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 changes in the value-added content of trade between 1970 and 2009. The ratio of value-added to gross exports fell by roughly 10 percentage points worldwide. The ratio declined 20 percentage points in manufacturing, but rose in nonmanufacturing sectors. Declines also differ across countries and trade partners: they are larger for fast-growing countries, for nearby trade partners, and among partners that adopt regional trade agreements. Using a multisector structural gravity model with input-output linkages, we show that changes in trade frictions play a dominant role in explaining all these facts.

I. Introduction

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. 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 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 42 countries back to 1970. These synthetic tables track shipments of final and intermediate goods within and between countries. Using this framework, we compute value-added exports: the amount of value added from a given source country that is consumed in each destination (i.e., embodied in final goods absorbed in that destination) (Johnson & Noguera, 2012a). Value-added exports measure international transactions in a manner consistent with commonly used value-added representations of production and preferences.[1] 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 to their final destination.

This work builds on and extends an active literature on global input-output accounting and trade in value added.[2] 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. 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 10 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 20 percentage points

Received for publication November 24, 2014. Revision accepted for publication November 14, 2016. Editor: Gordon Hanson.

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We thank Pol Antràs, Rudolfs Bems, Emily Blanchard, Donald Davis, Andreas Moxnes, Nina Pavcnik, Robert Staiger, Jonathan Vogel, David Weinstein, and Kei-Mu Yi for helpful conversations. We also thank seminar participants at Columbia University, the International Monetary Fund, the London School of Economics, MIT, the University of Colorado, and the University of Houston, as well as the 2012 NBER Spring ITI Meetings and 2014 HKUST Conference on International Economics. R.J. thanks the Rockefeller-Haney fund at Dartmouth College for financial support and Joseph Celli, Michael Lenkeit, and Sean Zhang for research assistance.

A supplemental appendix is available online at http://www.mitpressjournals.org/doi/suppl/10.1162/REST_a_00665.

[1] 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, embodied in both domestic and imported final goods.

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

The Review of Economics and Statistics, December 2017, 99(5): 896–911

doi:10.1162/REST_a_00665

within manufacturing but has risen outside manufacturing (fact 2). Across countries, declines in value-added to gross exports range from near 0 to over 25 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 5% to 11%. 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.

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.[3] 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 in 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.[4] We show that declines in trade frictions over time play an important role in explaining all five stylized facts we have highlighted. 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.

[3] Our model shares many similarities with recent multisector Ricardian models, which incorporate trade in both final and intermediate inputs (Caliendo & Parro, 2015; Levchenko & Zhang, 2016; Eaton et al., 2016). Though we rely on Armington rather than Ricardian microfoundations 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.

[4] Our long-horizon analysis complements Eaton et al. (2016), who examine high-frequency (business 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.

The paper proceeds as follows. Section II outlines the procedure and data we use to measure value-added exports. Section III documents five stylized facts about differences between gross and value-added exports. Section IV 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 V. Section VI concludes.

II. 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 (2012a). 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.

A. *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 (e.g., capital, labor) and intermediate inputs, that 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 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.

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 be 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.

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.

B. *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 identify 42 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.[5] We have four composite sectors: (1) agriculture, hunting, forestry, and fishing; (2) nonmanufacturing industrial production; (3) manufacturing; and (4) services.

Starting with macrodata 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 U.N. National Accounts Database. Using the share of goods and services in exports and imports from the IMF balance-of-payments statistics, we split exports and imports in the GDP data into goods (sectors a to c 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.

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 42 countries after 1995, for Asian countries from 1985, and for 10 major industrialized countries (the G7 plus Australia, Denmark, and the Netherlands) from the 1970s.

In combining these data, we face two challenges. First, there are discrepancies across alternative data sources due to both 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 nonbenchmark 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 42 countries.[6] 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.

III. Changes in Value-Added versus Gross Exports

Using the framework and data already introduced, we document five stylized time series facts regarding changes in the ratio of value-added to gross exports over time. We start at the multilateral level, documenting changes at the world, sector, and country levels. 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 IV.

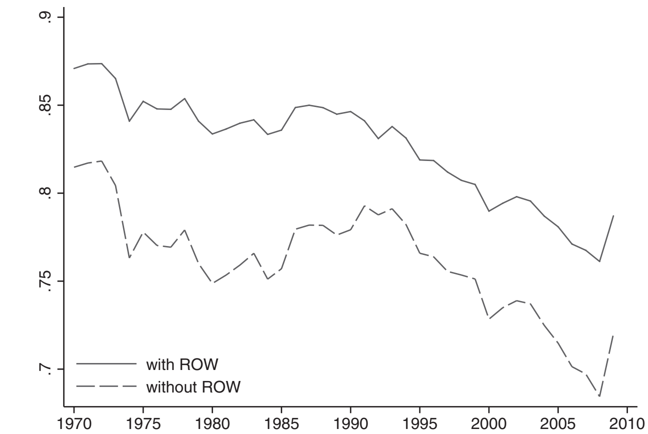
A. *World, Sector, and Country Changes*

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 to 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. This decline is spread unevenly over time. During the 1970 to 1989 interval, there is only a small net decline value added relative to gross

[5] The countries in our sample (listed in the online appendix) account for roughly 80% of world GDP and 70% to 80% of world trade in the 1970–1990 period, rising to over 90% of GDP and 80% to 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 the 1970s and 1980s.

[6] We do not have production or input-output data for countries in the rest of the world, so we assume that exports from countries in our data to the rest of the world are absorbed there. This assumption has little practical effect (Johnson & Noguera, 2012b).

FIGURE 1.—RATIO OF VALUE-ADDED TO GROSS EXPORTS FOR THE WORLD



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

exports, on the order of a few percentage points. In contrast, value added relative to gross exports falls rapidly, by 8.5 (9.5 excluding the ROW) percentage points from 1990 to 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 nonmanufacturing industrial production.[7]

In figure 3, we plot changes in value-added to export ratios at the country level. Figure 3a contains cumulative changes in the ratio of value-added to gross exports from 1970 to 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 United Kingdom, and Brazil) have smaller declines. Among countries with large declines are 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 figure 3b. The correlation is negative and statistically significant at the 1% level. Cumulated over four decades, the point estimate implies that a country at the 90th percentile of the growth distribution (5.8% per year) has a decline in the ratio of roughly 0.21, while a country at the 10th 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 that gross exports have risen more than value-added exports on average for these countries.

B. *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 $\left(VAX_{ijt} \equiv \frac{va_{ijt}}{x_{ijt}}\right)$ 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:

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

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 $\log(VAX_{ijt}) = \log(va_{ijt}) - \log(x_{ijt})$.

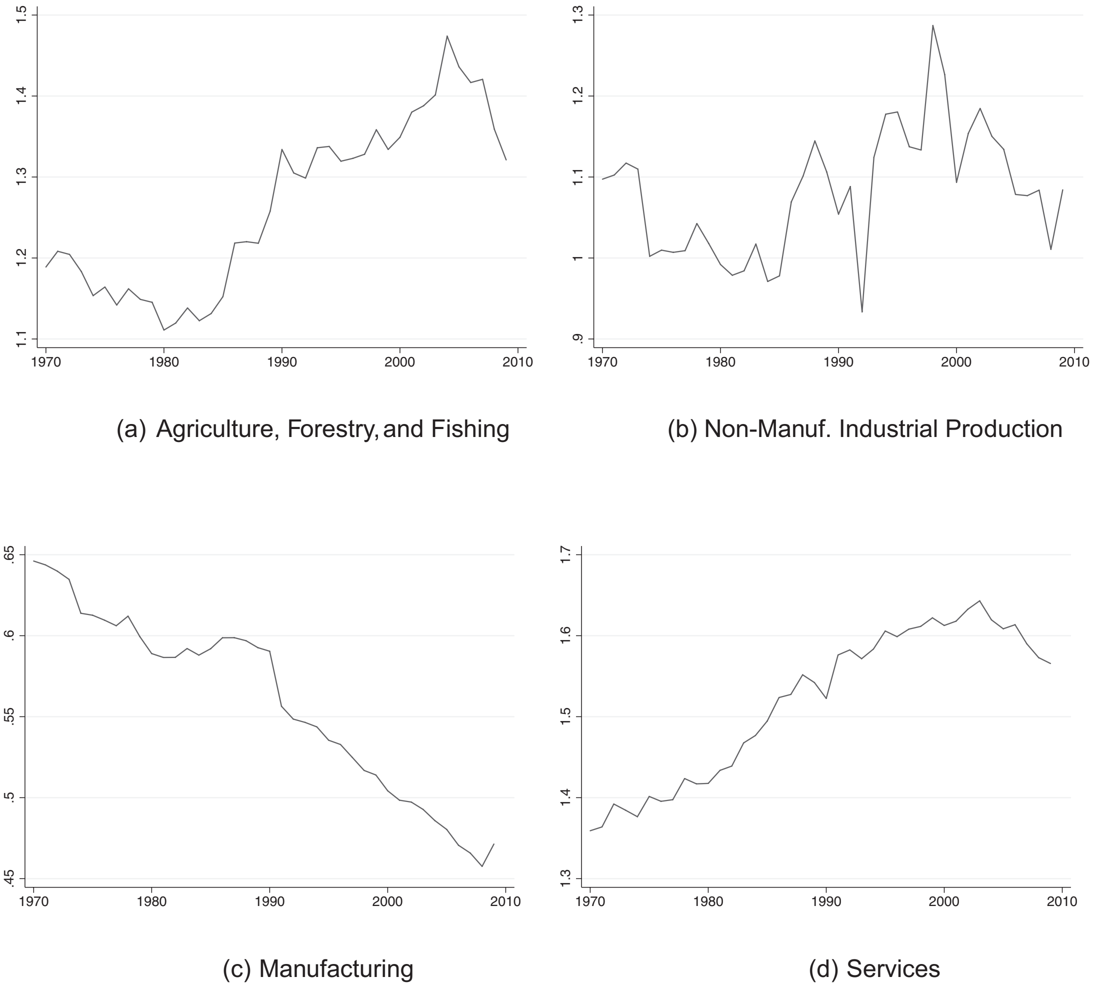
The distance coefficients estimated in equation (3) are plotted in figure 4.[8] In the left panel, the ratio of value-added to gross exports is higher for more distant markets. This is reflected in the separate distance coefficients for gross versus value-added exports in the right panel. While distance depresses both, gross exports fall more strongly with distance than do value-added exports—that is, 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 the distance coefficient for gross exports has risen (in absolute value) over time, from roughly 0.9 to 1.1.[9]

[7] The sector-level value-added to export ratio is not bounded by 1, because each sector exports value added both directly (embodied in gross exports from the sector) and indirectly (embodied in gross exports from other sectors). Nonmanufacturing inputs are used in the production of manufactured goods, so nonmanufacturing value added is indirectly exported embodied in manufactures.

[8] Very small bilateral gross trade flows often lead to extreme value-added to export ratios, which distort the point estimates. These outliers are mainly for emerging markets with low-quality data during the 1970–1985 period. We remove them by dropping bilateral flows less than $1 million and value-added to gross export ratios greater than 10.

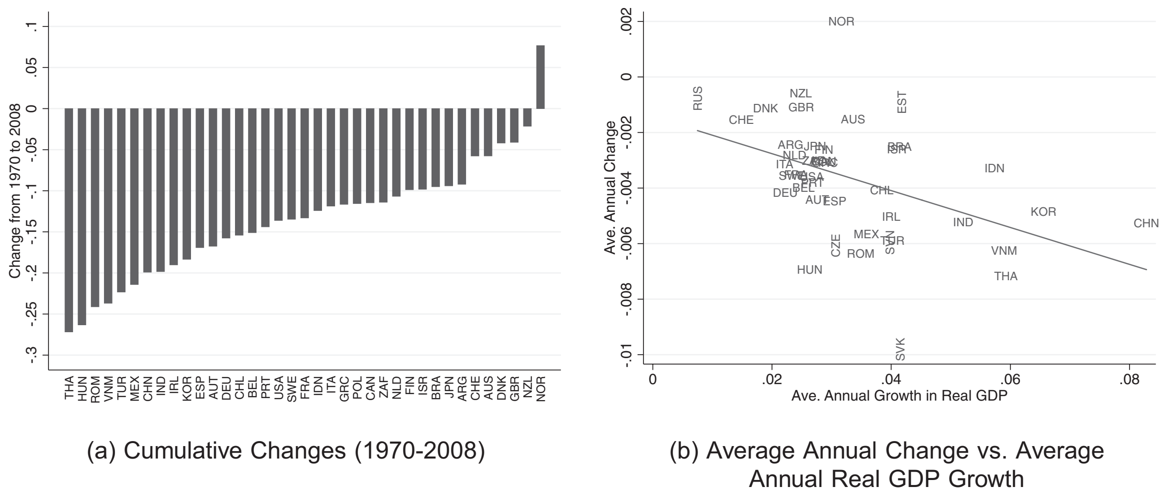
[9] In the online appendix, we show that changes in these coefficients are robust to adding additional gravity controls (e.g., indicators for common language, border, and colonial origin) and country-pair fixed effects. Further, distance stands out among gravity variables in terms of its ability to explain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

FIGURE 2.—RATIO OF VALUE-ADDED TO GROSS EXPORTS FOR THE WORLD, BY SECTOR



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

FIGURE 3.—CHANGES IN RATIO OF VALUE-ADDED TO GROSS EXPORTS, BY COUNTRY



Real GDP data are from the U.N. 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 fewer than forty years of data. The line denotes the 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

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 data set. The middle solid line indicates the point estimate, and the upper and lower dashed lines denote 90% confidence intervals. Standard errors are clustered by country pair.

Regional trade agreements. We now examine how value-added and gross exports respond to the adoption of regional trade agreements.[10]

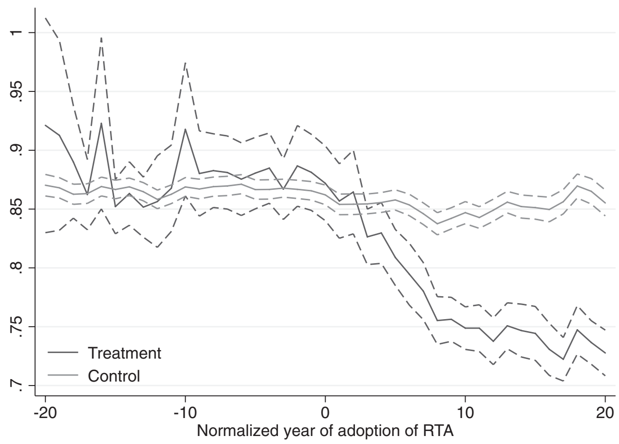
To demonstrate the main result visually, we take an event study approach. We compare the evolution of the value-added to export ratio for the treatment group of bilateral country pairs that form new RTAs during our sample to outcomes for a pair-specific control group in a window surrounding adoption 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 in relation to the set of countries with which both i and j never form an RTA.[11]

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

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

FIGURE 5.—BILATERAL VALUE-ADDED TO EXPORT RATIOS AROUND ADOPTION OF REGIONAL TRADE AGREEMENTS



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

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.[12] We consider several different specifications for $TradeAgreement_{ijt}$. The first uses a single indicator for whether countries have an RTA in force, the second distinguishes shallow from deep agreements, and the third allows for phase-in effects.[13] We estimate this equa-

[10] We use data on economic integration agreements assembled by Scott Baier and Jeffrey Bergstrand (September 2015 revision; http://www3.nd.edu/~jbergstr/). Our RTA indicator takes the value 1 if a country pair has a free trade agreement or stronger.

[11] 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 which 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.

[12] 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.

[13] 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 fifth year, $RTA_{ijt}(3)$ equals 1 in the tenth year, and $RTA_{ijt}(4)$ equals 1 for years 15 onward.

TABLE 1.—PANEL REGRESSIONS WITH REGIONAL TRADE AGREEMENTS

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
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
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
Observations	11,158	11,158	11,158	11,158		11,158	11,158

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. Significant at $*p < .1$, $**p < .05$, $***p < .01$. Sample excludes pair-year observations with bilateral exports smaller than \$1 million or VAX ratios larger than ten.

tion 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% and 12%, whereas adoption of a FTA is associated with a drop of 4% to 5%. The responses of gross and value-added trade flows to RTA adoption are reported in panels B and C of table 1. 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.[14] Upon adoption of the RTA, the ratio of value-added to gross exports falls by 3% to 5% and then continues to fall over the duration of the agreement. The total effect levels off at around 9% to 11%. Value-added and gross exports follow similar adjustment dynamics, with

[14] Adjustment dynamics may arise for several reasons. First, trade agreements are typically phased in, so impact of the agreement may grow 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.

value-added exports rising between 28% and 39% and gross exports rising between 37% and 50% in the long run.

C. *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 10 percentage points and mostly after 1990. The second is that the ratio of value-added to gross exports has fallen for manufacturing, but risen outside 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.

IV. What Driving Forces Account for the Facts?

In this section, we ask: What driving forces account for the five stylized facts identified in section III? 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) 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 & 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.

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 V.

A. *Framework*

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

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

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

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

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

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

where the λ's denote CES share parameters.[15] 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

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

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:

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

[15] We impose constant share parameters $\lambda_i^V(s)$ in equation (5) because we do not have the gross output price data necessary to infer changes in $\lambda_i^V(s)$. Because we omit CES weight parameters in equations (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 & 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.

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 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.[16] 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.

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 parameterization, computation, and counterfactual analysis. The two sectors are manufacturing (m) and nonmanufacturing (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 an elasticity of substitution of 4—to match standard estimates of the trade elasticity.[17] 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 nonmanufacturing 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.[18]

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.[19] 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 data not already included in our global input-output data. We need changes in the price of real value added in each sector $\hat{p}^V_i(s)$ and changes in the price of final expenditure $\hat{p}^F_i$. Drawing on national accounts sources, we set $\hat{p}^V_i(s)$ equal to changes in GDP deflators in the manufacturing and nonmanufacturing sectors, and we set $\hat{p}^F_i$ equal to changes in the ratio of nominal to real final expenditure.[20] We use these 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.[21] Globally, iceberg trade frictions decline by 35% from 1970 to 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

[16] 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.

[17] This is the mean SITC three-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 nonmanufacturing (SITC 1-4) and manufacturing (SITC 5-8) are both close to 4.

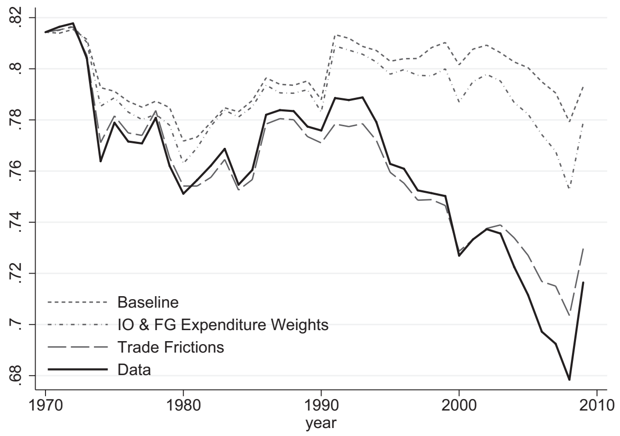
[18] The low final expenditure elasticity is consistent with the fact that both the share of nonmanufacturing in final expenditure and the relative price of nonmanufacturing output have been rising over time. Low substitutability in production is consistent with recent estimates by Atalay (forthcoming) and Oberfield and Raval (2014).

[19] If domestic trade frictions are constant, 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.

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

[21] 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.

FIGURE 6.—ACTUAL AND SIMULATED WORLD VALUE-ADDED TO GROSS EXPORT RATIOS



in both manufacturing and nonmanufacturing sectors, though declines are somewhat larger for manufactures. As we discuss further in section VB, 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 nonmanufacturing sectors, while input expenditure weights have tended to pull input expenditure toward nonmanufacturing.

B. *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, $\hat{\omega}^X_{it}(s', s) = \hat{\omega}^F_{it}(s) = \hat{\omega}^X_{jit}(s', s) = \hat{\omega}^F_{jit}(s) = 1$, 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.

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.[22] 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 rises 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 nonmanufacturing 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 nonmanufacturing sector almost completely and explain more than half of the steady decline in manufacturing.

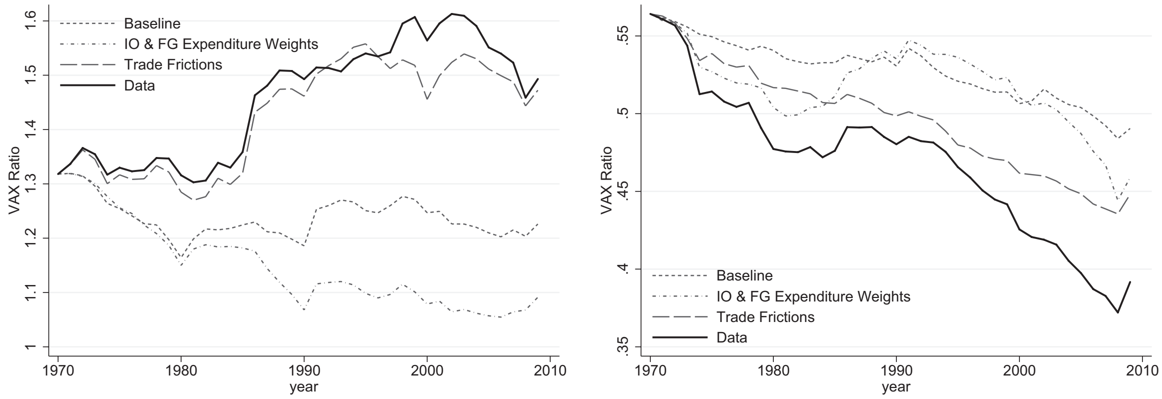
Figure 8 plots changes in value-added to export ratios from 1975 to 2005 at the country level. As in previous figures, both the baseline simulation and the simulation with changes in expenditure weights struggle to match the data. The baseline simulation underpredicts the magnitude of the declines, particularly 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 II 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, initially, they appear to help explain declines in the value-added to export ratio surrounding RTAs. This apparent good performance is misleading. Looking at panels B and C, we see that changes in input-output and final goods expenditure weights lower the simulated bilateral VAX ratio because they lead bilateral value-added exports to fall after RTA adoption, while gross exports are unchanged—both results grossly inconsistent with the data. Changes in trade frictions,

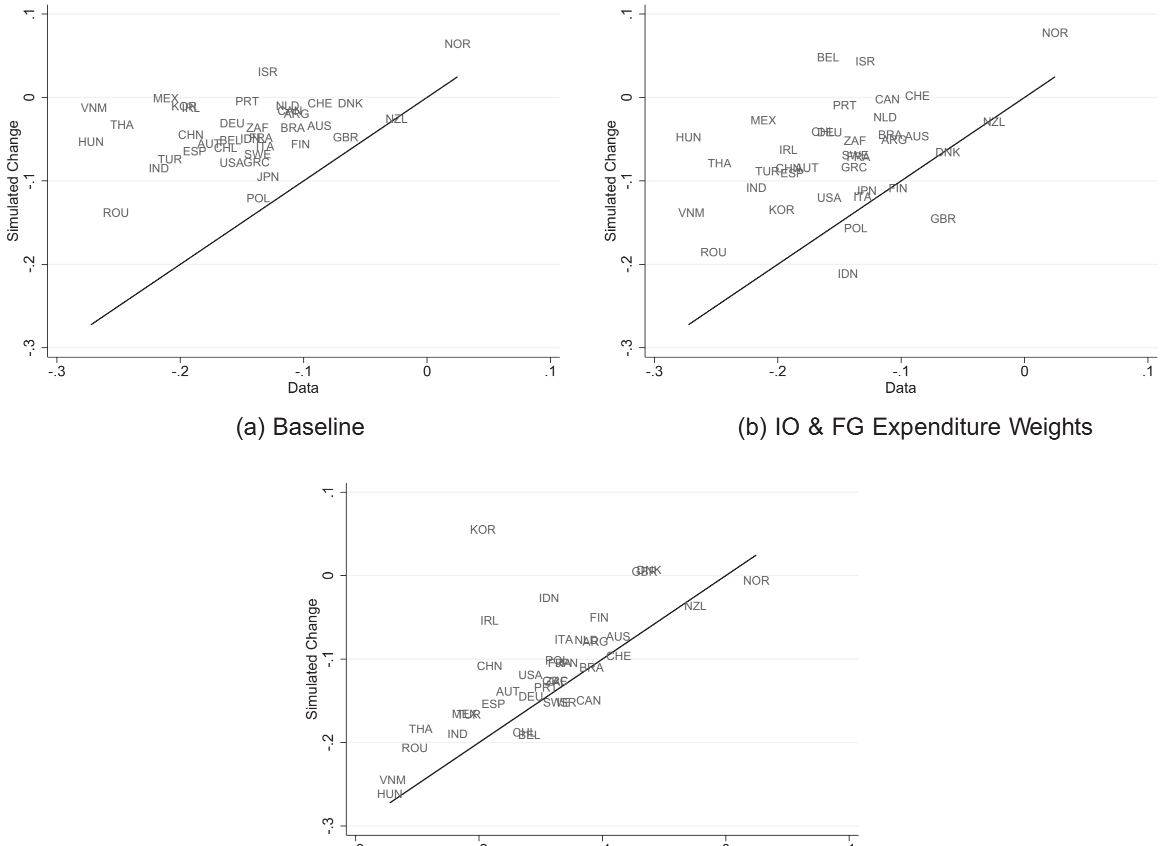
[22] To match the simulation, the true value-added to export ratios in these figures are computed using a 37-country, two-sector aggregation of the data.

FIGURE 7.—ACTUAL AND SIMULATED WORLD VALUE-ADDED TO GROSS EXPORT RATIOS, BY SECTOR



(a) Nonmanufacturing (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

The solid black line depicts a 45-degree line.

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 after 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.

V. 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

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

Distance

	Data	Baseline	Expenditure Weights	Trade Frictions
A1. Change in Log VAX Ratio	(A1)	(A2)	(A3)	(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
B1. Change in Log Value-Added Exports	(B1)	(B2)	(B3)	(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
C1. Change in Log Gross Exports	(C1)	(C2)	(C3)	(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
Observations	1,171	1,171	1,171	1,171

Regional Trade Agreements

	Data	Baseline	Expenditure Weights	Trade Frictions
A2. Log VAX Ratio	(A5)	(A6)	(A7)	(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
B2. Log Value-Added Exports	(B5)	(B6)	(B7)	(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
C2. Log Gross Exports	(C5)	(C6)	(C7)	(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
Observations	11,291	11,291	11,291	11,291

Panels A1, B1, and C1 regress the change in change in the specified variable from 1975 to 2005 on log distance, importer fixed effects, and exporter fixed effects. Panels A2, B2, and C2 replicate the specification from column 1 of table 1. Significant at $^*p < .1$, $^{**}p < .05$, $^{***}p < .01$. Samples excludes pairs with bilateral exports smaller than \$1 million or VAX ratios larger than ten in 1975.

distinguish trade frictions by sector (manufacturing versus nonmanufacturing) and end use (final versus 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.

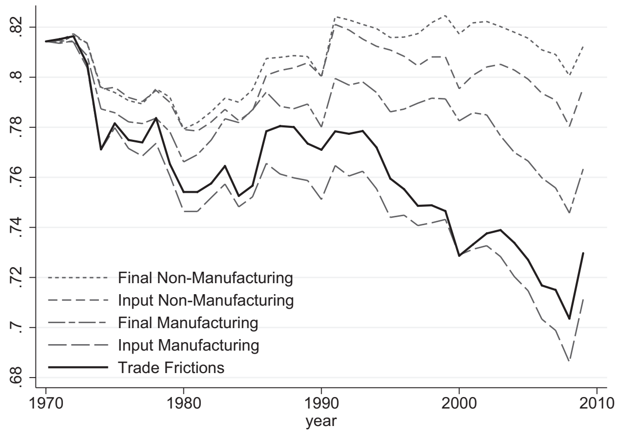
A. *Unpacking Trade Frictions*

We run four new counterfactual simulations with changes in (a) final nonmanufacturing trade frictions, holding other trade frictions fixed ($\hat{\omega}^F_{jit}(m) = \hat{\omega}^X_{jit}(s', s) = 1$); (b) input nonmanufacturing trade frictions (with $\hat{\omega}^F_{jit}(s) = \hat{\omega}^X_{jit}(m, s) = 1$); (c) final manufacturing trade frictions (with $\hat{\omega}^F_{jit}(n) = \hat{\omega}^X_{jit}(s', s) = 1$); and (d) 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 to that simulation in the following analysis.

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 nonmanufacturing 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

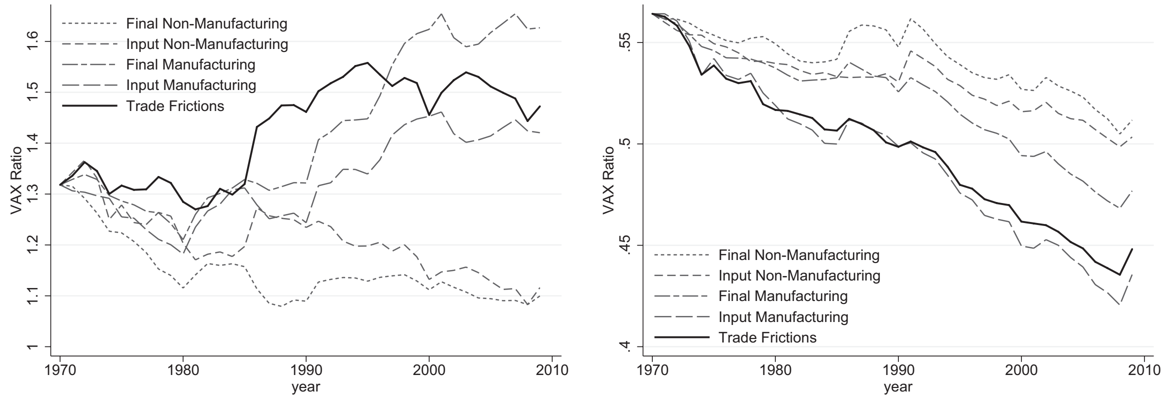
Figure 9.—Simulated World Value-Added to Gross Export Ratios with Changes in Trade Frictions



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 after 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 nonmanufacturing 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.

FIGURE 10.—SIMULATED WORLD VALUE-ADDED TO GROSS EXPORT RATIOS WITH CHANGES IN TRADE FRICTIONS, BY SECTOR



(a) Nonmanufacturing (b) Manufacturing

At the country level, all four simulations generate data that are positively correlated with the composite trade frictions simulation, and roughly equally so (the correlations are all near 0.5). However, simulations with changes in nonmanufacturing frictions alone underpredict the size of the declines in value-added to export ratios: the mean error is 0.10 in simulation and 0.08 in simulation b. 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 c and −0.006 in simulation d. From this, we conclude that frictions for manufactured inputs are most important in explaining country-level ratios as well.

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 nonmanufacturing ratio because manufactures account for 60% to 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 nonmanufacturing. The between term is modest in size because changes in trade shares are small (a few percentage points).

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 nonmanufacturing	0.00	0.11	−0.11
Input nonmanufacturing	−0.02	0.10	−0.12
Final manufacturing	−0.05	−0.08	0.03
Input manufacturing	−0.10	−0.05	−0.06

$VAX_{2009} - VAX_{1970}$ 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.

Turning to simulation results, the trade frictions counterfactual generates negative within and between effects, consistent with the data. When we break 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.[23] Falling input frictions

[23] Nonmanufacturing trade costs generate negative within effects but (counterfactual) positive between effects. The between effects arise because declines in nonmanufacturing trade frictions raise the share of nonmanufacturing in trade, and nonmanufacturing 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

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.

Sector trends. We now turn 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 et al., 2001). As an empirical matter, sector-level domestic content is approximately equal to sector-level value-added exports (Johnson & Noguera, 2012a). 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. 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 on both 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, we see that 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 nonmanufacturing sector. Falling frictions on final manufactures have similar compositional effects, which explains why they too raise the value-added to export ratio in nonmanufacturing. 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. When we look 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 nonmanufacturing. Further, the level of the nonmanufacturing 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.

B. *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.[24]

As expected, our estimates indicate that RTA adoption lowers bilateral trade frictions among adopting countries.[25] To summarize the magnitudes, trade frictions fall by roughly 7% to 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%

frictions raise the share of manufactures in trade. The positive within effect is a product of the strong rise in VAX ratios for nonmanufacturing in response to falling final manufacturing trade frictions.

[24] 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.

[25] See table C3 of the online appendix for the full set of estimates.

TABLE 4.—PANEL REGRESSIONS IN SIMULATED DATA WITH REGIONAL TRADE AGREEMENTS REMOVED

A. Log VAX Ratio				
		Approach to Removing RTAs		
	Data (A1)	Binary RTA (A2)	Split Agreement Types (A3)	With Phase-in (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
B. Log Value-Added Exports				
		Approach to Removing RTAs		
	Data (B1)	Binary RTA (B2)	Split Agreement Types (B3)	With Phase-in (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
C. Log Gross Exports				
		Approach to Removing RTAs		
	Data (C1)	Binary RTA (C2)	Split Agreement Types (C3)	With Phase-in (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
Observations	11,291	11,291	11,291	11,291

Columns 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. Significant at *$p < .1$, **$p < .05$, ***$p < .01$.

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

Using the simulated data, we reestimate 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 table 4A, the RTA coefficient is numerically close to, and statistically indistinguishable from, 0. 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% to 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.

VI. Conclusion

With the rise of cross-border supply chains, conventional (gross) trade data are 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 that 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 before. Second, the large role of trade frictions in explaining changes in gross versus value-added trade calls for revisiting 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 versus 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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