NBER WORKING PAPER SERIES

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Working Paper 18186
http://www.nber.org/papers/w18186

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
June 2012

We thank Rudolfs Bems, Emily Blanchard, Donald Davis, Andreas Moxnes, Nina Pavcnik, Jonathan Vogel, David Weinstein, and Kei-Mu Yi for helpful conversations, as well as seminar participants at Columbia, the IMF, MIT, the NBER Spring ITI Meetings, University of Colorado, and University of Houston. Johnson thanks the Rockefeller-Haney fund at Dartmouth College for financial support, and Joseph Celli, Michael Lenkeit, and Sean Zhang for research assistance. The views expressed herein are those of the authors and do not necessarily reflect the views of the National Bureau of Economic Research.

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NBER Working Paper No. 18186
June 2012
JEL No. F1

ABSTRACT

We combine data on trade, production, and input use to compute the value added content of trade for forty-two countries from 1970 to 2009. For the world, the ratio of value added to gross trade falls by ten to fifteen percentage points, with two-thirds of this decline in the last two decades. Across countries, declines range from zero to twenty-five percentage points, with large declines concentrated among countries undergoing structural transformation. Across bilateral trade partners, declines are larger for nearby partners and partners that adopt regional trade agreements. That is, both policy and non-policy trade costs shape production fragmentation.

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Recent decades have seen the emergence of global supply chains in which production stages are sliced up and distributed across countries. Despite their prominence, we lack a comprehensive understanding of the causes and consequences of this production fragmentation. One reason is that measuring changes in supply chains across countries and over time in a systematic way has proven difficult. A fundamental challenge is that the national accounts record data on gross shipments of goods across borders, not the locations at which value is added at different stages of the production process. Yet for many questions, ranging from how global supply chains influence income distribution to how they transmit shocks across borders, what we care about is how fragments of value added are combined via the global supply chain to form final goods.[1] That is, we would like to pierce the veil of the gross flows and measure 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 main contributions. First, we combine time series data on trade, production, and input use to construct an annual sequence of global input-output tables covering forty-two countries back to 1970. For each year, we link national input-output tables together using bilateral trade data to form a synthetic global input-output table that tracks shipments of final and intermediate goods between countries. We then use this global table to compute 'value added exports.' Analogous to gross exports, value added exports measure 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).

In the aggregate, the ratio of value added to gross exports measures the extent of double-counting in trade statistics, an important metric of production fragmentation in the context of models of sequential, multi-stage production.[2] At the bilateral level, the ratio of value added to gross trade is a marker for both bilateral production chains, as well as multi-country production chains in which value added transits through third countries en route from source to destination. Therefore, changes in the ratio of value added to gross trade through time are a metric for changes in the structure of cross-border supply chains. Measuring these changes is a prerequisite both for empirical work aimed at identifying the fundamental drivers of fragmentation and for calibrating models that measure the consequences of rising fragmentation.

[1] As Grossman and Rossi-Hansberg (2007, p.66-67) put it: "The measurement of trade as gross values of imports and exports was perhaps appropriate at a time when trade flows comprised mostly finished goods. But such measures are inadequate to the task of measuring the extent of a country's international integration in a world with global supply chains...we would like to know the sources of the value added embodied in the goods and the uses to which the goods are eventually put."

[2] For example, see Dixit and Grossman (1982), Yi (2003, 2010), Baldwin and Venables (2010), or Costinot, Vogel, and Wang (forthcoming). Standard 'gravity-style' trade models also often include an input-output loop that can be interpreted as a multi-stage production process.

Our second contribution is to document new stylized facts regarding the evolution of fragmentation for the world as a whole, individual countries, and among bilateral trade partners. For the world as a whole, the ratio of value added to gross exports – henceforth the 'VAX ratio' for short – is declining over time, falling by ten to fifteen percentage points over four decades. Interestingly, this decline is not uniform through time: the world VAX ratio falls during the 1970's, is stable through the 1980's, and then falls dramatically during the 1990's. The decline in the VAX ratio after 1990 is roughly three times as fast as the decline prior to 1990.

Beneath these global results, both the magnitude and timing of declines in VAX ratios differ across countries and bilateral trading partners. Across countries, the median decline is roughly -0.13 (for the Netherlands or France), with an interdecile range of -0.24 (for Ireland) to -0.04 (for the United Kingdom or Japan). We show that declines tend to be largest for fast growing countries undergoing structural transformation, but some advanced countries (e.g., Germany) also experience large declines. Across bilateral partners, there is also ample variation. For example, the VAX ratio falls by 0.29 for U.S. exports to Mexico, but is nearly unchanged for U.S. exports to Japan. This bilateral variation reflects both changes in the extent to which exports to a given destination are used in production of exports (i.e., the extent of vertical specialization in the destination), as well as changes in how a given source country serves the destination via third markets.

Our third contribution is to show that trade barriers are significant determinants of changes in fragmentation patterns. Among non-policy trade barriers, distance is particularly important. In the cross-section, bilateral VAX ratios are higher for distant trading partners, meaning that on average value added exports 'travel further' than gross exports. In the time series, distance is a strong predictor of changes in the VAX ratio, with the largest declines in VAX ratios concentrated among proximate trading partners.[3] While both gross and value added trade become more sensitive to distance over time, the change for gross trade is significantly larger than trade in value added. This suggests that fragmentation may be important in explaining the increasing influence of distance on trade, highlighted by Disdier and Head (2008).

Turning to policy trade barriers, we show that regional trade agreements have large effects on bilateral VAX ratios. In levels, these agreements raise both gross and value added trade, but gross trade rises substantially more. For a typical agreement, gross trade rises by around 30% and value added trade rises by 23%, so the VAX ratio falls by 7%. Further, deep trade agreements (e.g., common markets and economic unions) are associated with larger declines in VAX ratios than shallow agreements (e.g., preferential agreements or free trade

[3]See Johnson and Noguera (2012b) for additional results on distance and fragmentation.

agreements). These results demonstrate that trade policy changes influence fragmentation. They are also interesting in light of the fact that many agreements were explicitly adopted to promote integration of production chains across borders, yet systematic evidence that they have succeeded in this goal is scarce.

Our study contributes to an active recent literature on global input-output linkages.[4] To date, this literature mostly focuses on measuring trade in value added over short time spans, often a single recent year. In contrast, we focus here on changes over long periods of time. In that focus, our work is closely related to Hummels, Ishii, and Yi (2001), who constructed measures of the import content of exports for ten countries from 1970 to 1990. Our work extends both country and time coverage relative to Hummels et al. Most importantly, the global input-output framework we use allows us to measure changes in value added trade at the bilateral level, a dimension of the data that has been under-explored.[5]

The paper proceeds as follows. Section 1 articulates the input-output framework we use to construct measures of trade in value added, and Section 2 discusses interpretation of value added trade flows. Section 3 then describes how we construct the empirical counterpart to this framework from available data, with details on data and methods in the appendix. Section 4 provides a general overview of variation in VAX ratios through time for the world, individual countries, and bilateral trade partners. We then explore the role of trade costs in shaping bilateral flows in detail in Section 5. Section 6 concludes.

1 Tracking Value Added in Global Supply Chains

We begin by laying out the global input-output framework, drawing on the exposition in Johnson and Noguera (2012a). We then demonstrate how to compute the value added content of trade. The basic procedure has two main steps. First, using the global input requirements matrix, we compute the total output from each country and sector needed to produce the vector of final goods absorbed in a given destination. Second, we use source country value added to export ratios to compute the domestic value added embodied in that output.

[4] Among others, see Bems, Johnson, and Yi (2010), Trefler and Zhu (2010), Daudin, Rifflart, and Schweisguth (2011), Erumban, Los, Stehrer, Timmer, and de Vries (2011), Johnson and Noguera (2012a, 2012b), and Koopman, Powers, Wang, and Wei (2011). This literature itself builds on a long tradition of multi-region input-output models, dating to Moses (1955).

[5] Other related work aimed at measuring changes in input-output linkages over time includes the IDE-JETRO Asian Input-Output Tables (which we draw on for data) and the new World Input-Output Database (WIOD). Working contemporaneously, WIOD researchers assembled detailed data for the 1995-2007 period (see Timmer (2012)). See also Wang (2011) for work on the post-1995 period. These post-1995 tables miss many important changes in value added versus gross trade over time. As will be evident below, most of our results depend on measuring linkages over longer periods of time.

1.1 A Global Input-Output Framework

To start, let there be S sectors and N countries in a given year t. Output in each sector of each country is produced using domestic factors (capital, labor, etc.) and intermediate inputs, which may be sourced from home or foreign suppliers. Output is tradable in all sectors, and may used to satisfy final demand or used as an intermediate input in production at home or abroad. Final demand itself consists of consumption, investment, and government expenditure.

To track shipments of final and intermediate goods, we define a four-dimensional notation denoting source and destination country, as well as source and destination sectors for shipments of intermediates. We define i to be the source country, j to be the destination country, s to be the source sector, and s' to be the destination sector.

For a given year, the global input-output framework organizes these flows using market clearing conditions. Because we observe the value of cross-border transactions in the data, not quantities shipped, we write these market clearing conditions in value terms. 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. We write the market clearing condition 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 shipped to sector s' in country j. Gross bilateral exports, denoted $x_{ijt}(s)$, include goods destined for both final and intermediate use abroad: $x_{ijt}(s) = f_{ijt}(s) + \sum_{s'} m_{ijt}(s, s')$. Then Equation (1) equivalently says that output is divided between domestic final use, domestic intermediate use, and gross exports.

These market clearing conditions can be stacked to form a compact global input-output system. First, we collect the total value of production in each sector in the $S \times 1$ vector y_{it}. Second, we organize shipments of final goods from i to country j into $S \times 1$ vectors f_{ijt}. Third, we denote use of intermediate inputs from i by country j by $A_{ijt} y_{jt}$, where A_{ijt} is an $S \times S$ input-output matrix with elements $A_{ijt}(s, s') = m_{ijt}(s, s')/y_{jt}(s')$. A typical element describes the value of output from sector s in source country i used in the production of sector s' output by destination country j. The vector of gross exports from i to j ($i \neq j$) is then $x_{ijt} = f_{ijt} + A_{ijt} y_{jt}$.

Then we can rewrite the $S \times N$ market clearing conditions from Equation (1) as:

$$y_t = A_t y_t + f_t, \tag{2}$$

$$\text{with} \quad A_t \equiv \begin{pmatrix} A_{11t} & A_{12t} & \dots & A_{1Nt} \\ A_{21t} & A_{22t} & \cdots & A_{2Nt} \\ \vdots & \vdots & \ddots & \vdots \\ A_{N1t} & A_{N2t} & \dots & A_{NNt} \end{pmatrix}, \quad y_t \equiv \begin{pmatrix} y_{1t} \\ y_{2t} \\ \vdots \\ y_{Nt} \end{pmatrix}, \quad \text{and} \quad f_t \equiv \begin{pmatrix} \sum_j f_{1jt} \\ \sum_j f_{2jt} \\ \vdots \\ \sum_j f_{Njt} \end{pmatrix}. \tag{3}$$

We refer to A_t as the global input-output matrix. It concisely summarizes the entire structure of within-country, cross-country, and cross-sector intermediate goods linkages at a given point in time.

Rearranging Equation (2), we can write the output vector as:

$$y_t = (I - A_t)^{-1} f_t. \tag{4}$$

The matrix $(I - A_t)^{-1}$ is the "Leontief inverse" of the global input-output matrix. The Leontief inverse tells us how much output from each country and sector is required to produce a given vector of final goods, where here the vector of final goods is total world absorption of final goods f_t. The gross output required to produce f_t includes the final goods themselves plus all the intermediate goods used up in successive rounds of the production process.

1.2 The Value Added Content of Trade

To compute the value added content of trade, we split f_t into destination specific vectors $\tilde{f}_{jt}$, where $\tilde{f}_{jt}$ is the $(SN \times 1)$ vector of final goods absorbed in country j. Then Equation (4) can be re-written as:

$$y_t = \sum_j (I - A_t)^{-1} \tilde{f}_{jt} \quad \text{with} \quad \tilde{f}_{jt} \equiv \begin{pmatrix} f_{1jt} \\ f_{2jt} \\ \vdots \\ f_{Njt} \end{pmatrix}. \tag{5}$$

Inside the summation, $(I - A_t)^{-1} \tilde{f}_{jt}$ is the vector of output used directly and indirectly to produce final goods absorbed in country j.

Then, Equation (5) decomposes output from each source country i into the amount of output from the source used to produce final goods absorbed in each destination. To formalize this, we define:

$$\begin{pmatrix} y_{1jt} \\ y_{2jt} \\ \vdots \\ y_{Njt} \end{pmatrix} \equiv (I - A_t)^{-1} \tilde{f}_{jt}, \tag{6}$$

where y_{ijt} is the $S \times 1$ vector of output from i used to produce final goods absorbed in j.

Given that we know how much output from each source is needed to produce final goods in each destination, then we can naturally compute the value added from the source country embedded in this output. 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 y_{ijt} defined above. We refer to $va_{ijt}(s)$ as value added exports.

2 Interpreting Value Added Trade

To guide interpretation of the empirical results below, we pause here to discuss the mechanics of the value added calculation.[6] First, we highlight how the value added to export ratio can be linked to alternative models with fragmented production. Second, we interpret differences between value added and gross exports using a first-order approximation to the full value added calculation. Third, we discuss how value added trade is related to measures of trade in intermediate goods.

2.1 Models with Fragmented Production

The basic accounting system outlined in Equations (1) and (2) above could be consistent with various underlying models of production, as it simply tracks shipments of intermediates and final goods by industrial sector. Moving from Equations (2) to (4) entails making the assumption that the production process is circular, composed of an effectively infinite number of stages, where input requirements and the uses of output at each stage are identical.

These are strong restrictions, yet they are embedded into many standard trade models. For example, many gravity-style models satisfy these restrictions. These models typically assume that gross output is produced using a CES composite intermediate input, which aggregates tradable intermediates from different sectors and country sources, and is allocated interchangeably to final and intermediate uses.[7] Therefore, the procedure for computing the

[6] See also Johnson and Noguera (2012a) for interpretative discussion.

[7] See Caliendo and Parro (2010), Eaton, Kortum, Neiman, and Romalis (2011), and Levchenko and Zhang

value added content of trade naturally emerges from these models.

Models of sequential multi-stage production also generate flows of final and intermediate that are consistent with Equations (1) and (2).[8] In this type of model, there is a sequence of production stages that must be performed in order, with intermediate output being passed from one stage to the next. When stages are split across countries, this feature generates gross trade that is a multiple of trade in value added. This discrepancy between gross and value added trade flows is a key metric that summarizes how much fragmentation has taken place.

It is worth noting, however, that multi-stage models do not necessarily feature circularity in the production process, and therefore need not imply the inversion operation in Equation (4). For example, in the two-stage model of Yi (2003), stage one goods are used to produce stage two goods, which are then fed into final demand channels. As such, there is no intermediate goods loop in which stage two goods are used as intermediates in stage one. Nonetheless, that model does produce double-counting in trade statistics, even if it does not imply the exact accounting procedure in this paper.[9] We now turn to explaining the link between two-step and many-step production processes in detail, as the two-step process is useful for building intuition.

2.2 Approximate Accounting

To aid interpretation, we outline an approximate two-step formulation of the general accounting procedure. This approximation enables us write down simple analytical expressions for value added and gross trade that capture the first-order influence of cross-border input linkages. These expressions echo the two-step computations in Hummels, Ishii, and Yi (2001) and Yi (2003), though extended here for the multilateral context. This approximation also captures roughly half of the bilateral variation in the true data, so it will prove useful to study the mechanics underlying deviations of value added from gross trade.[10]

To understand the approximation, note that the Leontief Inverse can be expressed as a geometric series: $(I - A)^{-1} = \sum_{k=0}^{\infty} A^k$. If we multiply the k-th order term by the final demand vector – i.e. compute $A^k \tilde{f}_{jt}$ – then we get the value of intermediates used in the

(2011) for Ricardian models with these features. Armington type gravity models with production functions for gross output also typically satisfy these restrictions.

[8]See Yi (2003, 2010), Dixit and Grossman (1982), Baldwin and Venables (2010), or Costinot, Vogel, and Wang (2011).

[9]Yi (2010) does include an intermediate goods loop, in which the second stage goods are used to form a CES composite input used in the first stage. Mapping this model to our data is topic for future work.

[10]Though the algebra is more cumbersome, we can obviously perform higher order approximations as well. By definition, these fit the data better and capture an additional layer of nuance. They do not add new fundamental insights, however.

k-th step of the production process. The two-step approximation restricts attention to the zero and first order terms of this expansion: the final goods themselves and intermediates directly used to produce them. That is, we compute the first-order approximate amount of output needed to produce final goods, defined as: $\bar{y}_t \equiv \sum_j [I + A_t]\tilde{f}_{jt}$. The output from country i used to produce $\tilde{f}_{jt}$ is then: $\bar{y}_{ij} \equiv f_{ij} + \sum_k A_{ik} f_{kj}$.

Using these output transfers, along with the underlying shipments of final and intermediate goods, we construct approximate gross and value added exports as:

$$\overline{x}_{ij} \equiv \underbrace{f_{ij} + A_{ij} f_{jj}}_{\text{absorption}} + \underbrace{A_{ij} f_{ji}}_{\text{reflection}} + \underbrace{\sum_{k \neq i,j} A_{ik} f_{kj}}_{\text{redirection}} \tag{7}$$

$$\overline{va}_{ij} \equiv \underbrace{f_{ij} + A_{ii} f_{ij} + A_{ij} f_{jj} - \left[\iota\left[A_{ii} + A_{Ii}\right] diag(f_{ij})\right]'}_{\text{net absorption}} + \underbrace{\sum_{k \neq i,j} A_{ik} f_{kj}}_{\text{indirect exports}}, \tag{8}$$

where $A_{Ii} = \sum_{k \neq i} A_{ki}$ is the overall imported input use matrix for country i.

We group the components of approximate exports into three terms.[11] First, $f_{ij} + A_{ij} f_{jj}$ is shipments from i to j that are absorbed in j, including both final goods (f_{ij}) and intermediates from i embodied in country j's consumption of its own final goods ($A_{ij} f_{jj}$). Second, $A_{ij} f_{ji}$ is shipments of intermediates from i to j that are 'reflected' back to country i, embodied in final goods produced by j. Third, $\sum_{k \neq i,j} A_{ik} f_{kj}$ is shipments of intermediates from i to j that are 'redirected' onward to third markets, embodied in final goods produced by j.

We group the components of approximate value added exports into two terms. Aggregated across sectors, the first term is equal to 'absorption' (defined above) minus the imported intermediate goods used to produce exported final goods f_{ij}, given by $[\iota A_{Ii} diag(f_{ij})]'$. We therefore refer to this term as 'net absorption'.[12] The second term records 'indirect exports': the amount of value added from country i absorbed in country j that travels through third countries. In the two-step calculation, this is equal to shipments of intermediates from i to third destinations k that are embodied in final goods produced by k and absorbed in j.

At the bilateral level, we can then define the approximate ratio of value added to gross

[11] In Johnson and Noguera (2012a), we defined these terms somewhat differently. Rather than decomposing approximate exports, we chose to decompose actual exports in that paper. The intuition for how we broke down actual gross exports is closely related to the intuition presented here.

[12] At the sector level, net absorption is equal to absorption plus the domestic intermediates used to produce final goods exports ($A_{ii} f_{ij}$) minus total intermediate use ($[\iota\left[A_{ii} + A_{Ii}\right] diag(f_{ij})]'$). Aggregating across sectors, domestic intermediates cancel out. Further, recall that we have a two-step production process here, so no intermediates are used to produce intermediates. Therefore, intermediates themselves are 100% value added under this approximation.

exports as:

$$\overline{VAX}_{ij} = \frac{\iota\overline{va}_{ij}}{\iota\overline{x}_{ij}} = \frac{\text{net absorption}_{ij} + \text{indirect exports}_{ij}}{\text{absorption}_{ij} + \text{reflection}_{ij} + \text{redirection}_{ij}}. \tag{9}$$

Note three ways in which production fragmentation influences the approximate VAX ratio.

First, if 'indirect exports' are zero, then $\overline{VAX}_{ij}$ is less then one. Absorption less imported inputs is guaranteed to be less than absorption itself, and gross exports are composed of absorption plus reflected/redirected exports. Further, note that for a given source country i, the ratio of net absorption to total absorption varies across destinations only to the extent that final goods sectors vary in imported input intensity and the composition of final goods exports varies across destinations.[13] In practice, this limits variation in $\overline{VAX}_{ij}$, because export composition tends to be similar across destinations for a given exporter.

Second, if 'indirect exports' are greater than zero, these push up $\overline{VAX}_{ij}$. In fact, if indirect exports are large enough, then $\overline{VAX}_{ij}$ may exceed one. These indirect exports are a natural outcome of fragmented production, as they reflect redirection trade in third destinations ($k \neq i, j$)).

Third, $\overline{VAX}_{ij}$ is decreasing in the extent of 're-direction and reflection' in bilateral trade. This component of gross exports reflects double-counting, as it includes shipments to j that are not absorbed there, but show up in j's own exports.

For convenience, we refer to these three margins of adjustment in approximate VAX ratios as the absorption, indirect exports, and reflection/redirection margins. All three reflect different dimensions of cross-border fragmentation, so we use this breakdown to illustrate the mechanics of changes in VAX in later sections. As we move from approximate to actual bilateral VAX ratios that include higher order terms, we lose this exact decomposition. However, the basic intuition of the approximate decomposition survives. The core of this intuition is that bilateral value added to export ratios are shaped by both bilateral production chains, which involve back-and-forth shipments of intermediates and final goods between bilateral partners, as well as multilateral production chains that involve three or more countries.

Moving from bilateral to multilateral trade, the multilateral VAX ratio is straightforward to interpret. Starting with the approximation, note that the indirect exports and redirection terms are two sides of the same coin. As we aggregate across destinations, these then appear in both the numerator and denominator. So in the aggregate, they do not affect the value added to export ratio. The only remaining components are: (a) the use of imported inputs to produce exports, driving a wedge between absorption and net absorption, and (b) the

[13] This is an outcome of the assumption that gross output is homogeneous within sectors, so input requirements do not depend on how the good is used or where it is shipped.

reflection of exports back to the source, embodied in final goods imports. Increases in either of these drive the aggregate VAX ratio down.[14] This intuition survives intact when moving from the approximate to full calculation.

2.3 Trade in Intermediates

In contrast to our focus on value added versus gross trade, many other researchers have used measures of intermediate goods trade or trade in parts and components as a measure fragmentation.[15] These measures capture different information than the information embedded in value added to export ratios. We therefore pause to contrast our approach to this alternative.

While countries must trade intermediates in order to have gross trade in excess of value added trade, trade in intermediates does not guarantee this result. Specifically, what matters is how intermediates are used in particular destinations. If shipments of intermediates are used to produce goods absorbed in the destination, then these intermediate goods shipments represent trade in value added. This is captured in the $A_{ij} f_{jj}$ term in approximate value added exports above. In contrast, if the intermediates are reflected or redirected to be absorbed either in the source or third countries, then there is a wedge between gross and value added trade.

The fact that intermediate goods trade and value added to export ratios capture different information helps us reconcile the observation that the share of intermediate goods in trade has not apparently risen over time, documented for example by Chen, Kondratowicz, and Yi (2005), with our observation that the global ratio of value added to gross trade is falling. It also guides us in interpreting our results on RTAs. Whereas we detect differential effects of RTAs on gross and value added trade, Orefice and Rocha (2011) find that trade in parts and components increases by the same amount as 'final' trade (i.e., total trade less parts and components) following adoption of bilateral trade agreements.[16] These examples make the point that care is needed in reading our results in the context of this related literature.

[14] Further, the ratio of value added to gross exports is bounded by one.

[15] Among others, see Yeats (2001), Baldwin and Taglioni (2011), Behar and Freund (2011), and Orefice and Rocha (2011).

[16] Also related to our results below, they find that final and intermediates goods respond similarly to increasing depth of trade agreements.

3 Empirical Procedure

To measure the value added content of trade, we need to track output y_t, the global input-output matrix A_t, final goods shipments f_{ijt}, and value added to output ratios r_{it} through time. We confront two challenges in doing so. First, sector-level production, input use, and trade data for many countries is incomplete and split across sources. Therefore, we need to clean and harmonize available data sources. Second, national input-output tables do not disaggregate imported inputs and final goods across sources. Therefore, we need to apply proportionality assumptions to construct bilateral input use and bilateral final goods shipments. We describe how we deal with these two issues here, and relegate additional details regarding data construction to Appendix A.

3.1 Data Sources

We take annual trade data from national accounts and commodity trade statistics, annual production data from national accounts and industrial output sources, and data on final and intermediate use from national accounts and input-output tables for benchmark years. Broadly speaking, our objective is to assemble hard data where available, fill in missing data where needed using reasonable imputation techniques, and impose internal consistency across data sources and countries using accepted harmonization procedures.

We focus on building the global input-output framework for four composite sectors: (1) agriculture, hunting, forestry, and fishing; (2) non-manufacturing industrial production; (3) manufacturing; and (4) services. We focus on four sectors for several reasons. First, aggregation allows us to maximize the country and time coverage of our estimates. National accounts GDP data for these four sectors is available for nearly all countries after 1970. Aggregation also facilitates linking data sources recorded in different sector classifications (e.g., commodity vs. industry classifications). Second, only a small number of sectors are needed to generate accurate value added estimates in practice.[17] We lose relatively little information in aggregation because individual sectors within the four composite sectors are more similar among themselves than to sectors in other composite sectors.

Data availability governs the set of countries that we include in the global input-output framework. For information on input use and disaggregate final demand, we rely on national input-output tables from the OECD Input-Output Database and the IDE-JETRO Asian Input-Output Tables. We use tables for 42 countries, covering the OECD plus many emerging markets (including Brazil, Russia, India, and China), for benchmark years from 1970 to the present. These 42 countries – listed with benchmark years in Appendix A – account for

[17] We document this assertion in the appendix using disaggregated data for one benchmark year.

roughly 80% of world GDP and 70-80% of world trade in the 1970-1990 period, rising to cover over 90% of GDP and 80-90% of world trade after 1990. The remaining countries are aggregated into a rest of the world composite.[18]

In using this input-output data, we face two challenges. First, even where benchmark years are available, data in the input-output tables is not consistent with national accounts aggregates or sector-level trade data available from other sources.[19] Second, benchmark years are infrequent, unevenly spaced, and asynchronous across countries. To construct a time series or even conduct cross country comparisons at a single point in time, we therefore need to extrapolate the benchmark data to non-benchmark years.

To deal with both these challenges simultaneously, we apply a procedure that imputes input-output coefficients subject to hard data constraints. In this procedure, unknowns include sector-level input shares for domestic and imported intermediates and sector-level shares for domestic and imported final goods absorption. In each year, we solve for these unknowns using a constrained least squares procedure. We solve for shares that are: (a) close (in a least squares sense) to the observed coefficients in benchmark years (or interpolations thereof if two or more benchmark years are available); and (b) satisfy adding up constraints in the data. We impose that the solution must match sector-level GDPs, sector-level exports and imports, and aggregate final demand data exactly.

The result of this procedure is a dataset containing gross output by sector (y_{it}), value added to output ratios by sector (r_{it}), final demand for domestic and imported goods by sector (f_{iit} and f_{Iit}), and domestic and imported intermediate use matrices (A_{iit} and A_{Iit}) for 42 countries. In our calculations, we do not use any information on these objects for the rest-of-the-world composite. To make this work, we assume that all exports from the 42 countries in our data to the rest-of-the-world composite region are absorbed there.[20] We discuss the robustness of our results to relaxing this assumption in Appendix A.

3.2 Assembling the Global Input-Output Framework

To set up the global input-output framework, we need to split imported input use and final goods imports across bilateral trading partners. That is, we need to turn A_{Ii} into bilateral

[18]Due to lack of data, we include the Czech Republic, Estonia, Russia, Slovakia, and Slovenia in the rest of the world composite during 1970's and 1980's, and report results for them separately starting in the 1990's.

[19]These discrepancies are partly due to differences in definitions across different data sources. They also arise due to measurement error. Based on examination of OECD data documentation, we believe measurement error is more severe in the input-output data than in the national accounts sources. Therefore, we give priority to national accounts data in our reconciliation procedures.

[20]Assuming that exports to the rest-of-the-world are composed entirely of final goods is sufficient to guarantee this assumption holds. However, this assumption can also hold if exports of intermediates to the rest-of-the-world are only used to produce final goods absorbed there.

matrices A_{ji}, and turn f_{Ii} into bilateral final goods shipments f_{ji} for all $j \neq i$.

To do so, we use bilateral trade data and a proportionality assumption. Specifically, we assume that within each sector imports from each source country are split between final and intermediate use in proportion to the overall split of imports between final and intermediate use in the destination. Further, conditional on being allocated to intermediate use, we assume that imported intermediates from each source are split across purchasing sectors in proportion to overall imported intermediate use in the destination. These assumptions can be written as:

$$A_{ji}(s,s') = A_{Ii}(s,s')\left(\frac{x_{ji}(s)}{\sum_j x_{ji}(s)}\right) \quad \text{and} \quad f_{ji}(s) = f_{Ii}(s)\left(\frac{x_{ji}(s)}{\sum_j x_{ji}(s)}\right).$$

To form the bilateral trade shares here and sector-level trade data used above, we combine national accounts and bilateral trade data sources. Aggregate exports and imports, covering all sectors, are taken from the national accounts. We split this aggregate trade across goods and services sectors using balance of payments statistics. Then we further disaggregate non-services trade across sectors and countries using trade shares constructed from bilateral commodity trade data, including the NBER-UN Database for 1970-2000 and the CEPII BACI Database for 1995-2009. As is well known, bilateral services trade data has not been collected with the same scope and rigor as goods trade data. We therefore apply an imputation procedure to form bilateral services trade shares. See Appendix A for details regarding how we combine trade data sources.

4 The Evolution of Fragmentation

This section summarizes how the value added content of trade has evolved over the last four decades. We present results for the world as a whole, for individual countries aggregated across trading partners, and for bilateral trading partners separately. We focus on describing stylized facts in this section, and defer formal analysis to the next section.

4.1 The World

We begin by plotting the value added to export ratio for the world as a whole in Panel (a) of Figure 1, computed as the sum of value added exports divided by the sum of gross exports across all country pairs and sectors: $VAX_{world} \equiv \frac{\sum_{i \neq j}\sum_s va_{ij}(s)}{\sum_{i \neq j}\sum_s x_{ij}(s)}$. We plot two series in the figure: one that includes shipments to/from the rest of the world and one that excludes them. In most figures below, we plot results including these shipments.[21]

The world VAX ratio declines by 0.10 including the ROW and 0.13 excluding the ROW from 1970-2009.[22] These cumulative changes are attenuated by a rise in the world VAX ratio coincident with the collapse of world trade in 2009.[23] Truncating the sample in 2008 to exclude the trade collapse, the VAX ratio declines by 0.13 including the ROW and by 0.16 excluding the ROW.

This decline is spread unevenly over time. We identify three stages in the evolution of the world VAX ratio. There is a first wave of fragmentation in the 1970s, taking the ratio from 0.87 to 0.84 (including the ROW). The 1980s are the lost decade, with almost no change in the ratio. A second wave of fragmentation starts around 1990, taking the ratio from 0.84 to 0.74 in 2008 and rebounding to 0.77 in 2009. The decline in the VAX ratio is roughly three times as fast during the 1990-2008 period as during the pre-1990 period.[24]

Disaggregating these results, we plot sector-level VAX ratios in Figure 1, where these ratios are defined as: $VAX_{world}(s) \equiv \frac{\sum_{i \neq j} va_{ij}(s)}{\sum_{i \neq j} x_{ij}(s)}$. Strikingly, manufacturing is the only sector in which the VAX ratio is falling over time. The ratio is increasing for agriculture and services and stable in non-manufacturing industrial production. Linking these sector-level results to the overall VAX ratio above, we can decompose the overall decline in the world VAX ratio into components due to changes in VAX ratios within sectors versus changes in composition of trade across the three sectors. That is, the decline in the overall VAX ratio could either be due to the declining VAX ratio within manufacturing, or composition shifts that put a larger weight manufacturing, which has a relatively low VAX ratio.

To examine the role of each force, we decompose changes in the world VAX ratio into within and between effects. As an accounting identity, yearly changes in world VAX ratio can be decomposed into the yearly change in sector-level VAX ratios (within effect) and into the yearly change in sector shares in world exports (between effect):

$$\Delta VAX_t = \underbrace{\sum_s \Delta VAX_t(s) \left(\frac{\omega_t(s) + \omega_{t-1}(s)}{2} \right)}_{\text{Within}} + \underbrace{\sum_s \Delta \omega_t(s) \left(\frac{VAX_t(s) + VAX_{t-1}(s)}{2} \right)}_{\text{Between}},$$

where $\omega_t(s) = \frac{x_t(s)}{x_t}$ and we define $\Delta x_t \equiv x_t - x_{t-1}$.

[21] The VAX ratio including the ROW is larger partly due to our assumption that all exports to the ROW are absorbed there. The dynamics of the VAX ratio are similar for the two series.

[22] The annual series, including the ROW, is included in the final column of Table 6 of Appendix B.

[23] Bems, Johnson, and Yi (2011) discuss how composition effects can drive changes in the world VAX ratio. That paper focuses on a simulation exercise to explore these composition effects, whereas the new data introduced here can be used in an explicit accounting exercise.

[24] Including the rebound in 2009, the decline is still twice as fast post-1990.

Performing this decomposition from 1970 to 2009, we find that the Within term accounts for about 85% of the total change in the world VAX ratio.[25] Given that VAX ratios outside manufacturing are stable or increasing, the Within term picks up the large decline in the VAX ratio within the manufacturing sector, interacted with the large share of manufactures in total trade ($\approx 60 - 70\%$). The Between term is not important because sectoral trade shares at the world level are relatively stable from 1970-2009. The slight negative Between effect is driven by the declining share of agriculture and natural resources, and corresponding increase in manufactures, in total trade.

4.2 Individual Countries

Moving down one level of aggregation from the world to individual countries, significant cross-country heterogeneity emerges. First, the total size of declines is heterogeneous across countries and correlated with country characteristics, such as growth in GDP per capita. Second, the sources of declines in VAX ratios differ across countries. Third, the timing of changes in fragmentation is heterogeneous across countries. We discuss each point in turn.

Figure 2 contains cumulative VAX ratio changes from 1970-2009 for the 37 countries for which we have data back to 1970.[26] Nearly all countries experience falling VAX ratios.[27] Most experience declines larger than 10 percentage points, though some large and prominent countries (e.g., Japan, the UK, Brazil, etc.) 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 variation across countries, we plot the average annual change in the VAX ratio against the average annual growth rate in real GDP per capita in Figure 3.[28] The correlation is negative and statistically significant at the 5% level. Cumulated over four decades, the point estimate implies that a country at the 90^{th} percentile of the growth distribution (4.5% per year) has a decline in the VAX ratio of roughly 0.14, while a country at the 10^{th} percentile (1% per year) has a decline of 0.04. Because emerging markets on average have higher growth than advanced countries, this also reinforces the observation

[25] The data needed to perform this decomposition are presented in Table 6 of Appendix B.

[26] These declines are reported in the second column of Table 7 in Appendix B, along with declines for the Czech Republic, Estonia, Russia, Slovakia, and Slovenia who have shorter time coverage. We also report total VAX ratio changes for manufacturing versus non-manufacturing. As in the world-level data, VAX ratios within manufacturing fall markedly and rise within non-manufacturing for most countries.

[27] The initial level of the VAX ratio in 1970 is uncorrelated with subsequent changes, so there is no tendency toward convergence in VAX ratios across countries over time.

[28] We compute the average annual growth rate in real GDP per capita taking log differences in PPP GDP per capita from the WDI. For Poland and Vietnam, PPP GDP per capita data is available for only the last 20 years from the WDI, so we plot changes over this shorter interval for these countries.

above that VAX declines are larger on average for these countries.

Underlying this result, changes in the composition of trade are important determinants of the aggregate VAX ratio.[29] Broadly, the share of manufactures in trade is rising in most (though not all) countries, with the largest increases in non-commodity exporter emerging markets. Since the VAX ratio is lower for manufacturing than non-manufacturing, an increase in the share of manufacturing in trade mechanically lowers the aggregate VAX ratio.

To examine the role of trade composition versus sector-level changes in VAX ratios, we compute a Between-Within decomposition of the change in each country's VAX ratio:

$$\Delta VAX_{it} = \underbrace{\sum_s \Delta VAX_{it}(s) \left(\frac{\omega_{it}(s) + \omega_{i,t-1}(s)}{2} \right)}_{\text{Within}_i} + \underbrace{\sum_s \Delta \omega_{it}(s) \left(\frac{VAX_{it}(s) + VAX_{i,t-1}(s)}{2} \right)}_{\text{Between}_i},$$

where $\omega_{it}(s) = \frac{x_{it}(s)}{x_{it}}$ and we define $\Delta x_{it} \equiv x_{it} - x_{i,t-1}$. To reiterate, the Between effect is driven by changes in trade shares for a given country, while the Within effect is driven by changes in VAX ratios within sectors in that country.

We project these Between and Within terms on income growth in Figure 4.[30] 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 VAX ratio is entirely due to the Between term. That is, structural change in which fast growing countries increase the share of manufacturing in their exports is the driving force behind the overall correlation. The Within term tends to be more important for advanced countries that have already completed the structural transformation process. For example, the decline in the Within term is larger than the overall VAX change for Germany, Japan, and the United States.

These country-level results focus on cumulative changes over the 1970-2009 period. However, there is also important variation in the time dimension. Declines in VAX ratios are not uniformly distributed through time, nor coincident across countries. Reflecting the aggregate world series, VAX ratio declines for most countries are most rapid during the 1990's. However, the exact timing of declines do not line up across countries. To illustrate this, we plot VAX ratios over time for the four largest exporters (U.S., Germany, China, and Japan) in Figure 5. For the big four exporters, there are notable crossing points where country orderings are reversed. For example, China starts with the highest VAX ratio, and ends up with a VAX ratio lower than both Japan and the U.S. Further, there are notable accelerations/decelerations in the figure. For example, Germany's VAX ratio decline accelerates

[29] Changes in the share of manufactures in exports are reported in column five of Table 7 in Appendix B.

[30] Numerical values for the Between and Within terms are provided in Table 7 in Appendix B.

post-1990, which points to intensified integration of the European production structure.

Differences in the timing of changes in VAX ratios is even clearer looking at the emerging market countries, and so we plot selected emerging markets in Figure 6. Thailand's value added to export ratio falls precipitously starting in the mid-1980's, coincident with the beginning of their export-led industrialization boom and transition out of agriculture. Poland's VAX ratio declines post-1990, signaling re-integration into the European production structure. Finally, Mexico's value added to export ratio starts declining during the mid-1980's as well, first falling during a unilateral trade liberalization and then continuing to fall as the process of North American integration accelerates. In contrast, Brazil stands out in the figure as a country whose VAX ratio has had a modest decline. Whereas Mexico begins on par with Brazil in 1970, Mexico ends up with a value added to export ratio that is 20 percentage points lower than Brazil as of the late 2000's.

4.3 Bilateral Country Pairs

Shifting our focus from the country level to bilateral country pairs, further heterogeneity emerges. There is ample variation in VAX ratios both across pairs in the cross-section and within pairs over time. Because our focus below is on changes in VAX ratios over time, we focus on this dimension of the data here.[31]

Changes in value added to export ratios through time differ substantially across bilateral partners. We plot changes in bilateral value added to export ratios across trade partners for four large countries (Germany, Japan, United Kingdom, and United States) in Figure 7. Though country mean/median changes differ, there is wide variation in bilateral changes around these average levels. For example, for the United States, the interdecile range of VAX changes across bilateral export destinations is $(-0.31, 0.04)$. Similar patterns obtain for other countries as well. To illustrate the magnitude and sources of variation, we examine two decompositions.

First, we construct a Between-Within decomposition at the bilateral level (analogous to those above) to check whether changes in the composition of bilateral exports drive these changes. Looking at a variance decomposition of $\Delta VAX_{ijt} = VAX_{ij,2009} - VAX_{ij,1970}$, we find that the Within term accounts for nearly all the variation in bilateral changes.[32] That is, changes in trade composition plays a small role in explaining bilateral changes.

Second, we draw on the approximate accounting exercise from Section 2.2 to break down

[31] See Johnson and Noguera (2012a) for extensive discussion of cross-sectional differences in VAX ratios.

[32] The components of this decomposition are: $var(\Delta VAX_{ijt}) = 0.037$, $var(\text{Within}) = 0.074$, $var(\text{Between}) = 0.039$, and $cov(\text{Within,Between}) = -0.038$. We plot elements of this Between-Within decomposition against changes in bilateral VAX ratios in Appendix B.

changes across margins of trade. To do this, we split the log bilateral VAX ratios into three terms:

$$\log(VAX_{ijt}) = \underbrace{\log\left(\frac{\text{net absorption}_{ijt}}{\text{absorption}_{ijt}}\right)}_{\text{Absorption Ratio}} + \underbrace{\log\left(1 + \frac{\text{indirect exports}_{ijt}}{\text{net absorption}_{ijt}}\right)}_{\text{Indirect Exports Adjustment}} - \underbrace{\log\left(1 + \frac{\text{reflection}_{ijt} + \text{redirection}_{ijt}}{\text{absorption}_{ijt}}\right)}_{\text{Reflection/Redirection Adjustment}}. \tag{10}$$

The first term picks up changes in net absorption, and we call this the Absorption Ratio. The second term picks up changes in indirect exports as a share of value added trade, and we call this the Indirect Exports Adjustment. The third term picks up changes in reflection/redirection trade, and we call this the Reflection/Redirection Adjustment.

We plot changes in the actual bilateral VAX ratio, approximate VAX ratio, and these margins for four representative countries (Australia, Chile, Germany, and Italy) in Figure 8. The upper left figure in each group is a plot of changes in the VAX ratio against changes in the approximate VAX ratio. As is evident, the two series are highly correlated, though changes in the approximate VAX ratio are approximately one-half the size of the true change. Therefore, the decomposition of the approximate VAX ratio captures the mechanics of adjustment for roughly half the overall variation in the data. Thus, we view this decomposition as illustrative evidence on channels of adjustment, though it should be kept in mind that higher order elements matter as well.

For the four countries depicted, as in countries not in the figure, net absorption plays a relatively small role in explaining bilateral changes, which is consistent with the Between-Within decomposition above since net absorption is driven entirely by differences in composition of final goods shipments across destinations. The role played by the indirect exports margin versus the reflection/redirection margin varies across countries. For example, reflection/redirection trade plays a strong role for Germany and Italy, but changes in indirect exports are much more important for Chile and Australia.[33] The median country in the data tends to look more like Chile/Australia than Germany/Italy, with changes in indirect exports accounting for around 80% of the variation in approximate bilateral VAX ratios across destinations. That said, reflection/redirection accounts for more than 40% of the variation in roughly 1/3 of the countries, including the United States, France, and Japan (plus Germany and Italy in the figure).

[33] In the cross-section, indirect trade tends to be more important for commodity exporters. It is also very important early in the period for many former Communist countries, who had relatively concentrated bilateral trade patterns before 1990.

As in the aggregate country-level time series, there is also variation in the timing of changes in bilateral VAX ratios across trading partners. For example, we plot VAX ratios for U.S. exports to France and Germany in the left panel of Figure 9. Despite the similarity between France and Germany in income levels and trade policy, the dynamics of the VAX ratios differ sharply across the two destinations. While VAX ratios are initially similar, they diverge sharply after 1990, despite the absence of obvious changes in bilateral trade policy or frictions. Sharp changes at the bilateral level can be seen for other trading partners as well. For example, we plot U.S. VAX ratios to Mexico and Canada in the right panel of Figure 9. Here there are sharp changes occur during the period of North American integration, starting with CUSFTA in 1989 and continuing with the adoption (and phase-in) of NAFTA in 1994. Whereas the French/German example above suggests factors other than bilateral trade policy may shape bilateral VAX ratios, these point to the role of trade policy. We focus on sorting through possible drivers VAX ratio changes below.

5 Trade Costs and Fragmentation

Theoretical work focuses on trade costs as an important driver of production fragmentation.[34] In this section, we use our bilateral data to explore how various types of bilateral trade costs and proxies thereof are related to bilateral VAX ratios over time. We also document how trade costs influence gross exports and value added trade separately, which aids in understanding why the VAX ratio responds to trade costs.

In our analysis of trade costs, we focus on trade costs that are bilateral in nature. We examine commonly used bilateral proxies for non-policy barriers, such as distance, language, borders, and colonial origin. We then turn to analyzing responses to changes in trade policy, specifically the adoption of regional trade agreements. We begin this section explaining how we use trade cost measures in a general regression framework, and then explain the details of each empirical specification we run as we discuss the results.

5.1 Empirical Framework

Our analysis is built around three equations, one each for the bilateral VAX ratio, gross exports, and value added exports. If we let $y_{ijt} \in \{VAX_{ijt}, x_{ijt}, va_{ijt}\}$ be the outcome

[34] See Yi (2003, 2010), Bridgman (2008, 2012), or Baldwin and Venables (2010).

variable of interest, then the core specification we use can be written as:

$$\begin{aligned} \log(y_{ijt}) &= \phi^y_{it} + \phi^y_{jt} + \beta^y \log(\tau_{ijt}) + \varepsilon_{ijt} \\ \text{with} \quad \varepsilon_{ijt} &= \gamma^y_{ij} + \eta^y_{ijt}, \end{aligned} \tag{11}$$

where the parameters ϕ^y denote source and destination fixed effects associated with outcome y and τ_{ijt} is a vector of time-varying bilateral trade costs (with β^y being the associated row vector of coefficients for outcome y). Further, the composite error ε_{ijt} is the sum of a pair-specific latent variable γ^y_{ij} and an idiosyncratic error η^y_{ijt}. In all specifications, we assume that the idiosyncratic error η^y_{ijt} is uncorrelated with the regressors at all leads/lags. We vary assumptions regarding the correlation of γ^y_{ij} with regressors depending on the context, and we elaborate on these assumptions where appropriate below.

The meaning of the time varying costs τ_{ijt} deserves additional comment here. In some cases, we have measures of trade costs that are explicitly time varying, such as indicator variables for membership in a regional trade agreement. In others, we have time invariant proxies for bilateral trade costs, such as distance, for which we analyze how the influence of that proxy changes over time. For example, we are interested in how the influence of distance changes over time. We can model these effects by writing the trade cost as $\log(\tau_{ijt}) = \delta_t \log(dist_{ij})$, where δ_t is a time-varying distance coefficient measuring the penalty associated with distance in a particular year. With this interpretation, we can then accommodate all the results below within the general specification above.

We see two complementary motivations for Equation (11). The first is a mechanical identification argument. We are interested in narrowing our focus on analyzing the response of bilateral trade to bilateral frictions. The fixed effects in Equation (11) help us hone in on this dimension of the data. The source-year and destination-year fixed effects absorb all time-varying source and destination characteristics that influence all trade partners symmetrically. For example, a unilateral tariff liberalization that applies to all trade partners symmetrically would be captured by the destination fixed effects. When we include a pair fixed effect in the regression, then this absorbs all time invariant bilateral characteristics as well.

The second motivation builds on the large literature on gravity regressions. Equation (11) for gross exports is simply a reduced form gravity regression, identical to specifications that emerge from several prominent trade models.[35] By analogy to gravity for gross exports, one can substitute value added exports for gross exports and reinterpret Equation (11) as 'gravity for value added.' While the analogy is clear, it comes with an important caveat. Whereas the reduced form for gross exports can be explicitly derived from structural models,

[35]See Anderson and van Wincoop (2003), Eaton and Kortum (2002), and Chaney (2008).

there is currently no theory of fragmentation or trade in value added that would imply that value added trade should also follow a gravity-type equation. However, from a practical perspective, this specification does fit the data well.

Once one accepts the specification of the regressions for gross and value added trade, then the specification for the VAX ratio follows. Because $\log(VAX_{ijt}) = \log(va_{ijt}) - \log(x_{ijt})$ by construction, the difference in coefficients on variable trade costs in these regressions – $\beta^{va} - \beta^{x}$ – equals the coefficient on trade costs (β^{vax}) in the VAX ratio regression. The three trade cost coefficients then provide an integrated description of how VAX ratios, gross trade, and value added trade are shaped by trade costs.

5.2 Non-Policy Trade Barriers

There are a large number of commonly used proxies for non-policy trade costs. We focus here on four of the most common: distance, language, common borders (contiguity), and common colonial origin.[36] We are interested in two questions. First, how do VAX ratios, gross trade, and value added trade respond to bilateral frictions? Second, how have these responses changed over time?

To address these questions, we start by estimating:

$$\log(y_{ijt}) = \phi^{y}_{it} + \phi^{y}_{jt} + \tilde{\beta}^{y}_{1t}\log(dist_{ij}) + \tilde{\beta}^{y}_{2t}contig_{ij} + \tilde{\beta}^{y}_{3t}language_{ij} + \tilde{\beta}^{y}_{4t}colony_{ij} + \varepsilon_{ijt}, \quad (12)$$

where we have substituted $\log(\tau_{ijt}) = \delta_{1t}\log(dist_{ij}) + \delta_{2t}contig_{ij} + \delta_{3t}language_{ij} + \delta_{4t}colony_{ij}$ into Equation (11) and therefore define $\tilde{\beta}^{y}_{kt} \equiv \beta^{y}_{kt}\delta_{kt}$. In doing so, we assume that ε_{ijt} is uncorrelated with the trade cost proxies and cluster standard errors by country pair. This specification has the advantage of allowing us to recover the level of the trade cost coefficients, as well as allowing us to look at their evolution through time. The countervailing concern, however, is that there may be omitted bilateral pair-specific trade costs that are correlated with the proxies included in the regression and therefore bias the results.

To allow for possible unmodeled pair-specific, time-invariant trade costs, we also estimate Equation (12) in long differences. This specification takes the form:

$$\Delta\log(y_{ijt}) = \Delta\phi^{y}_{it} + \Delta\phi^{y}_{jt} + \breve{\beta}^{y}_{1t}\log(dist_{ij}) + \breve{\beta}^{y}_{2t}contig_{ij} + \breve{\beta}^{y}_{3t}language_{ij} + \breve{\beta}^{y}_{4t}colony_{ij} + \Delta\eta^{y}_{ijt}, \quad (13)$$

[36] We use data from the CEPII Gravity Dataset, available at `http://www.cepii.fr/anglaisgraph/bdd/gravity.htm`. We measure distances using the simple distance between the most populated cities in the two countries. 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. In the CEPII data, these correspond to variables 'dist', 'contiguity', 'colony', and 'commlang_off'.

where $t = \{1975, 2005\}$ and $\breve{\beta}^y_{kt} \equiv \Delta\tilde{\beta}^y_{kt}$ is an estimate of the change in regression coefficients over time. In taking differences over time, note that the pair specific latent variable γ^y_{ij} drops away.

Before turning to results, there are two issues regarding the estimation sample that merit comment. First, small bilateral trade flows tend to be associated with extreme VAX ratios (e.g., > 10), which muddy inference. Most of these observations appear to be due to problematic bilateral trade data for countries during the 1970's and early 1980's, where the raw data is of lower quality (e.g., for emerging markets or former communist countries). To remove these outliers, we drop bilateral flows less than one million dollars in the estimation and any remaining flows with VAX ratios greater than ten.[37] Second, our country sample includes advanced countries and emerging markets almost exclusively. This implies that one must be careful in comparing point estimates from our sample to estimates from the literature computed in samples that include developing countries.

Regression coefficients for trade cost proxies in Equation (12) are plotted in Figure 10. Coefficients for the VAX ratio are in the left panel, while coefficients for gross and value added trade are in the right panel. Looking first at distance, the correlation of VAX ratios and distance is generally positive. This means that on average, gross trade travels shorter distances than trade in value added. This is picked up in coefficients on gross and value added trade directly in the right panel. Both coefficients are negative, meaning that distance depresses both gross and value added trade. However, the absolute value of the distance coefficient on gross trade is larger in all years than the coefficient on value added trade.

Interestingly, there is also evidence that the differential effect of distance on gross and value added trade is strengthening over time. This is evident in the left panel, where the distance coefficient for the VAX ratio is rising over time. The point estimate rises slightly from around 0.05 to 0.1 prior to the mid-1980's and then rises to 0.2 by the end of the 2000's. This gap emerges primarily due to an increase in the absolute value of the distance coefficient for gross trade, which increases from roughly 0.9 to 1.1, concentrated in the 1985-1995 decade. The coefficient on value added trade also rises in absolute value during this period, however the change is about half as large.

Looking at the other trade cost proxies, country pairs with common language and colonial origin tend to have lower bilateral VAX ratios on average. These signs are intuitive, since common language and colonial origin ought to lower trade costs, thereby promoting fragmentation. Results for borders do not speak as clearly. Early in the sample, common

[37] Alternative sample criteria to deal with outliers yield similar results. We also implicitly drop all observations with zero trade flows. In practice, our raw data has relatively few exact zero trade flow observations since we work with aggregate bilateral trade among advanced and major emerging countries.

borders are associated with higher VAX ratios, but this effect goes to zero over time. Relative to the effect of distance on VAX ratios, the result that stands out here is that there are not large changes (if any) in the effect of these trade cost proxies over time. This is of course reflected in the coefficients on gross and value added trade. These coefficients trend over time, with coefficients on language and colonial origin falling somewhat over time and the coefficient on borders rising somewhat over time.[38] Yet, unlike for distance, coefficients for gross and value added trade move in lock step. Hence, there are minimal changes in terms of how VAX ratios vary with these trade cost proxies.

This basic story can be seen clearly in estimates of the long differences specification in Equation (13), which are presented in Table 1. In the table, we present results for regressions of $\Delta \log(VAX_{ijt})$, $\Delta \log(va_{ijt})$, $\Delta \log(x_{ijt})$ on the trade cost proxies. Looking at the results for the VAX ratio, we see that declines in the VAX ratio are smaller for countries that are farther apart. As in the time series presentation of coefficients above, there is no clear relationship between changes in the VAX ratio and common colonial origin, language, or borders.

Looking at gross and value added exports separately, increases in both gross and value added trade are smaller for countries that are far apart, but the costs of distance hit gross trade harder. It is also worth noting that even though there is no relationship between changes in VAX ratios and colonial origin or common language, these variables do help predict changes in trade. Common language and colonial origin are associated with smaller increases in both gross and value added trade, with roughly similar magnitudes. These effects are again consistent with trends in the level of the trade cost coefficients reported in Figure 10.

To examine the mechanics underlying the effect of distance on VAX ratios, we revisit the approximate accounting decomposition introduced Section 2.2. Specifically, we re-run the long difference regression specification in Equation (13) with the log of the Approximate VAX Ratio and components defined in Section 4.3 as dependent variables. The log Approximate VAX Ratio declines in distance with an elasticity of 0.043 ($s.e. = 0.006$). This elasticity is roughly half that reported for the actual VAX ratio in Table 1, consistent with the Approximate VAX ratio accounting for half the variation in overall VAX ratios. This elasticity is mostly a product of a strong positive correlation between the Indirect Exports Adjustment and distance, with a distance elasticity of 0.042 ($s.e. = 0.006$).[39] This suggests that an important reason why value added tends to 'travel further' than gross trade is

[38] See Head, Mayer, and Reis (2010) on the changing importance of colonial origin over time.

[39] The elasticity of the Absorption Ratio with distance is near zero (-0.001) and insignificant ($s.e. = 0.001$). The Reflection/Redirection Adjustment is negatively correlated with distance, but small in magnitude (-0.002 with $s.e. = .001$).

that source countries tend to serve distant destinations indirectly, exporting intermediates to third countries that get re-exported for absorption in distant destinations.[40] This echoes the logic of 'export platforms' in multinational production chains, though here applied to all trade rather than just multinational activity.

5.3 Trade Agreements

We now turn to analyzing the response of value added and gross trade to adoption of bilateral or regional trade agreements (RTAs).[41] We use two complementary approaches to evaluating the consequences of these agreements. We start with a quasi event study, in which we illustrate how bilateral VAX ratios change through time for country pairs as they enter preferential bilateral or regional agreements. To pin down the effects of the agreements with greater precision, we then turn to panel regressions for VAX ratios, gross trade, and value added trade.

We use data on economic integration agreements assembled by Scott Baier and Jeffrey Bergstrand, which covers the 1960-2005 period.[42] There are five types of trade agreements recorded in the Baier-Bergstrand data: (1) one-way preferential agreements, (2) two-way preferential agreements, (3) free trade agreements, (4) customs unions, (5) common markets, and (6) economic unions. These agreements are ordered from "shallow" to "deep," where deeper agreements entail larger border concessions, tighter integration of trade policies, and more substantial coordination of economic policy.[43]

We define an indicator for the existence of a regional trade agreement that takes the value one if a country pair has an agreement that is classified as a free trade agreement or stronger (i.e., agreements 3 to 6). Further, we present some results splitting agreements by type, defining separate indicators for preferential trade agreements (PTA) covering both one-way and two-way preferential agreements, free trade agreements (FTA), and "deep integration agreements" (CUCMEU) covering customs unions, common markets, and economic unions. With this classification, an individual country pair may transit from no agreement to an agreement, as well as transit from one type of agreement to another.[44]

[40]In the cross-section, indirect trade is particularly important for countries whose exports are dominated by agriculture and natural resources, which are extensively used as intermediates.

[41]One might expect that adoption of multilateral agreements, such as WTO entry, would influence fragmentation as well. Unfortunately, we cannot examine this proposition given the country coverage of our data. Since 38 of the 42 countries in our sample are WTO members during the entire sample, there is not enough variation to confidently pin down the effects of WTO entry.

[42]The data is available at: `http://www.nd.edu/~jbergstr/`.

[43]Agreement types 4 to 6 entail common tariff policies against outsiders. Common markets entail substantial behind-the-border integration. Economic unions are associated with coordination of economic policy, such as adoption of common monetary policy.

[44]For example, Argentina and Brazil have a pre-existing preferential agreement that switches to a free

5.3.1 Changes in VAX Ratios around RTAs

To begin, we present a visual demonstration of how VAX ratios change surrounding adoption of regional trade agreements. Loosely speaking, we take an event study approach. We compare VAX ratios for the 'treatment group' of bilateral country pairs that are members of an RTA during our sample to VAX ratios for a pair-specific 'control group' in a window surrounding adoption of the RTA.

To be concrete, let (i, j) denote a pair of countries that form an RTA during the sample period. Then we define the composite VAX ratio at time t for this pair as:

$$\begin{aligned} CVAX_t(i,j) &= \frac{va_{ijt} + va_{jit}}{x_{ijt} + x_{jit}} \\ &= VAX_{ijt}\left(\frac{x_{ijt}}{x_{ijt} + x_{jit}}\right) + VAX_{jit}\left(\frac{x_{jit}}{x_{ijt} + x_{jit}}\right). \end{aligned} \tag{14}$$

This is simply a trade-weighted average of VAX_{ijt} and VAX_{jit}. As a dating convention, we normalize t for each pair to count years before and after the adoption of the RTA.[45]

Further, let us define a set of countries $C(i, j)$ to be used in constructing counterfactual VAX ratios for pair (i, j). We define the composite VAX ratio for countries i and j vis-a-vis these countries as:

$$\begin{aligned} \overline{CVAX}_t(i,j) &= \sum_{c \in C(i,j)} \frac{(va_{cjt} + va_{jct}) + (va_{cit} + va_{ict})}{(x_{cjt} + x_{jct}) + (x_{cit} + x_{ict})} \\ &= \sum_{c \in C(i,j)} CVAX_t(c,j)\left(\frac{x_{cjt} + x_{jct}}{X(c)}\right) + CVAX_t(c,i)\left(\frac{x_{cit} + x_{ict}}{X(c)}\right), \end{aligned} \tag{15}$$

where $X(c) \equiv x_{cjt} + x_{jct} + x_{cit} + x_{ict}$. This counterfactual is the analog to Equation (14) constructed for countries i and j against the country set $C(i, j)$ separately, and then averaged across i and j using trade weights. There are many possible ways to define $C(i, j)$. Here we define $C(i, j)$ to be the set of countries with whom both i and j never form an RTA.[46]

For each pair, we compute $CVAX_t(i, j)$ and $\overline{CVAX}_t(i, j)$, and then take an unweighted

trade agreement with the adoption of Mercosur. Similarly, many Eastern European countries have FTAs during the 1990's that transition to CUCMEUs as they enter the EU.

[45] For example, the U.S. and Mexico have $t = 0$ in 1994 when NAFTA is formed, $t = -1$ in 1993, and $t = 1$ in 1995. In our calculations, we include country pairs that form RTAs prior to 1970 (e.g., France and Germany), starting the counter at $t = 0$ in 1970 for these pairs. Results are not sensitive to inclusion/exclusion of these pairs, since most RTA's are formed after 1970.

[46] For example, say i is Spain and j is Germany. Spain enters the EU in 1986, and we want to look at how the bilateral VAX ratio between Spain and Germany changes around that time. We compare this change to VAX ratios for Spain and Germany with countries that neither Spain nor Germany ever form an RTA (e.g., the United States, Japan, etc.).

average of each series across all pairs. We plot the resulting 'treatment' and 'control' series in Figure 11 in a forty year window around the date of adoption of the RTA. Most agreements are adopted near the middle of the sample, but obviously not all agreements have all twenty years of data on each side of the agreement. Therefore, we also plot a 90% confidence interval around the mean in the figure, which naturally increases as we move away from the event date as sample sizes fall.

Prior to RTA adoption, $CVAX_t(i,j)$ and $\overline{CVAX}_t(i,j)$ are quite similar across the treatment and control groups. There is then a strong divergence between the two, coinciding with adoption of the RTA. $CVAX_t(i,j)$ drops sharply near the RTA adoption date, and then continues to fall for roughly a decade thereafter. This slow adjustment is not surprising, both because RTAs are typically phased in and trade patterns may be slow to adjust. Suffice it to say, the sharp divergence in value added to export ratios between the 'treatment' and 'control' groups here is strong prima facie evidence that trade agreements influence fragmentation.

5.3.2 Panel Regressions

To formalize these results and control for confounding factors, we turn to panel regressions. Specifically, the core regression takes the form:

$$\log(y_{ijt}) = \phi_0^y + \phi_{it}^y + \phi_{jt}^y + \beta^y TradeAgreement_{ijt} + \gamma_{ij}^y + \eta_{ijt}^y, \tag{16}$$

where $TradeAgreement_{ijt}$ takes the value one if i and j are both in a particular trade agreement at time t. In some specifications, we add a pair-specific linear trend ($\delta_{ij}^y t$) as well.[47]

In this estimation, we treat the latent variable γ_{ij}^y as a fixed effect, following Baier and Bergstrand (2007). The pair fixed effect accounts for endogenous adoption of agreements based on characteristics of the bilateral pair that are not time varying.[48] The estimate of β^y is then an estimate of how outcomes vary within country pair before and after adoption of the trade agreement, controlling for time-varying source and destination effects. We also report results for specifications below that include a pair-specific linear trend, which further removes the concern that RTA adoption depends on pair-specific trends in trade or fragmentation.

[47] Given the correlation between VAX changes and distance, we have also run this specification controlling for the changing effect of distance over time. The results, included in Appendix B, are robust to including this additional control.

[48] See also Magee (2008) and Anderson and Yotov (2011). In addition, pair fixed effects obviously absorb pair-specific unobserved trade costs. They have therefore been used in related work not focused on RTAs, such as Glick and Rose (2002), Baldwin and Taglioni (2007), and Head, Mayer, and Reis (2010).

In Figure 2, we report estimation results for panel regressions with data at 5 year intervals from 1970 to 2005. We use data at five year intervals due to concerns about serial correlation in shocks and possibly sluggish adjustment of trade to shocks or policy changes.[49] Further, we run the panel regressions both in levels and first differences, and cluster standard errors in both specifications by country pair.

We turn first to estimation results for the VAX ratio in Panel A. We find that adoption of trade agreements typically lowers VAX ratios among countries in those agreements. For RTAs, we find that the VAX ratio falls by 5-7% following adoption of an agreement. In columns 3, 4, 7, and 8, we split out the effects of different agreements. We find that there is no effect on the VAX ratio of signing a preferential agreement (which does not induce the RTA indicator to switch on). In contrast, both adoption of an FTA or CUCMEU lower the VAX ratio. Further, "deeper" agreements are associated with larger declines in the VAX ratio than shallow agreements. Following adoption of a CUCMEU, the VAX ratio declines between 10-15% in the levels regresion, whereas adoption of a FTA is associated with a drop of 6-7%.[50]

The response of gross and value added trade flows to RTA adoption are reported in Panels B and C. Consistent with the changes in VAX ratios, we find that gross exports rise more following the adoption of RTAs than do value added exports, and more for "deep" rather than "shallow" agreements.[51] That said, both value added and gross exports rise following adoption of trade agreements in level terms. This is sensible, since RTAs lower trade costs for both final goods, as well as intermediate inputs (some of which are absorbed in the destination). The key is that there appears to be a differential effect on final versus intermediate trade that results in a lower value added content of bilateral trade.

In the specifications thus far, the RTA indicators measure the average treatment effect comparing all pre-agreement observations to all post-agreement observations for each pair. There are a number of reasons to believe that this may bias downwards the estimated effect of trade agreements. For one, trade agreements are phased in, so there may be a relatively small initial impact of the agreement that grows over time. Moreover, even once trade barriers come down, it may take some time for trade flows to respond to those changes. Finally, in the data, countries that adopt FTAs often adopt strong agreements (such as common

[49] Baier and Bergstrand (2007) and Anderson and Yotov (2011) also use data at four or five year intervals. The main problem with using the data at five year intervals is that many trade agreements are signed in intervening years, so we lose some precision in dating agreements. We have checked that our results go through in specifications using annual data and the exact timing of agreements.

[50] The effects are slightly smaller in the first differences specification, but the ordering of effects by agreement strength holds there as well.

[51] Magee (2008) and Roy (2010) have also documented larger responses of trade to deep versus shallow trade agreements.

markets) at a later date. So the depth of liberalization evolves over time within pairs. The adjustment dynamics observed in the 'event study' diagrams suggest these issues may be worth examining more carefully.

To illustrate the dynamics surrounding adoption of the trade agreements, we adopt a more flexible functional form.[52] We define separate indicator variables for five year intervals following adoption of an RTA: RTA one is the first year, RTA two is the 5th year, RTA three is the tenth year, and RTA four/more takes the value one for years 15 onward. Each coefficient then estimates the average difference in the VAX ratio in a particular year after the adoption of the RTA from the average VAX ratio during the pre-RTA period.

We report the coefficients on these phased-in RTA indicators in Table 3.[53] Consistent with the dynamics in Figure 11, the impact of RTA adoption appears to grow over time. Upon adoption of the RTA, VAX ratios fall by 5-7% and then continue to fall over the duration of the agreement. In the first-differenced specifications, the total effect of the RTA levels off at around 12% decline in the VAX ratio. Value added and gross exports follow similar adjustment dynamics, with value added exports rising between 25-35% and gross exports rising between 35-45% in the long run.

5.3.3 Decomposing Changes in VAX Ratios around RTAs

Finally, we use the approximate VAX ratio again to examine the mechanics of adjustment following RTA adoption. In Figure 12, we plot the log Approximate VAX Ratio and components for bilateral partners around four major trade reforms: United States-Mexico (Mexican liberalization and NAFTA), United States-Canada (CUSFTA), Argentina-Brazil (Mercosur), and Germany-Spain (EU entry and completion of the Single Market). In the figure, we break up the Reflection/Redirection Adjustment into separate terms for Reflection and Redirection, and we plot the negative of each term so that the four series in the figure sum to the log Approximate VAX ratio.[54] There are three points to take away from the figures.

First, changes in the Absorption Ratio and Reflection/Redirection Adjustments tend to dominate changes in the Approximate VAX ratio in these RTA episodes. In contrast, indirect

[52] Our approach is similar to Head, Mayer, and Reis (2010), who use this non-parametric procedure to explore trade dynamics following decolonization.

[53] All columns in this table include exporter-year and importer-year fixed effects. Columns 1 and 2 contain a pair fixed effect, while column 2 also contains a pair-specific linear trend. Columns 3 and 4 are regressions in first differenced data, where column 4 includes a pair fixed effect to absorb pair-specific linear trends.

[54] To do this, we use the fact that $\log\left(1+\frac{\text{reflection}_{ijt}+\text{redirection}_{ijt}}{\text{absorption}_{ijt}}\right) \approx \frac{\text{reflection}_{ijt}}{\text{absorption}_{ijt}} + \frac{\text{redirection}_{ijt}}{\text{absorption}_{ijt}}$ when reflection and redirection are small relative to absorption. In practice, this approximation is very accurate in our data. To keep the figures from getting cluttered, we do not plot the actual VAX ratios in the figure. Changes in actual VAX ratios tend to be about twice as large as changes in Approximate VAX ratios upon adoption of RTAs, consistent with previous results.

exports are smooth around RTA dates. For United States-Mexico, United States-Canada, and Argentina-Brazil, changes in indirect exports are practically zero. For Germany-Spain, indirect trade actually rises slowly over time, consistent with Spain and Germany serving each other through third countries (e.g., common EU partners). This attenuates the amount by which their bilateral VAX ratios fall. Second, adjustment tends to be asymmetric across partners depending on the direction of trade. A common pattern is that one partner sees changes in the Reflection/Redirection Adjustments, while the other sees changes in the Absorption Ratio.

This general characterization masks important heterogeneity across agreements in how reflection versus redirection adjust, however. This heterogeneity is the third takeaway. Looking at United States-Mexico or United States-Canada, the common pattern is that increases in Reflection trade dominate changes in Approximate VAX ratios for the United States exporting to Canada/Mexico. On the flipside, the VAX ratio for exports from Mexico/Canada to the United States falls mainly due to adjustment in the Absorption Ratio. These are of course two sides of the same coin, as one country's reflected/redirected exports are the other country's imported inputs used to produce exports. These agreements therefore induced fundamentally bilateral adjustments in production chains.

In contrast, for Argentina-Brazil or Germany-Spain, adjustments vis-a-vis third countries are more important. For example, for Argentina exporting to Brazil, there is a substantial decline in the Absorption Ratio, but no corresponding rise in reflection in flows from Brazil to Argentina. This is consistent with Argentina increasingly being used as a platform to serve the Brazilian market.[55] A similar triangular pattern emerges for Spanish exports to Germany after 1992, where redirection trade rises substantially. On the flip side, Germany's absorption ratio falls after 1992, explaining most of the drop in the VAX ratio for German exports to Spain. These example highlight the rich adjustment dynamics that underlie the overall decline in VAX ratios following RTAs.

6 Conclusion

Theorists and policymakers alike are devoting attention to analyzing cross-border production fragmentation. Consistent with this attention, we have shown that the rise in production fragmentation over time is pervasive. We highlight, however, changes in fragmentation are unevenly distributed across sectors, time, countries, and trade partners. The value added

[55] For Brazil exporting to Argentina, redirection trade becomes more important over time – particularly after the 2001 Argentine devaluation. This is further evidence suggesting that Argentina emerged as an input processing cog in triangular regional production chains.

content of trade has fallen most in the past two decades, fallen most within manufacturing, fallen most for countries undergoing structural transformation toward manufacturing, and fallen most among trade partners that are physically proximate or have adopted bilateral trade agreements.

The fact that fragmentation has increased unevenly suggests two paths for future work. On the one hand, one can take changes in fragmentation for granted and explore what they imply for analysis of international trade and macroeconomic data. For example, how does the rise in fragmentation influence the mapping between observed changes in trade and the associated production or welfare gains? Or, how has the rise of production fragmentation changed how shocks are transmitted across borders? On the other hand, one can explore the determinants of fragmentation within the context of quantitative models. For example, how important are trade frictions relative to country-specific determinants of fragmentation? Or, how might fragmentation patterns evolve under alternative policy scenarios? In future work, we plan to exploit the rich historical variation in fragmentation in parameterizing quantitative frameworks to address these questions.

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Table 1: Long Difference Panel Regressions with Proxies for Trade Costs

Panel A: Change in log of VAX Ratio

	(A1)	(A2)	(A3)	(A4)	(A5)
Log Distance	0.097***	0.092***	0.097***	0.096***	0.091***
	(0.011)	(0.013)	(0.011)	(0.011)	(0.013)
Contiguity		-0.038			-0.034
		(0.034)			(0.036)
Colonial Origin			0.008		0.021
			(0.032)		(0.038)
Common Language				-0.016	-0.016
				(0.026)	(0.031)
R^2	0.48	0.48	0.48	0.48	0.48

Panel B: Change in log of Value Added Exports

	(B1)	(B2)	(B3)	(B4)	(B5)
Log Distance	-0.089***	-0.111***	-0.087***	-0.112***	-0.109***
	(0.029)	(0.032)	(0.028)	(0.029)	(0.031)
Contiguity		-0.170			-0.054
		(0.106)			(0.110)
Colonial Origin			-0.444***		-0.338***
			(0.102)		(0.119)
Common Language				-0.280***	-0.177**
				(0.072)	(0.090)
R^2	0.66	0.66	0.67	0.66	0.67

Panel C: Change in log of Gross Exports

	(C1)	(C2)	(C3)	(C4)	(C5)
Log Distance	-0.186***	-0.203***	-0.184***	-0.207***	-0.200***
	(0.036)	(0.041)	(0.035)	(0.036)	(0.040)
Contiguity		-0.132			-0.019
		(0.126)			(0.130)
Colonial Origin			-0.451***		-0.358**
			(0.127)		(0.149)
Common Language				-0.264***	-0.161
				(0.090)	(0.111)
R^2	0.61	0.61	0.61	0.61	0.61
Obs.	1180	1180	1180	1180	1180

Note: Changes in the logs of bilateral VAX ratios, value added exports, and gross exports between 2005 and 1975 (e.g., $\log(y_{ij,2005}) - \log(y_{ij,1975})$ 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.

Table 2: Panel Regressions with Regional Trade Agreements

Panel A: log of VAX Ratio

	In Levels				In First Differences			
	(A1)	(A2)	(A3)	(A4)	(A5)	(A6)	(A7)	(A8)
RTA	-0.069***	-0.068***			-0.050***	-0.049***		
	(0.015)	(0.017)			(0.014)	(0.016)		
PTA			-0.005	-0.006			0.003	0.005
			(0.012)	(0.015)			(0.012)	(0.015)
FTA			-0.057***	-0.068***			-0.047***	-0.047***
			(0.016)	(0.018)			(0.015)	(0.017)
CUCMEU			-0.145***	-0.096***			-0.072***	-0.054***
			(0.019)	(0.023)			(0.017)	(0.020)
R^2	0.76	0.86	0.77	0.86	0.22	0.32	0.22	0.32

Panel B: log of Value Added Exports

	In Levels				In First Differences			
	(B1)	(B2)	(B3)	(B4)	(B5)	(B6)	(B7)	(B8)
RTA	0.256***	0.223***			0.167***	0.163***		
	(0.031)	(0.033)			(0.022)	(0.026)		
PTA			0.020	0.005			-0.001	-0.007
			(0.033)	(0.032)			(0.028)	(0.033)
FTA			0.235***	0.219***			0.161***	0.158***
			(0.034)	(0.035)			(0.025)	(0.030)
CUCMEU			0.418***	0.319***			0.262***	0.231***
			(0.045)	(0.046)			(0.032)	(0.041)
R^2	0.97	0.99	0.97	0.99	0.62	0.67	0.62	0.67

Panel C: log of Gross Exports

	In Levels				In First Differences			
	(C1)	(C2)	(C3)	(C4)	(C5)	(C6)	(C7)	(C8)
RTA	0.325***	0.290***			0.217***	0.212***		
	(0.041)	(0.045)			(0.032)	(0.038)		
PTA			0.025	0.011			-0.004	-0.012
			(0.041)	(0.043)			(0.037)	(0.044)
FTA			0.293***	0.287***			0.208***	0.205***
			(0.045)	(0.049)			(0.036)	(0.043)
CUCMEU			0.563***	0.415***			0.334***	0.285***
			(0.058)	(0.063)			(0.044)	(0.056)
R^2	0.96	0.98	0.96	0.98	0.47	0.53	0.47	0.53

Pair Trend		X		X		X		X
Obs.	11184	11184	11184	11184	9362	9362	9362	9362

Note: All regressions include exporter-year and importer-year fixed effects. Columns 1 to 4 include pair fixed effects, and columns 2 and 4 include a linear pair-specific trend. Columns 6 and 8 include pair fixed effects, capturing 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 3: Panel Regressions with Regional Trade Agreements with Phase In Effects

Panel A: log of VAX Ratio

	In Levels		In First Differences	
	(A1)	(A2)	(A3)	(A4)
RTA one	-0.057***	-0.067***	-0.056***	-0.060***
	(0.014)	(0.017)	(0.014)	(0.017)
RTA two	-0.089***	-0.103***	-0.083***	-0.090***
	(0.017)	(0.023)	(0.017)	(0.023)
RTA three	-0.130***	-0.117***	-0.098***	-0.099***
	(0.021)	(0.028)	(0.021)	(0.029)
RTA four/more	-0.169***	-0.144***	-0.115***	-0.114***
	(0.023)	(0.035)	(0.024)	(0.034)
R^2	0.77	0.86	0.22	0.33

Panel B: log of Value Added Exports

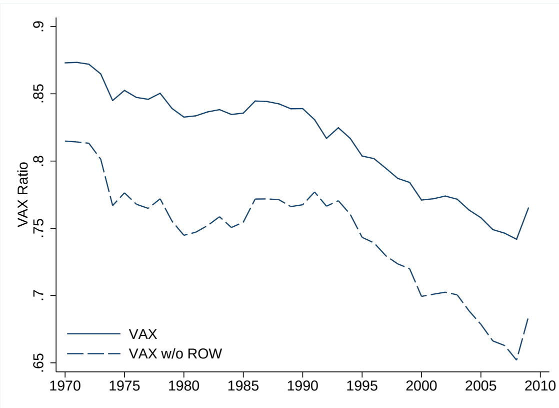
	In Levels		In First Differences	
	(B1)	(B2)	(B3)	(B4)
RTA one	0.201***	0.209***	0.183***	0.189***
	(0.027)	(0.032)	(0.023)	(0.029)
RTA two	0.309***	0.315***	0.265***	0.277***
	(0.036)	(0.046)	(0.031)	(0.044)
RTA three	0.409***	0.331***	0.280***	0.267***
	(0.046)	(0.057)	(0.038)	(0.056)
RTA four/more	0.358***	0.323***	0.260***	0.248***
	(0.054)	(0.069)	(0.045)	(0.068)
R^2	0.97	0.99	0.62	0.67

Panel C: log of Gross Exports

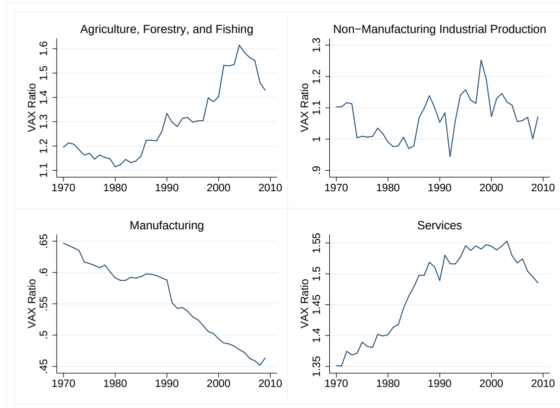
	In Levels		In First Differences	
	(C1)	(C2)	(C3)	(C4)
RTA one	0.258***	0.276***	0.239***	0.249***
	(0.030)	(0.034)	(0.032)	(0.037)
RTA two	0.398***	0.417***	0.348***	0.367***
	(0.036)	(0.045)	(0.046)	(0.058)
RTA three	0.539***	0.448***	0.378***	0.366***
	(0.043)	(0.054)	(0.059)	(0.077)
RTA four/more	0.527***	0.467***	0.375***	0.362***
	(0.048)	(0.067)	(0.072)	(0.092)
R^2	0.96	0.98	0.47	0.53
Obs.	11184	11184	9362	9362

Note: All regressions include exporter-year and importer-year fixed effects. Columns 1 and 2 contain pair fixed effects. Columns 2 and 4 control for linear pair 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.

Figure 1: World Value Added to Export Ratios

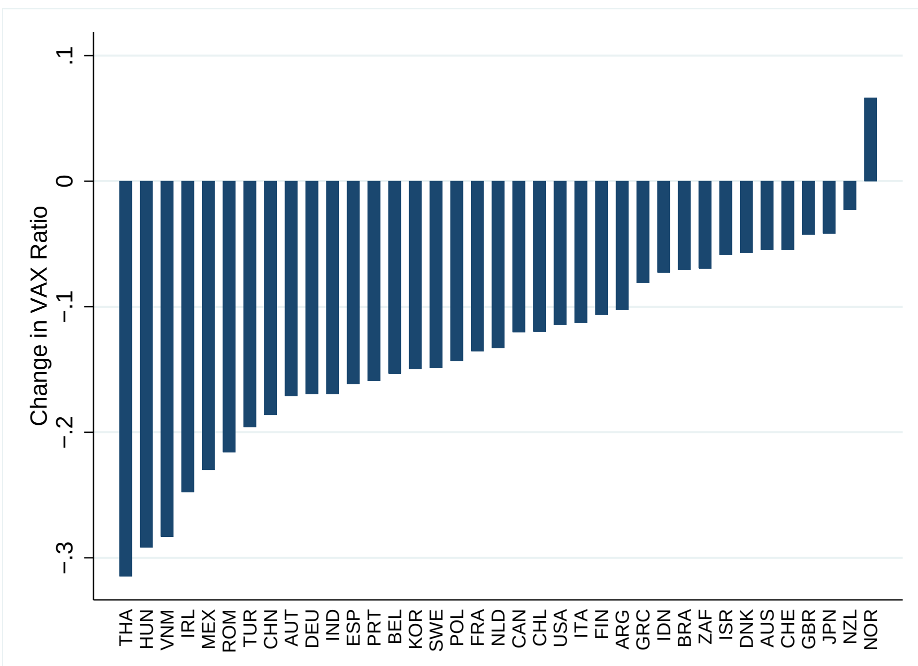


(a) Aggregate



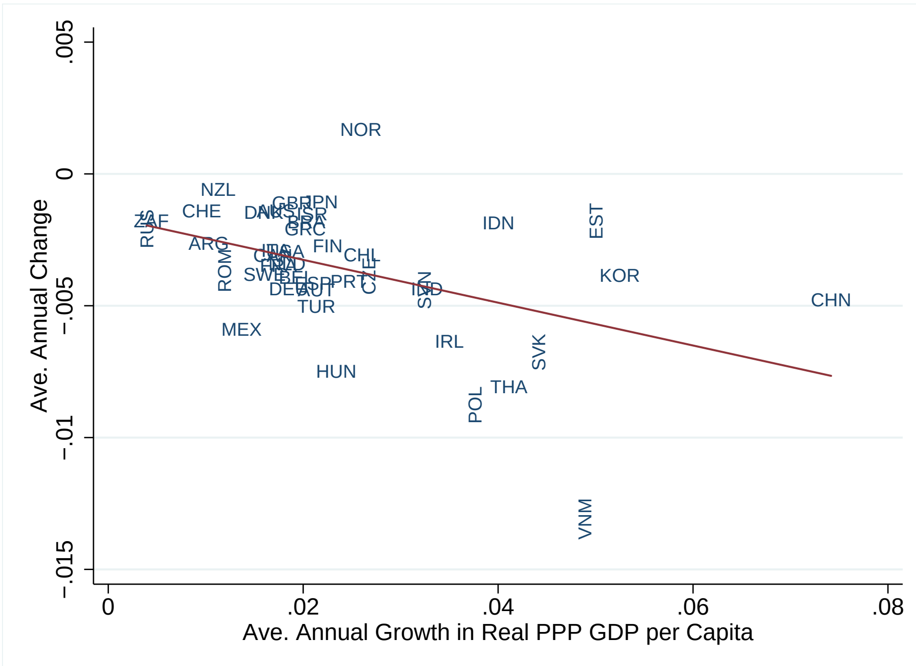
(b) By Sector

Figure 2: Changes in Value Added to Export Ratios from 1970 to 2009, by Country



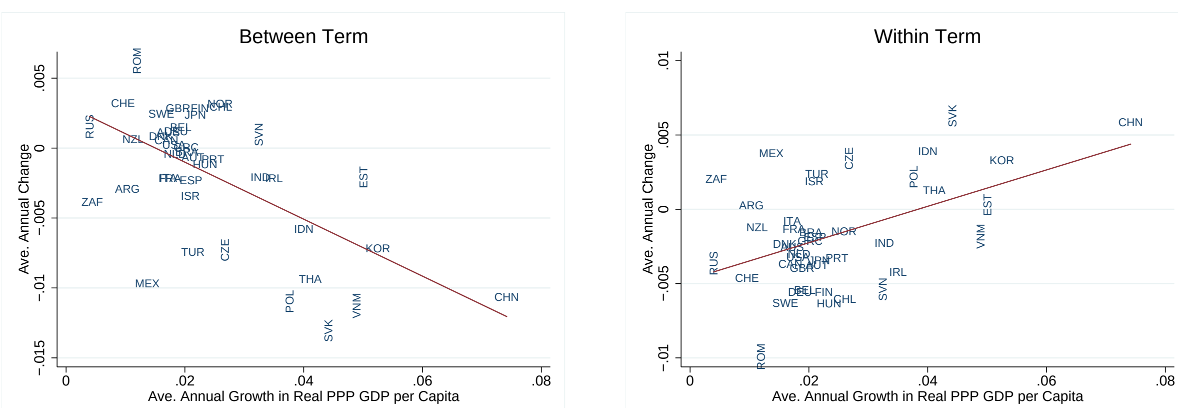
Note: Czech Republic, Estonia, Russia, Slovakia, and Slovenia are excluded due to missing data in 1970.

Figure 3: Average Annual Change in Value Added to Export Ratio versus Average Annual Real GDP Per Capita Growth, by Country



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

Figure 4: 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.

Figure 5: Aggregate Value Added to Export Ratios for China, Germany, Japan, and United States

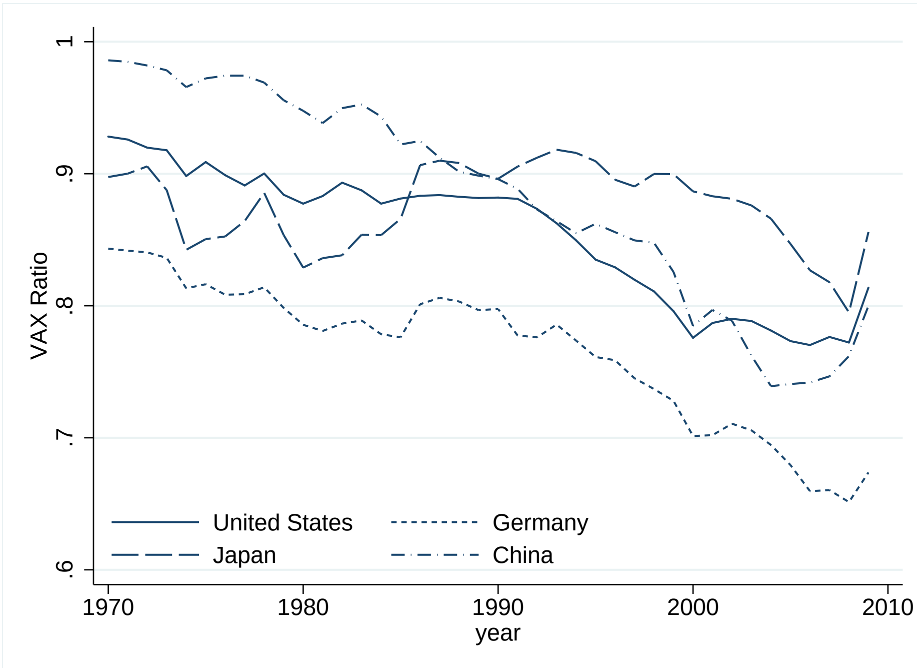


Figure 6: Aggregate Value Added to Export Ratios for Selected Emerging Markets

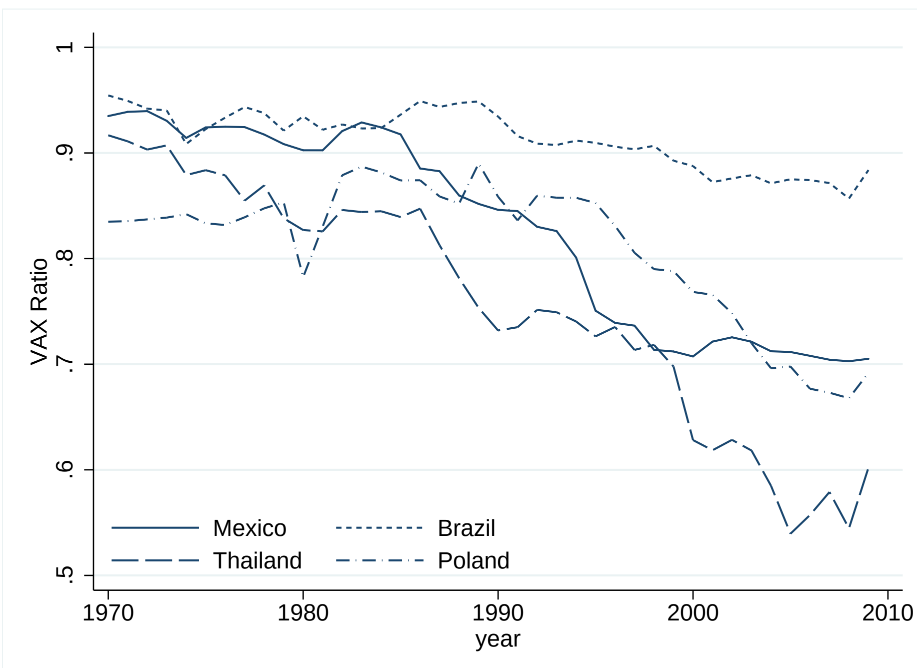


Figure 7: Changes in Bilateral Value Added to Export Ratios for Selected Countries

Figure 8: Changes in Approximate Bilateral VAX Ratios and the Margins of Trade from 1975 to 2005 for Selected Countries

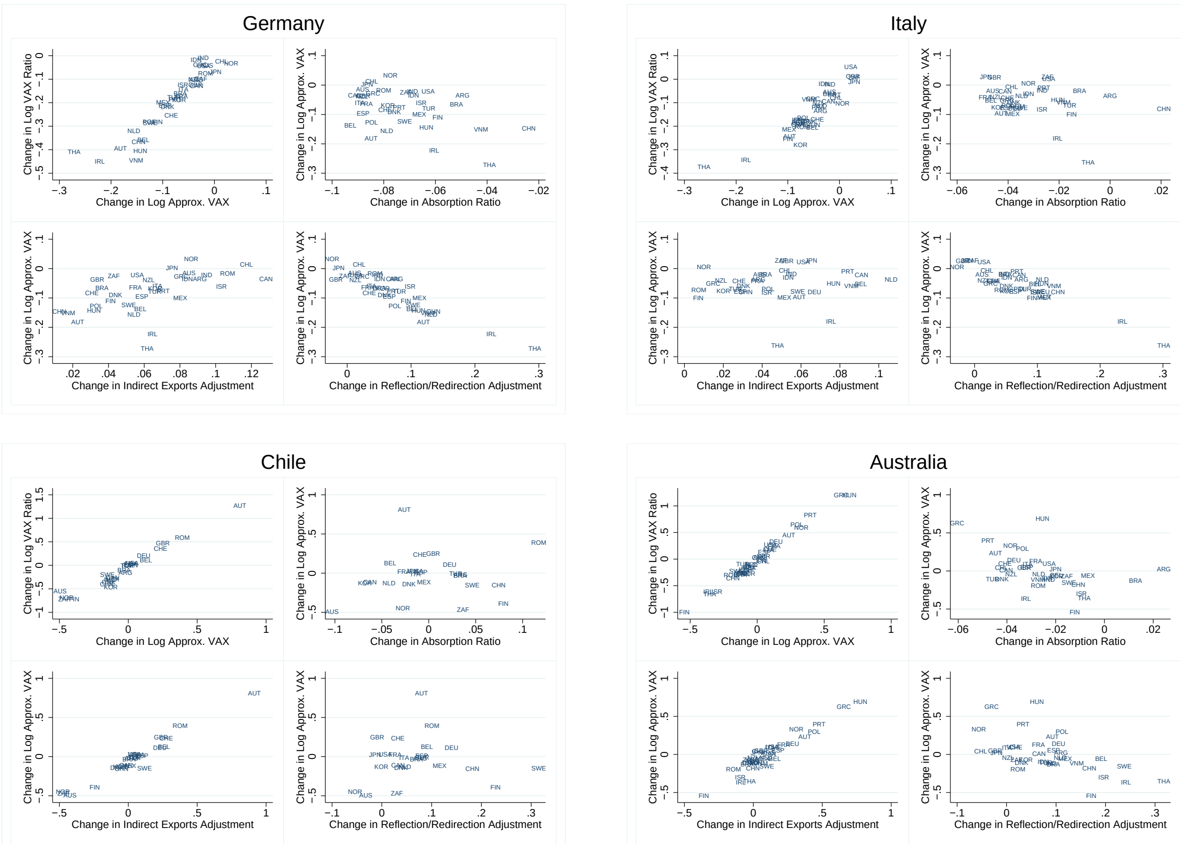


Figure 9: Bilateral Value Added to Export Ratios for the United States

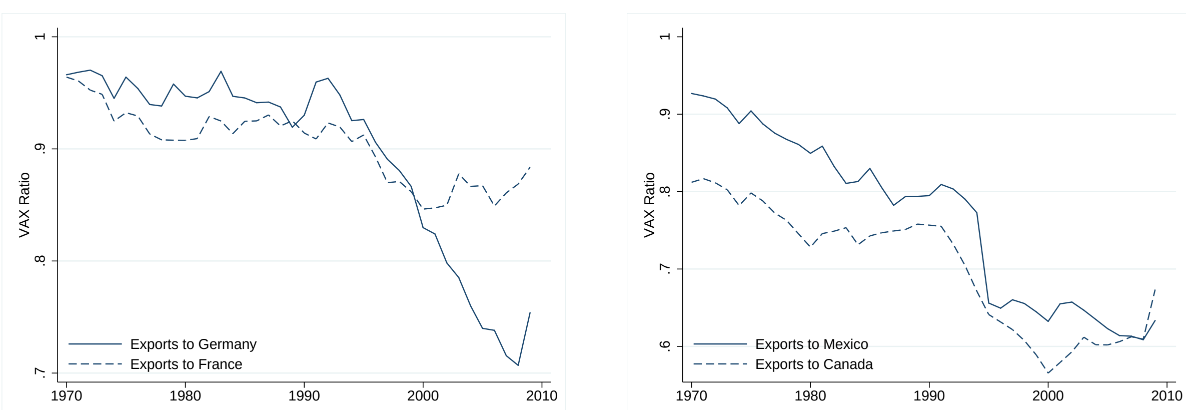
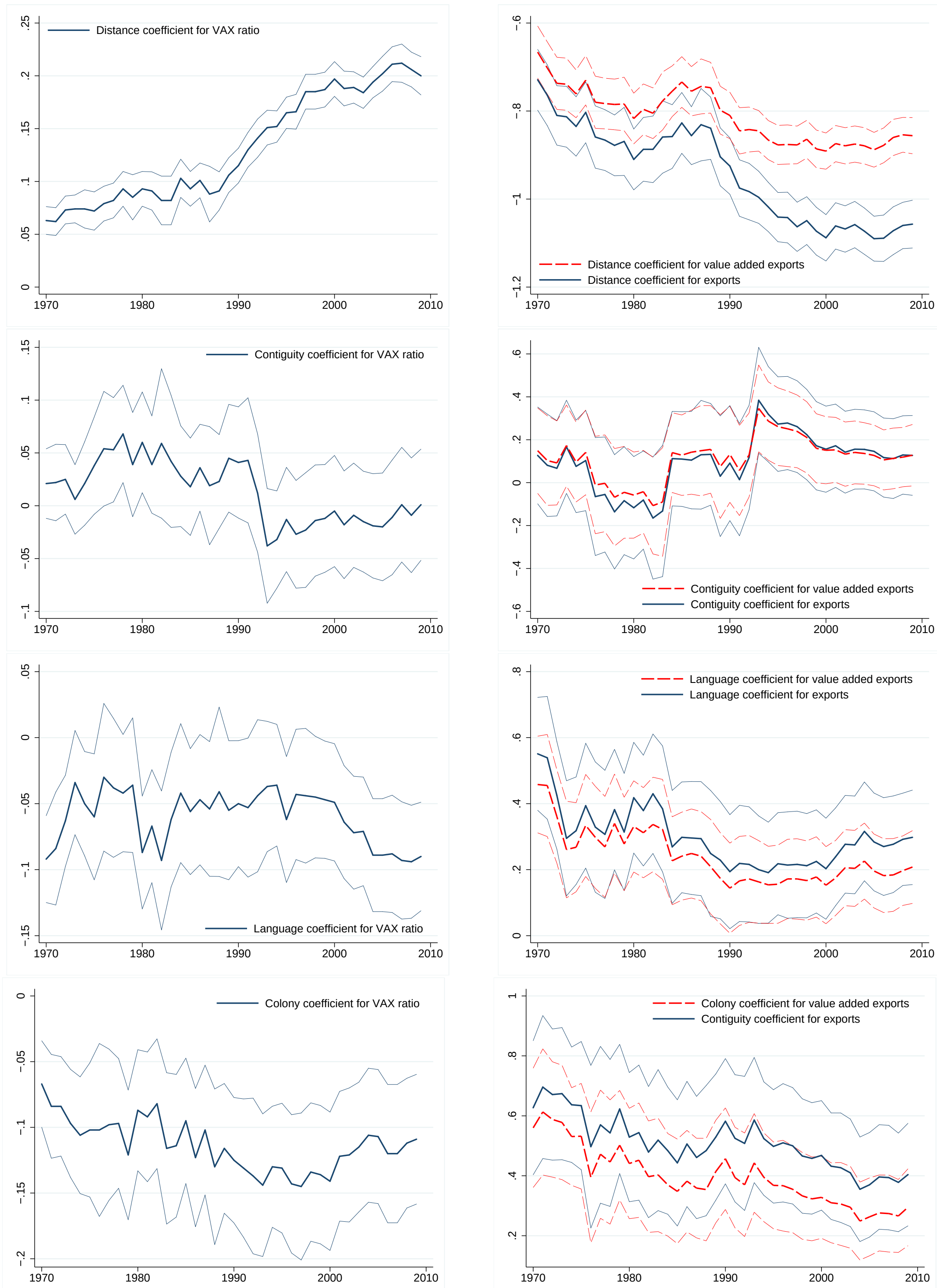


Figure 10: Coefficients on Proxies for Trade Costs from Panel Regressions



Note: See Equation (12) for regression specification. Regressions include time-varying source and destination fixed effects. In each set of lines, the middle line indicates the point estimate, and upper/lower lines denote 90% confidence intervals. Standard errors are clustered by country pair.

Figure 11: Bilateral Value Added to Export Ratios around Adoption of Regional Trade Agreements

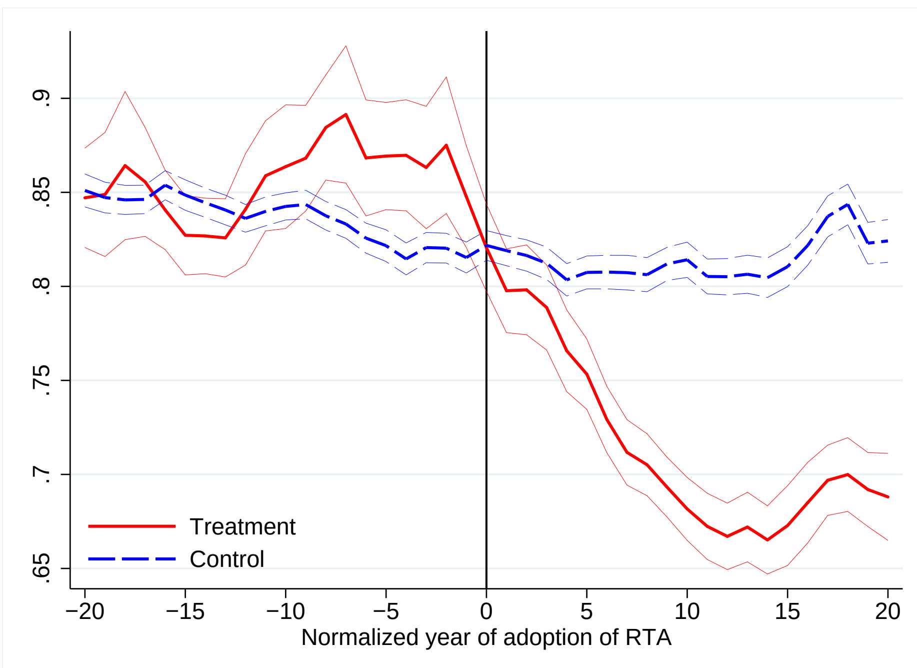
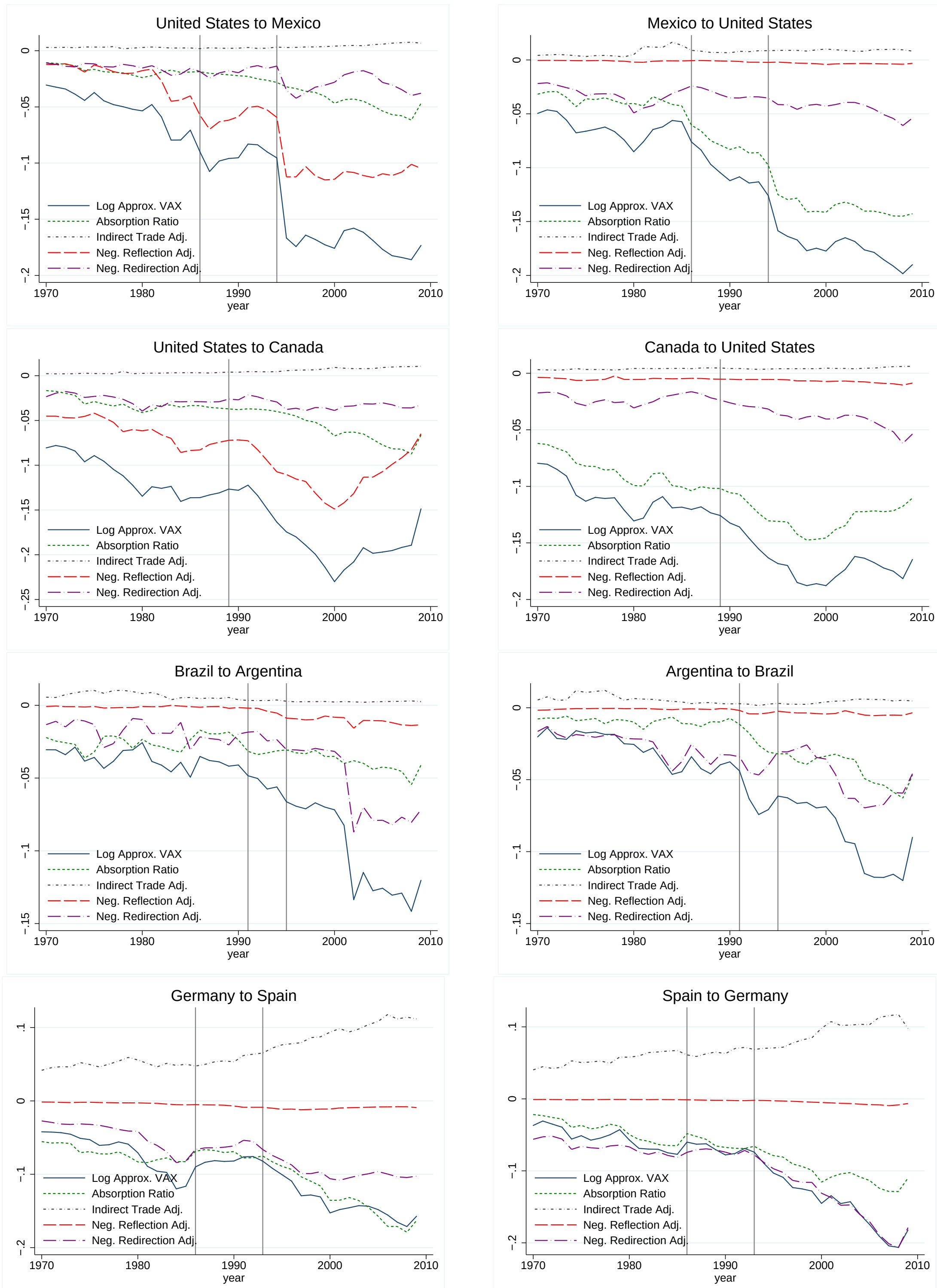


Figure 12: Approximate Bilateral VAX Ratios and the Margins of Trade around Adoption of Regional Trade Agreements



Note: Vertical lines indicate dates of trade liberalizations. US-Mexico lines indicate unilateral liberalization by Mexico in 1986 and NAFTA in 1994. US-Canada line indicates CUSFTA in 1989. Argentina-Brazil lines indicate Mercosur signing in 1991 and entry into force in 1995. Germany-Spain lines indicate Spanish EU entry in 1986 and Single Market in 1993.

A Data Appendix

A.1 Data Construction

This section describes the data sources and procedures that we use to construct the input-output framework.

A.1.1 Production and National Accounts

To measure macroeconomic aggregates and sector-level production over time, we use the United Nations National Accounts Main Aggregates Database and the World Bank's World Development Indicators (WDI).[56] 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 WDI for China.[57] We also take sector-level GDP data from these sources for the four composite sectors, and we include the sector definitions in Table 5. Finally, from the WDI, we also extract goods and services trade shares in total exports and total imports. These are based on Balance of Payments statistics, and we use these shares to split exports and imports from the expenditure-side GDP data into goods versus services.

A.1.2 Trade Data

We combine commodity trade statistics and the trade aggregates in the national accounts to generate a database of bilateral trade flows that is consistent in level terms with the national accounts. We discuss three issues in production of this data. First, we discuss bilateral commodity trade data sources and correspondences to industry data. Second, we discuss how we harmonize these 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 for 1970-2000 and the CEPII BACI Database for 1995-2009.[58] The country coverage of the trade data is nearly universal. We collapse the data to include the 42 countries and one composite rest-of-the-world region, including all remaining countries.

This data is reported on a commodity-basis, but can be translated from commodities to industries (e.g., ISIC-based industries) using existing correspondences. To convert the UN-NBER data from SITC Revision 2 to ISIC Revision 2, we use a correspondence developed by Marc Muendler.[59] To convert the BACI data from six-digit Harmonized System categories to ISIC Revision 3, we use correspondences from the United Nations and the CEPII.[60] We then map ISIC sectors into our four composite sectors.

[56] See `http://unstats.un.org/unsd/snaama` and `http://databank.worldbank.org`.

[57] 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 reliable.

[58] See `http://cid.econ.ucdavis.edu` and `http://www.cepii.fr/anglaisgraph/bdd/baci.htm`.

[59] See `http://econ.ucsd.edu/muendler/html/resource.html`.

[60] Priority is given to the official UN correspondence, available at `http://unstats.un.org/unsd/cr/registry/regdnld.asp`. We use the correspondence from the CEPII for remaining unmatched categories.

Using these correspondences, we are able to match upwards of 95% of trade to industries in most country years. The match quality for the post-1995 BACI data is nearly perfect. For most countries, the match quality is also quite good using the NBER-UN data. However, this historical data is of lower quality overall.[61] Further, there are some matching problems in this data for particular countries in specific years. These are due to problems in the raw source data, not in the correspondences. In the NBER-UN data, there are often fictional aggregate categories ending in 'X' (e.g., 04XX) 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 composite sectors. In some cases, there is trade in remaining unallocated SITC 1 digit residual categories, and we split this data across composite sectors using the world-level allocation shares for matched categories to composite sectors within that SITC 1-digit classification.

Having formed a complete bilateral goods trade dataset, we need to match this to aggregate exports and imports in the national accounts. We take bilateral trade shares within each composite sector from the bilateral goods trade data, and combine them with the levels of goods exports and imports reported in the national accounts to form bilateral trade flows. 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 for each country (e.g., the exporter report minus the reconciled trade flow) from trade flows with the rest of the world. This operation preserves overall reported exports and imports (and hence the trade balance) for each reporting country.

Next, we turn to constructing bilateral services trade flows using multilateral data on services trade and goods bilateral trade shares. The objective is for estimated bilateral services trade flows to follow closely goods bilateral trade flows while satisfying adding up constraints. Note that one cannot just apply the bilateral goods import shares to aggregate imports of services, as it is not guaranteed that the exporting countries produce enough services to export those volumes. To obtain a consistent dataset, we thus run an optimization program that finds the bilateral services flows that minimize the weighted squared distance from flows created with average bilateral goods exports for each bilateral pair, subject to the constraint that the sum of the bilateral flows be equal to multilateral exports and imports.

A.1.3 Input-Output Tables

We start with the OECD Input-Output Database (1995 and 2011 editions) and the IDE-JETRO Asian input-output tables (for 1985, 1990, 1995, and 2000).[62] We extract domestic and imported input-output matrices, as well as sector-level data on gross production, value added, domestic and imported final demand (encompassing household and government final consumption expenditure and gross capital formation), and multilateral exports and imports. Benchmark tables are available for various benchmark years, listed in Table 4. The original

[61] For example, Russia is missing import data for 1992-1995, and we impute import shares for these years using data for 1991 and 1996.

[62] See http://www.oecd.org/sti/inputoutput/ and http://www.ide.go.jp/.

OECD data covers 35 sectors for years before 1990 and 48 sectors for years after 1995. However, not all countries report data at this level of disaggregation, and therefore the raw data contain rows and columns filled with zeros.[63] Aggregation to the four composite sectors for our main calculation resolves these problems. We provide the mapping between OECD sectors and our four composite sectors in Table 5. We also include the mapping between 24 sectors in the IDE-JETRO data to our composite sectors.

In the input-output tables, there are other accounting variables that we do not explicitly provide for in our framework, such as statistical discrepancies, other adjustments, non-comparable imports, and net taxes. In general, these tend to be small or exactly zero.[64] To eliminate these entries, we distribute them across the variables in our framework by minimizing the weighted squared distance between adjusted values and the raw uncleaned data, subject to the constraint that input-output accounting identities hold. The algorithm is very similar to the one used for the main estimation described below, so we omit details here. In practice, the results of the full harmonization procedure are not very sensitive to how we resolve these data issues. 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 internally consistent, even in given years in which they are all directly observed. On top of this, input-output tables are available only for selected benchmark years, which differ across countries. To track changes through time, we would need (at the very least) data for all countries in a series of benchmark years. To track changes at higher frequencies between benchmark years, or to extrapolate recent benchmark years into the past where no benchmarks are available, we need to combine the benchmarks with information we can measure at higher frequencies over longer time spans.

In doing so, we give priority to matching the national accounts and commodity trade data discussed above, which are available in all years and likely measured with less error. We then adjust the input-output benchmarks to be consistent with these data using a constrained least squares procedure. The objective is to minimize the weighted squared distance between the estimates and the data for years in which we have input-output and final demand data and interpolations of that data for years in which we do not, subject to a set of accounting identities. We pause here to spell out this procedure.

To start, for each country i and year t, we collect sector-level value added in a 1×4 vector va_i^t, multilateral sector-level exports and imports in 4×1 vectors x_i^t and m_i^t, and define aggregate final demand as scalar f_i^t.[65] These data are available for all countries and years in the database.

Now let I_{Di}^t and I_{Ii}^t be 4×4 matrices of domestic and imported inputs, with elements $I_{Di}^t(s,r)$ and $I_{Ii}^t(s,r)$ representing domestic and imported inputs used in sector r supplied by sector s, let f_{Di}^t and f_{Ii}^t be 4×1 vectors of domestic and imported final demand, and

[63] For example, some countries include pharmaceuticals within chemical products rather than reporting them separately.

[64] Some entries are exactly zero due to how data is reported from national authorities to the OECD.

[65] We construct x_i^t and m_i^t by multiplying exports and imports in the national accounts by sector trade shares defined above.

let y_i^t be a 4×1 vector of sector-level output. Define b_i^t as a 44×1 vector containing the vectorized unknown elements of $I_{Di}^t, I_{Ii}^t, c_{Di}^t$, c_{Ii}^t and y_i^t, and let ι be a 4×1 vector of ones.

Omitting country and year indices, for each country and year we solve the following program:

$$\min_b \; (b-\beta)' W^{-1} (b-\beta)$$

$$\text{subject to} \quad \begin{aligned} y' &= \iota' I_I + \iota' I_D + va \\ y &= f_D + I_D \iota + x \\ m &= f_I + I_I \iota \\ f &= \iota' f_I + \iota' f_D \\ b &\geq 0, \end{aligned}$$

where β_i^t is a 44×1 vector containing initial values used in the computation, and W_i^t is a 44×44 weighting matrix with diagonal equal to β_i^t.

Initial values are chosen based on combining the input-output and national accounts data. We set the initial values for input-output coefficients to those in the input-output tables for benchmark years, and linear interpolations between benchmark years. For years outside the range of years bracketed by benchmarks, we set the initial values equal to the closest benchmark year.[66] We construct sector output by dividing sector value added by sector value added to output ratios from input-output tables for years in which we have them, linear interpolations for years between benchmark years, and nearest benchmark years for years outside the range of benchmarks. Following a similar procedure, we construct sector final demand by multiplying aggregate final demand by sector shares in final demand from input-output tables.

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. We emphasize that trade and macro data are given priority here, so we match GDP, GDP expenditure categories (including the trade balance), sector-level GDP, and sector-level trade exactly. All the adjustment is borne by input-output coefficients and sector-level demand shares. Upon inspection, these adjustments are reasonably small and generally plausible.

The remaining step in constructing the global input-output framework is to disaggregate input and final goods sourcing across bilateral partners in each year. That is, to take the imported input use matrix A_{Ii} and imported final demand vector c_{Ii} for each country and disaggregate them across trade partners. To do so, we apply the proportionality assumptions discussed in the main text.

A.2 Benchmarking the Data

In this section, we benchmark our results and explore their robustness to variation in assumptions. First, we compare our value added to export ratios against alternatives computed

[66] This is likely a conservative assumption, as it minimizes changes in input-output tables over time.

from different data sources. Second, using the GTAP data, we examine how aggregation and assumptions regarding the rest-of-the-world influence the results.

A.2.1 Benchmarking Value Added to Export Ratios

In Johnson and Noguera (2012a), we used data from the GTAP 7.1 Database for 2004 to parameterize the global input-output framework and compute bilateral value added to export ratios. This data is different than the data used in this paper in several dimensions. At the most basic level, the raw data sources used and the harmonization procedures applied to the data are different.[67] One major difference is that GTAP data is available at the 57 sector level of disaggregation, as opposed to our four sectors. Moreover, GTAP data is available for many more countries, with direct data on 94 separate countries plus imputed data for 19 composite regions.

To assess our data and procedures, we compare the VAX ratio estimates for 2004 in this paper to those in Johnson and Noguera (2012a). We start by comparing aggregate value added to export ratios for the 41 countries included in both data sets in Figure 13.[68] The data are evidently clustered tightly around the 45° line. Thus, the multilateral VAX ratio lines up well to the data reported in Johnson and Noguera (2012a).

Moving down to the sector level, we plot VAX ratios for non-manufacturing and manufacturing sectors in Figure 14. Here again the positive correlation between the two alternative measures is strong. The match is noisier at the sector level than in the aggregate, which is to be expected.[69] Further, for manufacturing, we see that on average the value added to export ratios in this paper tend to be somewhat lower than those reported in Johnson and Noguera (2012a). For non-manufacturing, average levels are similar. Notwithstanding these average differences, cross-country patterns are similar. Further, these level differences aggregate away because the share of manufactures in trade in our data (taken from the national accounts) is slightly lower than in the GTAP data.

Moving further down to the bilateral level, we plot bilateral value added to export ratios for the largest four exporters in Figure 15. The data matches up well for these four countries, within reasonable tolerances. Looking at all pairs with exports greater than $1 million and VAX ratios less than 10 (the core sample used in our regression results), the raw correlation is about 0.85. Thus, our bilateral results also match up well to our previous work.

This discussion implies that our data matches stylized facts that we have documented previously using cross-sectional GTAP data. This good match is remarkable for several reasons. First, given differences in sector detail across the two data sets, these results demonstrate that sector aggregation appears to be relatively unimportant. Second, given that the GTAP data contains detailed information for individual countries that we group

[67] In terms of raw data, a major difference is that GTAP collects input-output tables contributed from researchers in individual countries, often constructed directly from national sources. In contrast, we rely on data compiled and processed by the OECD. The differences in harmonization procedures between our data and GTAP are too numerous to list individually here.

[68] Whereas we have separate data for Israel, GTAP includes Israel in a composite region. Therefore, we drop Israel from all the analysis below.

[69] The raw data is noisier at the sector level than in the aggregate. Further, if errors are concentrated in relatively small sectors, then they will tend to have little influence on aggregates.

into a rest-of-the-world composite, these results also suggest that this data simplification does not distort results. We return to discussion of these two issues below.

In addition to these cross-sectional comparisons, we can also compare our data to existing results on changes in the value added content of trade through time. Hummels, Ishii, and Yi (2001) and Chen, Kondratowicz, and Yi (2005) compute the domestic content of exports using benchmark tables from the OECD for one country at a time. These calculations differ from ours in that they use the raw OECD data, and do not aggregate or harmonize the data with other data sources as we do. Moreover, they use a different – though related – formula to compute domestic content, which applies to a special case of our general framework.[70] Lastly, they present data for merchandise trade in their published work, which we compare to our statistics for total trade.

We plot a comparison of our VAX ratios to the domestic content of exports over time in Figure 16 and Figure 17.[71] Figure 16 plots all benchmark years for each country in a single figure, and therefore depicts how well the data matches level differences across countries simultaneously with changes over time. Figure 17 plots benchmark years for each country separately over time. Our VAX ratios match the cross-country variation in domestic content well, which is the dominant source of variation in Figure 16. Our VAX ratios also match the time series dynamics of domestic content for most countries, though levels are different for some countries. Where there are divergences, these are generated almost entirely by differences in the underlying data we use versus that used by Hummels et al. and Chen et al., not differences in formulas used in computing VAX ratios versus domestic content.[72] Further, some of these divergences may be explained by the fact that Hummels et al. and Chen et al. construct domestic content ratios for merchandise trade only, whereas we include all trade.

A.2.2 Sector Aggregation and Trade with the Rest-of-the-World

In computing VAX ratios in this paper, we aggregate sectors into four broad composite sectors and assume that all exports from the 42 countries in our framework to the rest-of-the-world are absorbed there (i.e., not used to produce imports from the rest of the world). The similarity of the VAX ratios in this paper to those using GTAP data, presented above, suggest that we do not lose much information in making these two simplifications.

To reinforce this point, we now demonstrate the consequences of these two assumptions in the GTAP data directly. This fixes the underlying data, and varies aggregation and rest-of-the-world assumptions only. Specifically, we aggregate the GTAP data from 57 to 4 sectors for 41 countries (as above) and a rest-of-the-world composite.[73] We then compute value added trade first using the input-output information for the rest-of-the-world contained in the GTAP data. We plot the resulting VAX ratios by country in the left panel of Figure 18,

[70] See Johnson and Noguera (2012a) for further discussion.

[71] The data on domestic content comes from Table 2 in Chen, Kondratowicz, and Yi (2005).

[72] We can compute the Hummels-Ishii-Yi measure of domestic content using our data and compare it to the aggregate VAX ratio presented in the figures. We find these are very similar. Results available on request.

[73] GTAP sectors 1 to 14 are included in agriculture and natural resources, sectors 15 to 18 and 43 to 46 are included in non-manufacturing industrial production, sectors 19 to 42 are included in manufacturing, and sectors 47 to 57 are included in services.

against VAX ratios computed using all 57 sectors. We then discard input-output information for the rest-of-the-world, and recompute VAX ratios assuming that all exports to the rest of the world are absorbed there. We then plot these VAX ratios by country against the 4 sector results in the right panel of Figure 18.

As is evident in the figure, the numerical values of the VAX ratios and country-rankings are not very sensitive to varying the level of aggregation or assumptions regarding the rest of the world.[74] Similar results hold for sector-level and bilateral VAX ratios. These results may seem initially surprising, but are an outcome of a basic fact in the data. In building sectors in input-output data, national accountants are guided in aggregation by the "principle of homogeneity." The principle requires that each composite industry's output is produced using a unique set of inputs, roughly speaking. In our data, sectors within our composite sectors are more similar among themselves than they are to other sectors.[75] Further, extending this idea from sectors to countries, aggregation among countries with similar production and trade structures will also tend to minimize the loss of information in aggregation. Combined with the fact the countries included separately in our framework account for the bulk of world trade and GDP, it is then not so surprising that the results are fairly robust to changes in assumptions regarding the rest-of-the-world.

[74]One point to note is that assuming all trade with the rest-of-the-world is absorbed there tends to push VAX ratios for the 41 countries down, which is related to the observation in figures above that our VAX estimates in this paper appear slightly lower in several figures than VAX estimates in Johnson and Noguera (2012a).

[75]For example, if one looks at manufacturing as a whole, value added to output ratios are relatively similar across sectors, as opposed to comparing manufacturing versus services. So this implies a minimal disaggregation of the aggregate economy requires splitting the data into manufacturing versus non-manufacturing. Further, within composite sectors, sub-sectors are also similar in the structure of their sectoral input linkages as well as economic openness.

Table 4: Input-Output Data Coverage

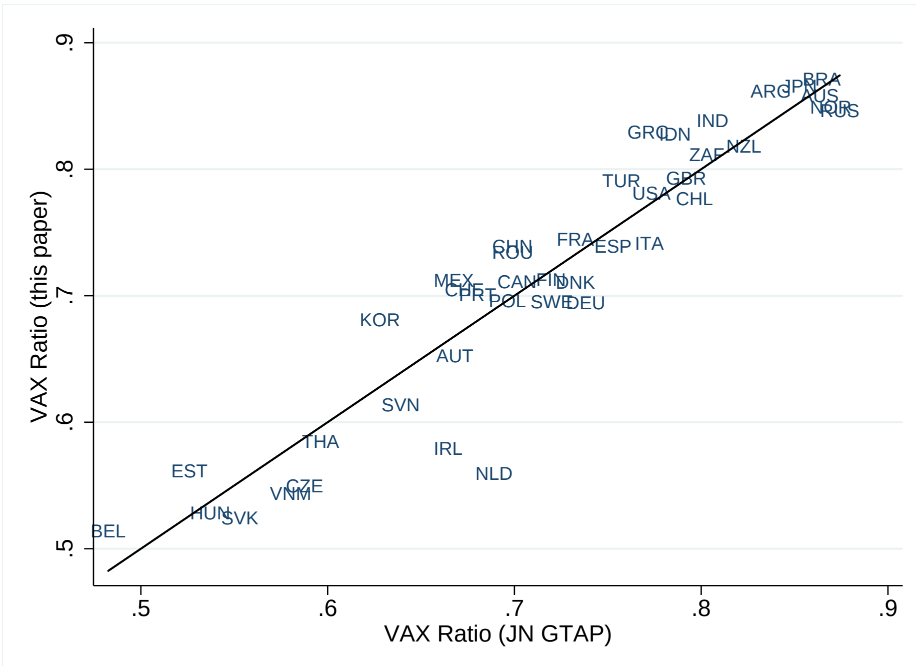
Country	Code	early 70s	mid 70s	early 80s	mid 80s	early 90s	mid 90s	early 00s	mid 00s
Argentina	ARG	.	.	.	.	.	1997	.	.
Australia	AUS	1968	1974	.	1986	1989	1994/95	2001/02	2004/05
Austria	AUT	.	.	.	.	.	1995	2000	2005
Belgium	BEL	.	.	.	.	.	1995	2000	2005
Brazil	BRA	.	.	.	.	.	1995	2000	2005
Canada	CAN	1971	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 5: Sector Aggregation and Definitions

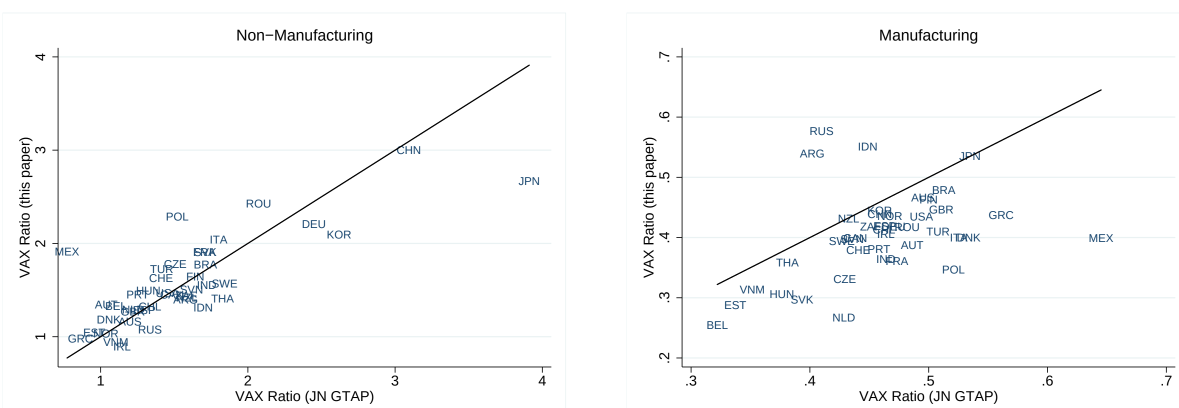
Sector	Name	ISIC Rev. 2	ISIC Rev. 3.1	1995 OECD codes	2011 OECD codes	Asian IO codes
1	Agriculture, hunting, forestry and fishing	1	A,B	1	1	1 to 5
2	Non-manufacturing industrial production	2,4,5	C,E,F	2,25,26	2, 3, 26 to 30	6,7,20,21
3	Manufactures	3	D	3 to 24, 35	4 to 25	8 to 19
4	Services	6 to 9	G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

Figure 13: Value Added to Export Ratios in 2004, by Country



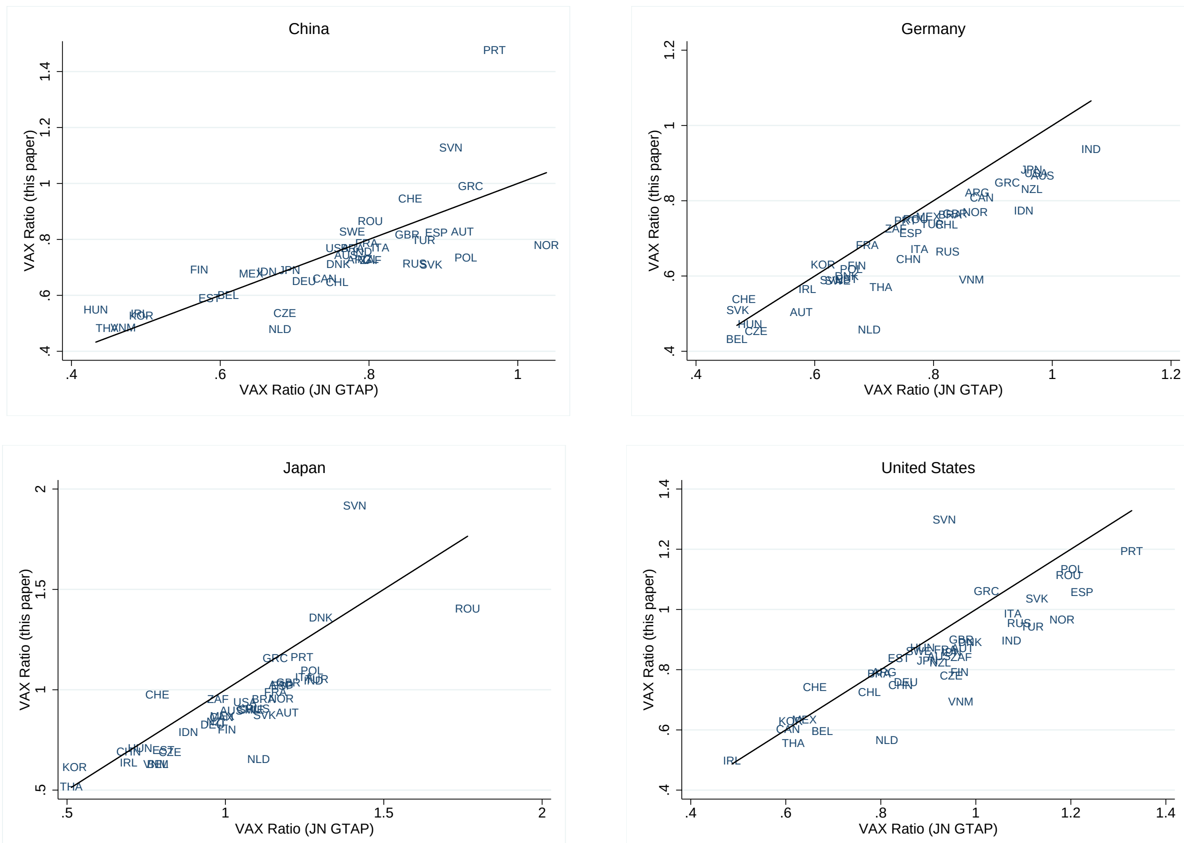
Note: Black line denotes the 45° line.

Figure 14: Value Added to Export Ratios in 2004, by Country and Composite Sector



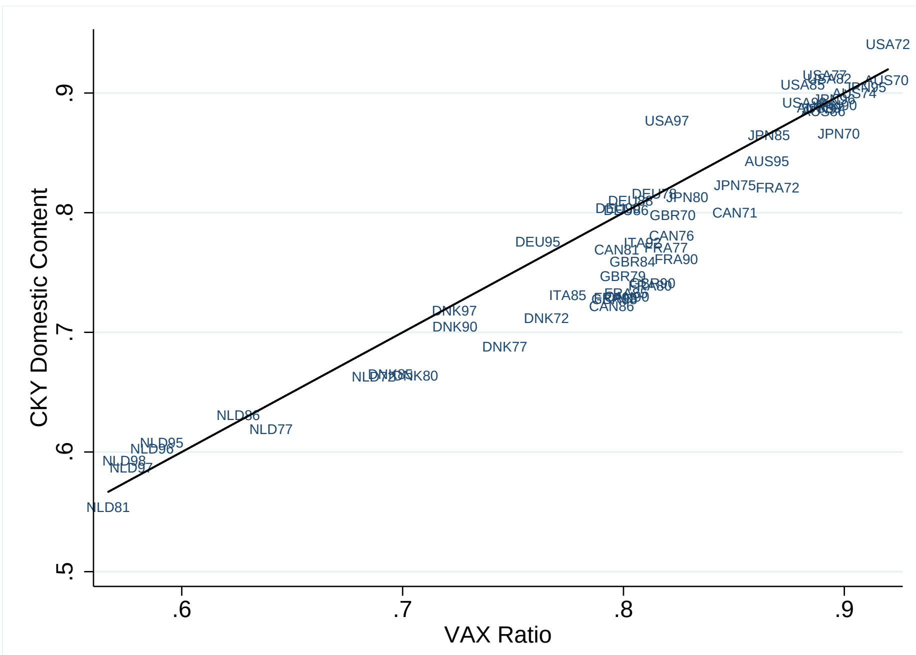
Note: Black line denotes the 45° line.

Figure 15: Bilateral Value Added to Export Ratios in 2004 for China, Germany, Japan, and United States



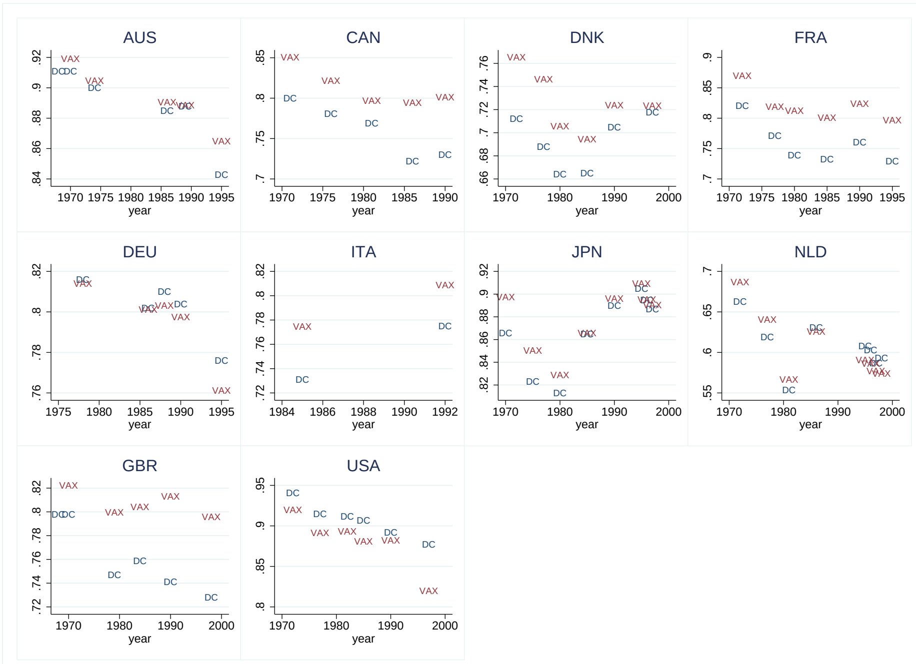
Note: Black line denotes the 45° line.

Figure 16: Value Added to Export Ratios Across Countries and Over Time



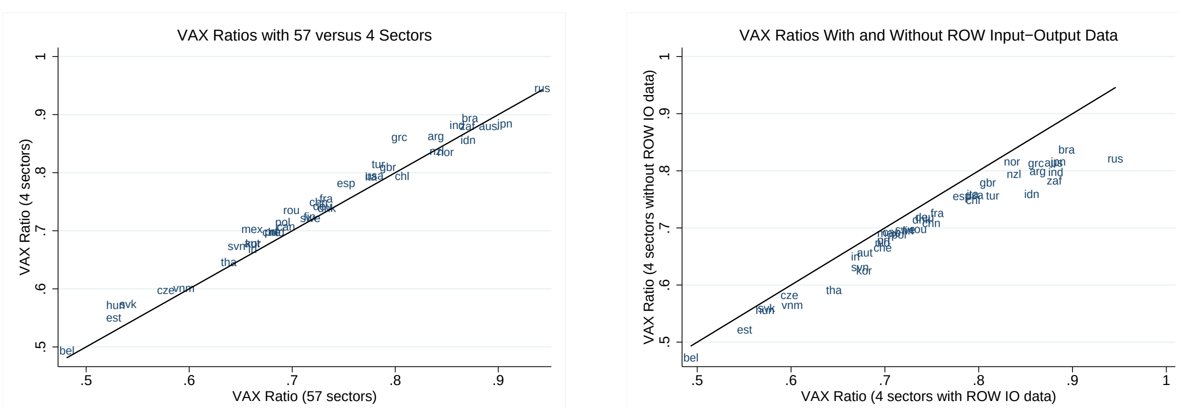
Note: Black line denotes the 45° line. The measure of Domestic Content is taken from Chen, Kondratowicz, and Yi (2005). Country and benchmark year for each data point are indicated by country abbreviation and last two digits of benchmark year.

Figure 17: Value Added to Export Ratios Over Time, by Country



Note: The measure of Domestic Content is taken from Chen, Kondratowicz, and Yi (2005). Marker label DC denotes domestic content, while marker label VAX denotes the value added to export ratio in this paper.

Figure 18: Value Added to Export Ratios in 2004 Computed using GTAP Data under Alternative Assumptions



Note: Black line denotes the 45° line.

B Supplemental Results

This appendix includes supplemental results mentioned in the text, but omitted from the main set of figures for brevity. Tables 6 and 7 include data underlying discussion in Sections 4.1 and 4.2. Table 6 includes VAX ratios by sector for the world as a whole, along with the share of each sector in world trade. Using this information, one can compute the world VAX ratio in the last column. Further, this information underlies the Between-Within decomposition at the world level. Figure 19 includes elements of the Between-Within decomposition of bilateral VAX ratios discussed in Section 4.3. Table 8 reports results for the main RTA regressions including distance interacted with year indicators as additional controls. This table is a robustness check corresponding to Table 2 in the main text.

Table 6: 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	1.20	0.09	1.10	0.07	0.65	0.64	1.35	0.21	0.87
1971	1.21	0.08	1.10	0.07	0.64	0.63	1.35	0.21	0.87
1972	1.21	0.09	1.12	0.07	0.64	0.64	1.37	0.21	0.87
1973	1.19	0.09	1.11	0.07	0.64	0.64	1.37	0.20	0.86
1974	1.16	0.08	1.00	0.12	0.62	0.62	1.37	0.18	0.84
1975	1.17	0.08	1.01	0.12	0.61	0.61	1.39	0.19	0.85
1976	1.15	0.08	1.01	0.12	0.61	0.61	1.38	0.19	0.85
1977	1.16	0.07	1.01	0.12	0.61	0.61	1.38	0.19	0.85
1978	1.15	0.07	1.03	0.11	0.61	0.63	1.40	0.19	0.85
1979	1.15	0.07	1.02	0.12	0.60	0.62	1.40	0.19	0.84
1980	1.12	0.06	0.99	0.15	0.59	0.61	1.40	0.18	0.83
1981	1.12	0.06	0.98	0.15	0.59	0.60	1.41	0.19	0.83
1982	1.15	0.06	0.98	0.14	0.59	0.61	1.42	0.20	0.84
1983	1.13	0.06	1.01	0.12	0.59	0.63	1.44	0.19	0.84
1984	1.14	0.06	0.97	0.13	0.59	0.63	1.46	0.19	0.83
1985	1.16	0.06	0.98	0.11	0.59	0.64	1.48	0.19	0.84
1986	1.22	0.05	1.07	0.08	0.60	0.67	1.50	0.20	0.84
1987	1.22	0.05	1.10	0.07	0.60	0.68	1.50	0.20	0.84
1988	1.22	0.05	1.14	0.06	0.60	0.69	1.52	0.20	0.84
1989	1.26	0.05	1.10	0.07	0.59	0.69	1.51	0.20	0.84
1990	1.33	0.04	1.05	0.07	0.59	0.68	1.49	0.21	0.84
1991	1.30	0.04	1.08	0.07	0.55	0.67	1.53	0.21	0.83
1992	1.28	0.04	0.94	0.08	0.54	0.66	1.52	0.22	0.82
1993	1.31	0.04	1.06	0.07	0.54	0.67	1.52	0.22	0.82
1994	1.32	0.04	1.14	0.06	0.54	0.69	1.53	0.21	0.82
1995	1.30	0.04	1.16	0.06	0.53	0.70	1.55	0.21	0.80
1996	1.30	0.04	1.12	0.06	0.52	0.69	1.54	0.21	0.80
1997	1.30	0.04	1.11	0.06	0.52	0.69	1.55	0.21	0.79
1998	1.40	0.03	1.25	0.05	0.51	0.71	1.54	0.21	0.79
1999	1.38	0.03	1.19	0.05	0.50	0.71	1.55	0.21	0.78
2000	1.40	0.03	1.07	0.07	0.49	0.70	1.54	0.20	0.77
2001	1.53	0.02	1.13	0.06	0.49	0.70	1.54	0.21	0.77
2002	1.53	0.02	1.15	0.06	0.49	0.70	1.55	0.21	0.77
2003	1.53	0.02	1.12	0.07	0.48	0.70	1.55	0.21	0.77
2004	1.61	0.02	1.11	0.07	0.48	0.70	1.53	0.21	0.76
2005	1.58	0.02	1.06	0.09	0.47	0.69	1.52	0.20	0.76
2006	1.56	0.02	1.06	0.09	0.46	0.69	1.52	0.20	0.75
2007	1.55	0.02	1.07	0.09	0.46	0.69	1.50	0.20	0.75
2008	1.46	0.02	1.00	0.11	0.45	0.67	1.50	0.20	0.74
2009	1.43	0.02	1.07	0.09	0.46	0.67	1.49	0.22	0.77

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 7: 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	-0.10	0.46	-0.35	0.16	0.01	-0.11
Australia	AUS	1970-2009	-0.05	-0.00	-0.23	-0.07	-0.10	0.04
Austria	AUT	1970-2009	-0.17	0.06	-0.26	0.03	-0.15	-0.03
Belgium	BEL	1970-2009	-0.15	0.01	-0.29	-0.07	-0.21	0.06
Brazil	BRA	1970-2009	-0.07	0.45	-0.39	0.24	-0.06	-0.01
Canada	CAN	1970-2009	-0.12	-0.16	-0.15	-0.04	-0.14	0.02
Chile	CHL	1970-2009	-0.12	-0.43	-0.14	-0.10	-0.24	0.12
China	CHN	1970-2009	-0.19	1.98	-0.21	0.34	0.23	-0.41
Czech Republic	CZE	1993-2009	-0.06	0.37	-0.03	0.12	0.05	-0.12
Denmark	DNK	1970-2009	-0.06	-0.08	-0.10	-0.05	-0.09	0.03
Estonia	EST	1993-2009	-0.03	0.19	-0.11	0.05	0.00	-0.03
Finland	FIN	1970-2009	-0.11	-0.54	-0.12	-0.11	-0.22	0.11
France	FRA	1970-2009	-0.14	0.35	-0.22	0.07	-0.05	-0.08
Germany	DEU	1970-2009	-0.17	-0.09	-0.24	-0.03	-0.22	0.05
Greece	GRC	1970-2009	-0.08	-0.05	-0.13	0.01	-0.08	0.00
Hungary	HUN	1970-2009	-0.29	-0.14	-0.25	0.08	-0.25	-0.04
India	IND	1970-2009	-0.17	-0.07	-0.10	0.08	-0.09	-0.08
Indonesia	IDN	1970-2009	-0.07	0.27	0.14	0.45	0.15	-0.23
Ireland	IRL	1970-2009	-0.25	-0.57	-0.08	-0.08	-0.16	-0.08
Israel	ISR	1970-2009	-0.06	0.42	-0.35	0.34	0.07	-0.13
Italy	ITA	1970-2009	-0.11	0.45	-0.18	0.07	-0.03	-0.08
Japan	JPN	1970-2009	-0.04	-0.37	-0.07	-0.05	-0.13	0.09
Korea	KOR	1970-2009	-0.15	0.44	0.03	0.20	0.13	-0.28
Mexico	MEX	1970-2009	-0.23	0.77	-0.19	0.43	0.15	-0.38
Netherlands	NLD	1970-2009	-0.13	0.13	-0.22	0.01	-0.12	-0.02
New Zealand	NZL	1970-2009	-0.02	-0.06	-0.06	-0.03	-0.05	0.03
Norway	NOR	1970-2009	0.07	-0.05	-0.09	-0.22	-0.06	0.12
Poland	POL	1970-2009	-0.14	0.90	-0.26	0.19	0.10	-0.24
Portugal	PRT	1970-2009	-0.16	-0.20	-0.10	0.03	-0.13	-0.03
Romania	ROM	1970-2009	-0.22	0.38	-0.37	0.04	-0.25	0.03
Russia	RUS	1990-2009	-0.04	0.00	-0.15	-0.07	-0.07	0.03
Slovak Republic	SVK	1993-2009	-0.11	0.90	-0.07	0.17	0.10	-0.21
Slovenia	SVN	1993-2009	-0.07	-0.15	-0.08	-0.02	-0.09	0.02
South Africa	ZAF	1970-2009	-0.07	0.42	-0.21	0.17	0.08	-0.15
Spain	ESP	1970-2009	-0.16	0.24	-0.34	0.18	-0.07	-0.09
Sweden	SWE	1970-2009	-0.15	-0.26	-0.23	-0.09	-0.25	0.10
Switzerland	CHE	1970-2009	-0.05	-0.48	-0.09	-0.10	-0.18	0.13
Thailand	THA	1970-2009	-0.31	0.38	-0.12	0.46	0.05	-0.36
Turkey	TUR	1970-2009	-0.20	0.80	-0.56	0.58	0.09	-0.29
United Kingdom	GBR	1970-2009	-0.04	-0.07	-0.18	-0.12	-0.15	0.11
United States	USA	1970-2009	-0.11	0.04	-0.21	-0.00	-0.12	0.01
Vietnam	VNM	1970-2009	-0.28	0.15	-0.19	0.40	-0.05	-0.23

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.

Figure 19: Between and Within Decomposition of Changes in Bilateral Value Added to Export Ratios for Country Pairs

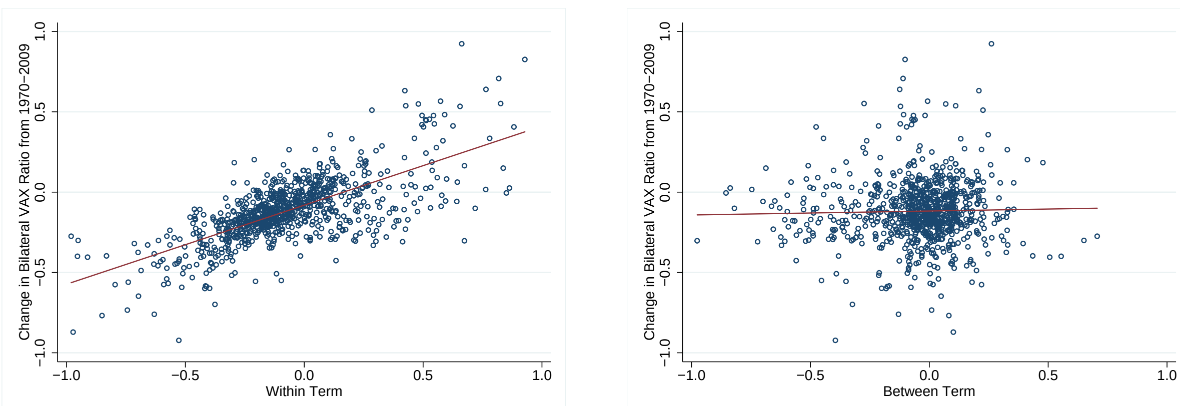


Table 8: Panel Regressions with Regional Trade Agreements and Time-Varying Distance Elasticity

Panel A: log of VAX Ratio

	In Levels				In First Differences			
	(A1)	(A2)	(A3)	(A4)	(A5)	(A6)	(A7)	(A8)
RTA	-0.037**	-0.068***			-0.043***	-0.049***		
	(0.015)	(0.017)			(0.014)	(0.016)		
PTA			-0.007	-0.007			0.001	0.001
			(0.013)	(0.016)			(0.013)	(0.015)
FTA			-0.033**	-0.069***			-0.042***	-0.048***
			(0.016)	(0.019)			(0.015)	(0.017)
CUCMEU			-0.090***	-0.097***			-0.061***	-0.058***
			(0.019)	(0.023)			(0.017)	(0.021)
R^2	0.77	0.86	0.77	0.86	0.22	0.33	0.22	0.33

Panel B: log of Value Added Exports

	In Levels				In First Differences			
	(B1)	(B2)	(B3)	(B4)	(B5)	(B6)	(B7)	(B8)
RTA	0.233***	0.219***			0.167***	0.163***		
	(0.030)	(0.034)			(0.022)	(0.026)		
PTA			0.029	0.013			-0.001	-0.007
			(0.033)	(0.032)			(0.028)	(0.033)
FTA			0.223***	0.218***			0.161***	0.158***
			(0.034)	(0.036)			(0.025)	(0.030)
CUCMEU			0.400***	0.321***			0.262***	0.231***
			(0.044)	(0.046)			(0.032)	(0.041)
R^2	0.97	0.99	0.97	0.99	0.62	0.67	0.62	0.67

Panel C: log of Gross Exports

	In Levels				In First Differences			
	(C1)	(C2)	(C3)	(C4)	(C5)	(C6)	(C7)	(C8)
RTA	0.271***	0.287***			0.206***	0.211***		
	(0.041)	(0.046)			(0.033)	(0.039)		
PTA			0.036	0.020			0.006	-0.002
			(0.041)	(0.044)			(0.039)	(0.046)
FTA			0.257***	0.287***			0.201***	0.207***
			(0.045)	(0.050)			(0.036)	(0.043)
CUCMEU			0.490***	0.418***			0.321***	0.287***
			(0.057)	(0.064)			(0.046)	(0.058)
R^2	0.96	0.98	0.96	0.98	0.47	0.53	0.47	0.53

Pair Trend		X		X		X		X
Obs.	11184	11184	11184	11184	9362	9362	9362	9362

Note: All regressions include exporter-year and importer-year fixed effects, plus log distance with a year-specific coefficient (coefficients not included in the table). Columns 1 to 4 include pair fixed effects, and columns 2 and 4 include a linear pair-specific trend. Columns 6 and 8 include pair fixed effects, capturing 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.