each sector in world trade. These are the data plotted in Figures 1 and 2. Table D2 includes data by country, in the aggregate and by composite sector. These are the country-level ratios plotted in Figure 3.

In Section 4, we mentioned that trade composition plays a large role in explaining differential changes in value-added to export ratios across countries. We document that assertion here via a Between-Within decomposition. Letting VAX_{it} and $VAX_{it}(s)$ denote aggregate and sector-level value-added to export ratios for country i, then we construct the decomposition as follows:

$$\Delta VAX_{it} = \underbrace{\sum_s \bar{\omega}_{it}(s) \Delta VAX_{it}(s)}_{\text{Within}_i} + + \underbrace{\sum_s \overline{VAX}_{it}(s) \Delta \omega_{it}(s)}_{\text{Between}_i}, \tag{D1}$$

where $\bar{\omega}_{it}(s) \equiv \frac{\omega_{it}(s)+\omega_{i,t-1}(s)}{2}$ with $\omega_{it}(s) = \frac{\sum_{j \neq i} x_{ijt}(s)}{\sum_{j \neq i} \sum_s x_{ijt}(s)}$, and $\overline{VAX}_{it}(s) \equiv \frac{VAX_{it}(s)+VAX_{i,t-1}(s)}{2}$. To reiterate, the between term is driven by changes in trade shares for a given country, while the within term is driven by changes in value-added to export ratios within sectors in that country.

Results for this decomposition are presented in the last two columns of Table D2. We also include data on changes in the share of manufacturing of exports in the table. The takeaway is that is that changes in the composition of trade are important determinants of difference in the magnitude of value-added to export ratio changes across countries. Broadly, the share of manufactures in trade increases in non-commodity exporter emerging markets. Since the value-added to export ratio is lower for manufacturing than non-manufacturing, an increase in the share of manufacturing in trade mechanically lowers the aggregate VAX ratio. Interesting, the within term is actually positive in many countries, where increases in the value-added to export ratio in non-manufacturing dominate declines in manufacturing (this can occur either due to the magnitude of the VAX changes themselves, or because non-manufacturing has a large weight in exports).

In Figure D1, we project the components of this Between-Within decomposition on income growth, similar to Panel (b) of Figure 3. The within term tends to be positively correlated with income growth, while the between term tends to be negatively correlated with income growth. As such, the fact that growth predicts declines in the overall value-added to export ratio is entirely due to the between term. That is, fast growing countries tend to see the share of manufacturing in their exports rise, and this drives the overall correlation between declining VAX ratios and growth at the country level.

In Section 2.2, we discussed how bilateral value-added to gross export ratios respond to distance, and how this response has changed over time. Here we document this result in a complementary way, which allows us to discuss the role of additional gravity proxies for trade costs as well. Building on Equation (3), we estimate a gravity-type equation in long differences:

$$\Delta \log(y_{ijt}) = \Delta\phi^y_{it} + \Delta\phi^y_{jt} + \breve{\beta}^y_t \log(dist_{ij}) + \breve{\gamma}^y_t GravProxy_{ij} + \Delta\eta^y_{ijt}, \quad \text{(D2)}$$

where $t = \{1975, 2005\}$ and $\breve{\beta}^y_t \equiv \Delta\tilde{\beta}^y_t$ is an estimate of the change in regression coefficients over time.[19] While $\log(dist_{ij})$ is bilateral distance (as in the main text), $GravProxy_{ij}$ is a stand-in variable for conventional gravity proxies included in the regression, with associated change in the gravity coefficient given by $\breve{\gamma}^y_t$. We examine three commonly used trade cost proxies to the regression – common language, common borders (contiguity), and common colonial origin.[20]

In Table D3, the estimates in Column (1) of Panel A indicate that declines in the ratio of value-added to gross exports are smaller for countries that are farther apart. Looking at gross and value-added exports separately, changes in both gross and value-added trade are smaller for countries that are far apart, but distance increasingly dampens gross exports more than value-added exports. These results confirm the results plotted in Figure 4.

In contrast to distance, we see that gross and value-added exports respond similarly to other gravity proxies for trade costs in columns (2)-(5) of Table D3. Common borders, common language and colonial origin are associated with smaller changes in both gross and value-added trade, with roughly similar magnitudes. As a result, there is no change in the correlation of value-added to export ratios with these variables over time. Moreover, adding these additional explanatory variables does not change the magnitude of the differential responses of gross and value-added trade to distance. In sum, distance stands out in terms of its explanatory power.

[19]Note that by estimating the gravity equation in first differences, we are implicitly including a pair-specific fixed effect that is differenced away. This controls for all omitted, bilateral, time-invariant variables.

[20]This data is also taken from the CEPII Gravity Dataset. The contiguity indicator takes the value one if the two countries share a land border. The common colonial origin indicator takes the value one if the two countries were ever in a colonial relationship. The common language indicator takes the value one if the two countries share a common official language.

Table D1: World Value Added to Export Ratio and Components

	Agriculture		Non-Manufacturing		Manufacturing		Services		
Year	VAX Ratio	Trade Share	VAX Ratio	Trade Share	VAX Ratio	Trade Share	VAX Ratio	Trade Share	Agg. VAX Ratio
1970	1.19	0.09	1.10	0.07	0.65	0.64	1.36	0.21	0.87
1971	1.21	0.09	1.10	0.07	0.64	0.64	1.36	0.21	0.87
1972	1.20	0.09	1.12	0.07	0.64	0.64	1.39	0.20	0.87
1973	1.18	0.09	1.11	0.07	0.63	0.64	1.38	0.20	0.87
1974	1.15	0.08	1.00	0.12	0.61	0.62	1.38	0.18	0.84
1975	1.16	0.08	1.01	0.12	0.61	0.61	1.40	0.19	0.85
1976	1.14	0.08	1.01	0.12	0.61	0.61	1.40	0.19	0.85
1977	1.16	0.08	1.01	0.12	0.61	0.61	1.40	0.19	0.85
1978	1.15	0.08	1.04	0.10	0.61	0.63	1.42	0.19	0.85
1979	1.15	0.07	1.02	0.12	0.60	0.62	1.42	0.19	0.84
1980	1.11	0.06	0.99	0.15	0.59	0.61	1.42	0.18	0.83
1981	1.12	0.06	0.98	0.15	0.59	0.60	1.43	0.19	0.84
1982	1.14	0.06	0.98	0.14	0.59	0.61	1.44	0.19	0.84
1983	1.12	0.06	1.02	0.11	0.59	0.63	1.47	0.19	0.84
1984	1.13	0.06	0.97	0.12	0.59	0.63	1.48	0.19	0.83
1985	1.15	0.06	0.98	0.12	0.59	0.64	1.49	0.19	0.84
1986	1.22	0.05	1.07	0.08	0.60	0.67	1.52	0.19	0.85
1987	1.22	0.05	1.10	0.07	0.60	0.68	1.53	0.20	0.85
1988	1.22	0.05	1.14	0.06	0.60	0.69	1.55	0.20	0.85
1989	1.26	0.05	1.11	0.07	0.59	0.69	1.54	0.20	0.84
1990	1.33	0.04	1.05	0.07	0.59	0.68	1.52	0.20	0.85
1991	1.30	0.04	1.09	0.08	0.56	0.67	1.58	0.21	0.84
1992	1.30	0.04	0.93	0.08	0.55	0.66	1.58	0.21	0.83
1993	1.34	0.04	1.12	0.07	0.55	0.68	1.57	0.22	0.84
1994	1.34	0.04	1.18	0.06	0.54	0.69	1.58	0.21	0.83
1995	1.32	0.04	1.18	0.06	0.54	0.70	1.61	0.20	0.82
1996	1.32	0.04	1.14	0.06	0.53	0.69	1.60	0.20	0.82
1997	1.33	0.04	1.13	0.06	0.52	0.70	1.61	0.20	0.81
1998	1.36	0.03	1.29	0.05	0.52	0.71	1.61	0.21	0.81
1999	1.33	0.03	1.23	0.05	0.51	0.71	1.62	0.21	0.80
2000	1.35	0.03	1.09	0.07	0.50	0.70	1.61	0.20	0.79
2001	1.38	0.03	1.15	0.07	0.50	0.70	1.62	0.20	0.79
2002	1.39	0.03	1.18	0.06	0.50	0.70	1.63	0.21	0.80
2003	1.40	0.03	1.15	0.07	0.49	0.70	1.64	0.20	0.80
2004	1.47	0.03	1.13	0.07	0.49	0.70	1.62	0.20	0.79
2005	1.44	0.03	1.08	0.09	0.48	0.69	1.61	0.20	0.78
2006	1.42	0.02	1.08	0.10	0.47	0.69	1.61	0.19	0.77
2007	1.42	0.03	1.08	0.09	0.47	0.69	1.59	0.20	0.77
2008	1.36	0.03	1.01	0.12	0.46	0.66	1.57	0.19	0.76
2009	1.32	0.03	1.08	0.09	0.47	0.66	1.57	0.21	0.79

Note: Data includes trade with the rest-of-the-world. Column 10 can be constructed as an export share weighted average of columns 2 through 9.

Table D2: Changes in Value Added to Export Ratio and Components, by Country

			VAX Changes				Decomposition	
Country	Abbrev.	Years	Aggregate	Non-Manuf.	Manuf.	Δ Manuf. Share	Within	Between
Argentina	ARG	1970-2009	-0.06	0.42	-0.30	0.12	0.02	-0.08
Australia	AUS	1970-2009	-0.04	0.00	-0.22	-0.09	-0.10	0.05
Austria	AUT	1970-2009	-0.13	0.14	-0.23	0.03	-0.10	-0.03
Belgium	BEL	1970-2009	-0.10	0.21	-0.28	-0.05	-0.15	0.05
Brazil	BRA	1970-2009	-0.06	0.41	-0.37	0.24	-0.05	-0.01
Canada	CAN	1970-2009	-0.10	-0.13	-0.15	-0.05	-0.13	0.03
Chile	CHL	1970-2009	-0.10	-0.56	-0.11	-0.16	-0.25	0.15
China	CHN	1970-2009	-0.16	1.93	-0.19	0.32	0.23	-0.40
Czech Republic	CZE	1993-2009	-0.05	0.44	-0.04	0.12	0.06	-0.12
Denmark	DNK	1970-2009	-0.01	-0.03	-0.07	-0.06	-0.05	0.04
Estonia	EST	1993-2009	0.04	0.30	-0.08	0.04	0.06	-0.03
Finland	FIN	1970-2009	-0.06	-0.40	-0.10	-0.11	-0.18	0.12
France	FRA	1970-2009	-0.10	0.43	-0.21	0.07	-0.02	-0.08
Germany	DEU	1970-2009	-0.13	0.04	-0.22	-0.03	-0.18	0.05
Greece	GRC	1970-2009	-0.07	-0.04	-0.12	0.01	-0.07	0.00
Hungary	HUN	1970-2009	-0.23	-0.03	-0.22	0.05	-0.21	-0.02
India	IND	1970-2009	-0.17	-0.11	-0.10	0.07	-0.11	-0.06
Indonesia	IDN	1970-2009	-0.07	0.22	0.15	0.42	0.13	-0.21
Ireland	IRL	1970-2009	-0.19	-0.47	-0.05	-0.08	-0.13	-0.06
Israel	ISR	1970-2009	-0.04	0.47	-0.28	0.36	0.12	-0.16
Italy	ITA	1970-2009	-0.08	0.55	-0.16	0.07	0.00	-0.08
Japan	JPN	1970-2009	-0.03	-0.30	-0.07	-0.05	-0.12	0.09
Korea	KOR	1970-2009	-0.14	0.44	0.03	0.19	0.13	-0.28
Mexico	MEX	1970-2009	-0.21	0.81	-0.18	0.41	0.17	-0.38
Netherlands	NLD	1970-2009	-0.08	0.32	-0.21	0.02	-0.06	-0.03
New Zealand	NZL	1970-2009	0.01	-0.02	-0.05	-0.04	-0.03	0.03
Norway	NOR	1970-2009	0.08	-0.08	-0.05	-0.26	-0.06	0.15
Poland	POL	1970-2009	-0.09	0.93	-0.23	0.14	0.11	-0.20
Portugal	PRT	1970-2009	-0.09	-0.10	-0.06	0.02	-0.08	-0.01
Romania	ROM	1970-2009	-0.22	0.40	-0.37	0.06	-0.25	0.02
Russia	RUS	1990-2009	-0.01	0.05	-0.14	-0.05	-0.03	0.02
Slovak Republic	SVK	1993-2009	-0.11	0.83	-0.06	0.17	0.09	-0.21
Slovenia	SVN	1993-2009	-0.05	-0.02	-0.08	-0.02	-0.06	0.02
South Africa	ZAF	1970-2009	-0.06	0.48	-0.19	0.18	0.10	-0.15
Spain	ESP	1970-2009	-0.13	0.27	-0.31	0.17	-0.04	-0.09
Sweden	SWE	1970-2009	-0.10	-0.15	-0.22	-0.09	-0.22	0.11
Switzerland	CHE	1970-2009	-0.03	-0.42	-0.09	-0.10	-0.16	0.13
Thailand	THA	1970-2009	-0.21	0.59	-0.07	0.43	0.14	-0.34
Turkey	TUR	1970-2009	-0.18	0.77	-0.55	0.57	0.09	-0.28
United Kingdom	GBR	1970-2009	-0.03	-0.01	-0.18	-0.12	-0.14	0.11
United States	USA	1970-2009	-0.09	0.07	-0.20	-0.01	-0.11	0.02
Vietnam	VNM	1970-2009	-0.22	0.08	-0.14	0.28	-0.06	-0.16

Note: VAX changes are cumulative changes in value added to export ratios over the period recorded in column 3. Δ Manuf. Share is the change in the manufacturing share of total exports over the period. The Between and Within columns decompose the overall VAX change into between-sector and within-sector components. See the text for the exact definition.

Table D3: Long Difference Panel Regressions with Proxies for Trade Costs

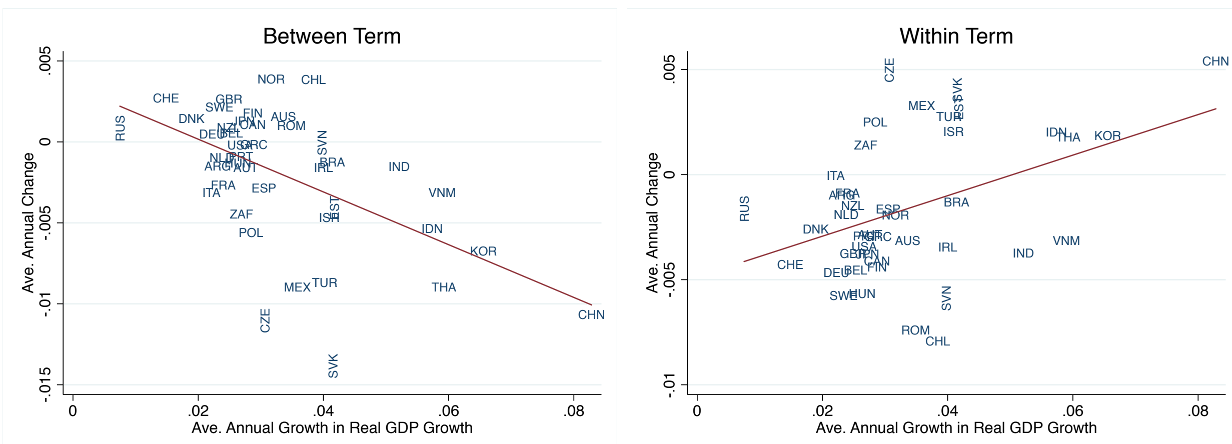
Panel A: Change in Log VAX Ratio					
	(A1)	(A2)	(A3)	(A4)	(A5)
Log Distance	0.095***	0.089***	0.095***	0.094***	0.089***
	(0.011)	(0.013)	(0.011)	(0.012)	(0.013)
Contiguity		-0.046			-0.047
		(0.034)			(0.036)
Colonial Origin			-0.003		0.002
			(0.032)		(0.038)
Common Language				-0.005	0.003
				(0.028)	(0.033)
R^2	0.40	0.40	0.40	0.40	0.40

Panel B: Change in Log Value-Added Exports					
	(B1)	(B2)	(B3)	(B4)	(B5)
Log Distance	-0.103***	-0.126***	-0.101***	-0.122***	-0.122***
	(0.029)	(0.033)	(0.028)	(0.030)	(0.032)
Contiguity		-0.180*			-0.077
		(0.106)			(0.110)
Colonial Origin			-0.447***		-0.363***
			(0.105)		(0.122)
Common Language				-0.247***	-0.132
				(0.071)	(0.088)
R^2	0.66	0.66	0.67	0.67	0.67

Panel C: Change in Log Gross Exports					
	(C1)	(C2)	(C3)	(C4)	(C5)
Log Distance	-0.197***	-0.215***	-0.195***	-0.216***	-0.210***
	(0.036)	(0.042)	(0.035)	(0.037)	(0.041)
Contiguity		-0.134			-0.030
		(0.124)			(0.128)
Colonial Origin			-0.444***		-0.365**
			(0.127)		(0.148)
Common Language				-0.242***	-0.135
				(0.089)	(0.110)
R^2	0.60	0.60	0.60	0.60	0.61
Obs.	1171	1171	1171	1171	1171

Note: Changes in log bilateral VAX ratios, log value-added exports, and log gross exports between 2005 and 1975 are regressed on trade cost proxies and exporter and importer fixed effects. Robust standard errors are in parentheses. Significance levels: * $p < .1$, ** $p < .05$, *** $p < .01$. Sample excludes pairs with bilateral exports smaller than $1 million or VAX ratios larger than ten in 1975.

Figure D1: Between and Within Decomposition of Changes in Value Added to Export Ratios versus Average Annual Real GDP Per Capita Growth, by Country



Note: Countries with vertical labels have less than 40 years of data.