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Inga Heiland, Patrik Šváb



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Estimating Gravity Equations for Trade in Value Added: A Structural Perspective

Abstract

A large number of recent papers employ value-added trade data alongside traditional gross measures of trade to estimate the impact of various trade costs on bilateral trade. Value-added gravity equations are typically justified by referencing the theoretical and empirical merits of traditional gravity equations for gross trade. Contradicting this notion, we use theory and simulations to show that value-added gravity equations are misspecified when the gross trade gravity equation is correct. Consequently, estimates from value-added gravity equations are difficult to interpret and prone to omitted variables bias.

JEL-Codes: F120, F150.

Keywords: structural gravity, trade in value added.

Inga Heiland* Norwegian University of Science and Technology Trondheim / Norway University of Oslo / Norway inga.heiland@ntnu.no Patrik Šváb Faculty of International Relations, Prague University of Economics and Business Prague / Czech Republic patrik.svab@vse.cz

*corresponding author

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1 Introduction

Many recent papers employ value-added (VA) trade data alongside with traditional gross measures of trade to estimate the impact of various trade costs on bilateral trade.¹ VA gravity equations are typically justified by citing the theoretical and empirical merits of traditional gravity equations for gross trade. Contradicting this view, we demonstrate that if bilateral gross trade follows gravity, bilateral VA trade does not. In other words, VA gravity equations are misspecified when the gross trade gravity equation is accurate.

In this paper, we show why reduced-form VA gravity equations are misspecified and explore the consequences for estimation. We are not the first to point out that trade cost elasticities obtained from reduced-form VA gravity equations are problematic from a structural point of view; Noguera (2012) derived a theory-grounded gravity equation with control terms that can be estimated with OLS. However, the majority of empirical studies have continued to use simple log-linear estimation models.² Our aim is to draw attention to a number of specific problems surrounding estimates obtained from VA gravity equations that are due to the misspecification. We employ the simplest possible theoretical model of gross trade and VA trade to pinpoint the origin of the misspecification and conduct simulation exercises to assess the importance of the issue in a controlled setting. Our results indicate that both the external and internal validity of partial trade cost elasticities estimated with reduced-form VA gravity equations are limited.

Specifically, we point out three issues that we think researchers must consider when interpreting coefficients on trade cost proxies in VA gravity equations. We use indicators for regional trade agreements (RTAs) to illustrate these issues, but our findings apply to any trade cost variable. First, the theoretical general gravity equation for VA trade, which

¹Our search of the Web of Science and the OECD iLibrary returned 32 published academic papers and 4 policy reports that employ reduced-form gravity equations with measures of bilateral VA trade flows as the left-hand-side variable.

²Some exceptions are discussed in the literature section below.

we derive from a structural gravity model for gross trade³, implies that the partial effects of RTAs are heterogeneous across pairs. Hence, the RTA elasticities that empirical VA equations seek to estimate are context-dependent. This means that estimated coefficients on RTAs are not comparable across samples, agreements, and time periods, and are not informative for future agreements.

Second, the theory implies that trade cost changes have heterogeneous effects on bilateral trade between third countries. This implies that the estimated partial elasticities of RTAs for member countries are confounded by indirect effects on non-member countries.

Third, any trade cost change happening elsewhere in the world will bias the RTA estimate unless both members' and non-members' GVCs are equally exposed to the third-country shock. Given that countries' GVCs are very different, such biases are generally likely and ambiguous in direction. What is more, the third-country effects are not limited to trade costs. Changes in other determinants of trade between third countries, such as productivity or infrastructure, generate similar biases if they coincide with the formation of the RTA.

In sum, our analysis suggests that VA gravity estimates in real-world settings are difficult to interpret. The first two issues significantly limit the external validity of these estimates; the second issue further implies that the best we can aim for is to estimate is the relative impact on treated versus control countries' trade. Meanwhile, the third issue undermines even the internal validity of the estimated relative effect.

We think these concerns about misspecification are serious because there is no viable theoretical solution in sight. All of the issues outlined above arise from the multilateral nature of VA trade and the uniqueness of each country's global value chain (GVC). Homogeneous exposure to trade cost shocks and other shocks in third countries, which would solve the these issues, would generally only occur if GVCs were trivial (i.e., no VA trade

³Our definition of general and structural gravity equations follows Head and Mayer (2014).

via third countries) or identical across countries. Neither of these scenarios are desirable characteristics for a model of VA trade. Consequently, we believe that the effects of trade cost changes on VA trade are better studied using quantitative trade models.

Our paper proceeds as follows. In Section 2, we discuss the related literature. In Section 3, we lay out the model and discuss its implications for the estimation of reduced-form VA gravity equations. In Section 4, we simulate the model and quantify the importance of the estimation issues. In Section 5, we discuss our findings and our assumptions. Section 6 concludes.

2 Related literature

Our paper builds on Noguera (2012), who applied a first-order approximation to the non-log-linear VA flows to derive a log-linear gravity equation that features both the direct and indirect effects of trade cost shocks on VA trade. One of our new results is that the indirect effects of a potentially large set of other third-country shocks – including country-specific ones like productivity growth and infrastructure development – must also be controlled for in order to identify the effects of trade cost shocks on VA trade. Njike (2021) also examines the VA gravity equation from a theoretical perspective and derives a structural expression for the indirect costs faced by VA trade, which can be computed and included in a regression. However, as we discuss in more detail below, there is no difference between the trade cost elasticity of gross trade and VA trade once all indirect effects are controlled for.

On the empirical side, we identified 32 academic papers and 4 policy reports that estimate VA trade flows in a reduced-form gravity framework (the list of papers and reports is provided in the Appendix). In several of these papers, the issue of third-country effects is discussed, though only a few papers attempt to tackle the misspecification problem, using either the methodology proposed by Noguera (2012) or alternative approaches. Among those papers is Laget et al. (2020), who estimate the impact of the depth of trade agreements on bilateral cross-border production linkages. To address the indirect effect of deep trade agreements signed by third countries along the supply chain, they follow Noguera (2012) and include pair-specific control terms that are exposure-weighted sums of trade agreements between other pairs of countries. A similar approach is used by Kang and Gapay (2024). Mulabdic et al. (2017) incorporate other interaction terms to accommodate heterogeneous effects of deep PTAs for the UK, a specification that is also used by Boffa et al. (2019) and Sanguinet et al. (2022).

3 A General Gravity Equation for Value Added

3.1 The Theoretical Model

We set up a model of bilateral trade between N countries, indexed by i, j, k, n, h, h_1 . Our analysis rests on two core assumptions.

(A1) Final goods trade C_{in} and intermediate goods trade A_{in} from country *i* to country *n* follow general gravity equations as defined by Head and Mayer (2014), respectively given by

$$C_{in} = \pi_{in}C_n$$
 and $A_{in} = \pi_{in}A_n$ with
 $\pi_{in} = \frac{\tau_{in}^{-\varepsilon}}{\Psi_i\Phi_n}$
 $\Phi_n = \sum_h = 1^N \frac{\tau_{hn}^{-\varepsilon}}{\Psi_h},$

where $A_n = \sum_i A_{in}$ and $C_n = \sum_i C_{in}$.

A1 stipulates that trade shares π_{in} are identical for final and intermediate goods,

implying that total trade also follows a general gravity equation:

$$X_{in} = \tau_{in}^{-\varepsilon} \frac{X_n}{\Psi_i \Phi_n},\tag{1}$$

where $X_n = A_n + C_n$.⁴

(A2) The share of VA from *i* embodied in final goods production in *h* equals $v_i b_{ih}$, where v_i is the VA per unit of output in *i* and b_{ih} is the output in country *i* that is generated per unit of final goods production in *h*, which is given by an element of the Leontief inverse $\mathbf{B} = (\mathbf{I} - \mathbf{a})$. The matrix **a** collects the direct input coefficients $a_{in} = \frac{A_{in}}{Y_n}$ where Y_n is the total output of country *n*.

A2 implies that VA exports from i to n observe

$$VA_{in} = v_i \sum_{h=1}^{N} b_{ih} C_{hn}.$$
 (2)

Equation (2) is identical to the (one-sector version of the) definition of VA exports in Johnson and Noguera (2012).

From A1 and A2, we derive a general gravity equation of VA exports equal to

$$VA_{in} = v_i \frac{C_n}{\Psi_i \Phi_n} \sigma_{in} \qquad \text{with} \qquad \sigma_{in} = \tau_{in}^{-\varepsilon} + \sum_h \sum_{h_1} \frac{\tau_{ih_1}^{-\varepsilon}}{\Phi_{h_1}} (1 - v_{h_1}) b_{h_1 h} \frac{\tau_{hn}^{-\varepsilon}}{\Psi_h}. \tag{3}$$

The details of the derivation have been relegated to the Appendix. In Equation (3), σ_{in} is an inverse measure of the frictions for VA exports from *i* to *n*. σ_{in} is clearly related to τ_{in} because the bilateral trade cost from *i* to *n* inhibits VA flowing to *n* directly, that is, embodied in final goods exports from *i* to *n*. However, in contrast to the gravity equation

⁴Trade shares π of the form assumed in A1 are implied, e.g., by the model of Eaton and Kortum (2002), the Armington model of Anderson and Van Wincoop (2003), or a model of monopolistic competition and CES preferences. The structural interpretation of Ψ_i differs across models. In the Eaton-Kortum model, ε also has a different structural interpretation. See footnote 20 in Eaton and Kortum (2002).

for gross trade (1), the bilateral friction is *not* log-proportional to the trade cost between *i* and *n*. Instead, it is also a function of the trade cost between all country pairs worldwide. Intuitively, this is because VA from *i* can reach *n* embodied in goods processed elsewhere, potentially in several countries. In (3), the infinite number of indirect travel routes for VA from *i* to *n* is reflected in the double summation. This term implies that, for given bilateral trade cost τ_{in} , VA_{in} is larger if country *n* buys relatively many intermediate goods from *h* (reflected in $\frac{\tau_{in}^{-\varepsilon}}{\Psi_h}$), if *h* sources a lot from h_1 (reflected in b_{h_1h} , which is a function of trade cost between all pairs), if h_1 uses a lot of intermediates in production (reflected in $1 - v_{h_1}$) and if h_1 sources a large share of inputs from *i* (reflected in $\frac{\tau_{in}^{-\varepsilon}}{\Phi_{h_1}}$).

The indirect nature of VA flows is, of course, well known. The purpose of deriving Equation (3) is to enable a structural interpretation of the coefficients in reduced-form VA gravity equations and to highlight several issues regarding the identification and interpretation of these estimates.

3.2 Estimating the Impact of RTAs on (VA) Trade

To map our setup directly into commonly used panel estimation frameworks, we now add a time dimension indexed by t and employ two additional assumptions:

(A3) Bilateral iceberg trade costs depend on RTAs and a vector of other observable trade barriers Z_{int} according to

$$\tau_{int} = \exp\left\{\delta RTA_{int} + \nu Z_{int}\right\}.$$
(4)

Combining (5) and (4), we derive the log-linear empirical gravity equation for gross trade

$$\ln X_{int} = \beta^X RT A_{int} + \nu Z_{int} + \gamma_{it} + \gamma_{nt} + \gamma_{in} + u_{int}.$$
(5)

Henceforth, we use ζ_{int} to denote the vector of covariates in (5).

(A4) We assume exogeneity of the covariates

$$\operatorname{E}\left[u_{ins}|\boldsymbol{\zeta}_{int}\right] = 0 \quad \text{for } s, t = 1, ..., T.$$

Under A4, (1) and (5) imply that the elasticity of gross trade to a trade cost change that is due to a change in RTA membership is

$$\beta^X = \frac{\partial \ln X_{in}}{\partial RTA_{in}} = -\varepsilon\delta.$$
(6)

In analogy to (5), VA gravity equations employ (variants of) the empirical model

$$\ln V A_{int} = \beta^{VA} RT A_{int} + \nu^{VA} Z_{int} + \gamma_{it} + \gamma_{nt} + \gamma_{in} + \epsilon_{int}$$
(7)

to estimate $\beta^{VA} = \frac{\partial \ln VA}{\partial RTA}$. However, the theoretical VA gravity equation (3) implies several issues that complicate the estimation of (7).

Issue (1): Coefficient heterogeneity. According to (3) and (4), the elasticity of VA trade to a change in RTA membership is

$$\frac{\partial \ln VA_{in}}{\partial RTA_{in}} = \frac{\partial \sigma_{in}}{\partial (\tau_{in}^{-\varepsilon})} \frac{\tau_{in}^{-\varepsilon}}{\sigma_{in}} \left(-\varepsilon\delta\right) \tag{8}$$

where

$$\frac{\partial \sigma_{in}}{\partial (\tau_{in}^{-\varepsilon})} = 1 + \sum_{h} (1 - v_n) \frac{b_{nh}}{\Phi_n} \frac{\tau_{hn}^{-\varepsilon}}{\Psi_h} + \sum_{h_1} \frac{\tau_{ih_1}}{\Phi_{h_1}} (1 - v_{h_1}) \frac{b_{h_1i}}{\Psi_i} + \sum_{h} \sum_{h_1} \frac{\tau_{ih_1}^{-\varepsilon}}{\Phi_{h_1}} (1 - v_{h_1}) \frac{\tau_{hn}^{-\varepsilon}}{\Psi_h} \frac{\partial b_{h_1h}}{\partial (\tau_{in}^{-\varepsilon})}$$
(9)

Note that $\frac{\partial \ln VA_{in}}{\partial RTA_{in}}$ depends on characteristics of the pair i, n. Thus, the best we can obtain by estimating (7) is the sample average of $\beta_{in}^{VA} = \frac{\partial \ln VA_{in}}{\partial RTA_{in}}$ for the pairs whose RTA status changes. The magnitude of this average effect, which we denote with $\beta^{VA,treated}$, will depend on the set of country pairs and the time period included in the estimation, even if the actual data were generated by a process consistent with A1-A4. Similarly, if a different set of countries implements an RTA with the same trade cost reduction effect δ , the effect on member countries' VA flows will vary.

In contrast, $\frac{\partial \ln X_{in}}{\partial RTA_{in}} = \beta^{X,treated} = -\varepsilon \delta$. Hence, under A1, A3, and A4, $\hat{\beta}^{X,treated}$ estimates $-\varepsilon \delta$, independent of the sample composition and the set of member countries of an RTA.

Issue (2): Lack of control group. Under A2, VA exports from j reach k via every possible route. This implies that a reduction in τ_{in} , e.g., due to a bilateral RTA between i and n, benefits VA trade from h to h_1 , which, in turn, benefits VA trade from j to k that travels via h and h_1 . Formally, except for knife-edge cases,

$$\frac{\partial \ln \sigma_{jk}}{\partial \ln(\tau_{in}^{-\varepsilon})} \neq 0 \qquad \forall \ i, n, j, k.$$
(10)

For example, for two countries j, k, which are not part of the RTA, the effect is

$$\frac{\partial \ln VA_{jk}}{\partial RTA_{in}} = \frac{\partial \sigma_{jk}}{\partial (\tau_{in}^{-\varepsilon})} \frac{\tau_{in}^{-\varepsilon}}{\sigma_{jk}} (-\varepsilon\delta) = \sum_{h} \sum_{h_1} \frac{\tau_{jh_1}^{-\varepsilon}}{\Phi_{h_1}} (1 - v_{h_1}) \frac{\tau_{hn}^{-\varepsilon}}{\Psi_h} \frac{\partial b_{h_1h}}{\partial (\tau_{in}^{-\varepsilon})} (-\varepsilon\delta) \neq 0.$$
(11)

Like the partial effect on the "treated" country pairs, the effect on "untreated" pairs is heterogeneous across pairs. Issue 2 implies that, under A1-A4, we will never be able to recover the (sample-dependent) $\beta^{VA,treated}$. All we can aim for is to identify the difference between the average effect of the RTA on members' trade with each other and the average effect on all other, indirectly affected pairs:

$$\hat{\beta}^{VA} = \hat{\beta}^{VA, treated} - \hat{\beta}^{VA, untreated}.$$
(12)

However, even this relative and sample-dependent effect is unlikely ever to be accurately identified because (9) opens the door for many omitted variables, that could bias the coefficient.

Issue (3): Omitted variables bias. The non-zero cross derivatives in (10) imply more generally that the effect of a given RTA cannot be identified separately from any trade cost change happening elsewhere in the world. Since $\frac{\partial \ln \sigma_{in}}{\partial \ln (\tau_{jk}^{-\varepsilon})}$ is non-zero and pair specific, i.e., not absorbed by exporter and importer fixed effects, any trade cost change across the world that coincides with the change in RTA_{in} will bias the coefficient $\hat{\beta}^{VA}$, except in special cases. Moreover, omitted variables bias is not limited to trade cost. In fact, even changes in the country-specific parameters Ψ_h and β_h entering σ_{in} will bias the coefficient if they coincide with the formation of the RTA. To make these biases explicit, the OLS estimate can be expressed as

$$\mathbf{E}\left[\hat{\beta}^{VA}\right] = \beta^{VA} + \sum_{h} \sum_{h1} \theta_{\tau_{hh_1}} + \sum_{h} \theta_{\Psi_h} + \sum_{h} \theta_{v_h}, \qquad (13)$$

where $\theta_{\tau_{hh_1}}$ is the coefficient on RTA_{int} in a regression of the omitted variable $\frac{\partial \ln VA_{int}}{\partial \ln \tau_{hh_1t}}\Big|_{y=\bar{y}} \tau_{hh_1t}$ on $\boldsymbol{\zeta}_{int}$. θ_{Ψ_h} and θ_{v_h} are defined analogously.⁵

$$\begin{aligned} \ln VA_{int} &\approx \frac{\partial \ln \sigma_{int}}{\partial \ln (\tau_{int}^{-\varepsilon})} \bigg|_{y=\bar{y}} (-\varepsilon \delta) RTA_{int} + \left. \frac{\partial \ln \sigma_{int}}{\partial \ln (\tau_{int}^{-\varepsilon})} \right|_{y=\bar{y}} \nu Z_{int} + \sum_{h} \sum_{h_1} \left. \frac{\partial \ln \sigma_{int}}{\partial \ln (\tau_{hh_1}^{-\varepsilon})} \right|_{y=\bar{y}} \ln (\tau_{hh_1}^{-\varepsilon}) \\ &+ \sum_{h} \left. \frac{\partial \ln \sigma_{int}}{\partial \ln \Psi_{ht}} \right|_{y=\bar{y}} \ln \Psi_{ht} + \sum_{h} \left. \frac{\partial \ln \sigma_{int}}{\partial \ln v_{ht}} \right|_{y=\bar{y}} \ln v_{ht} + g_{it} + g_{nt} + g_{in} \end{aligned}$$

where the pair fixed effect g_{in} absorbs the *i*, *n*-specific terms resulting from the approximation and time constant bilateral trade costs between *i* and *n*, g_{it} absorbs Ψ_{it} , v_{it} and g_{nt} absorbs C_{nt}/Φ_{nt} .

⁵Subscript $y = \bar{y}$ indicates that the partial derivatives are evaluated at parameter means across time. To derive (13), we linearize $\ln VA_{int}$ around the pair-specific mean

Note that in the case of gross trade, structural gravity implies that a change in τ_{hh_1} influences X_{in} only via the country-specific terms Ψ_i , Φ_n , X_n , which enter log-proportionately and can therefore be absorbed by exporter and importer fixed effects. In the case of VA trade, these general-equilibrium-type effects are also present and absorbed by fixed effects, but there remains the pair-and-time-specific influence that operates through σ_{in} . Intuitively, the bias arises because every country's GVC is unique, implying a countrypair-specific exposure to third-country effects. Only in the special cases where GVCs of treated and control pairs are symmetrically exposed to shocks all over the world will the bias be zero.

In the estimation, the bias could be mitigated by including terms for pair-specific exposure to all possible third-country shocks in the regression, similar to the indirect trade cost terms in Noguera (2012). However, the set of potential confounders is large and includes variables like productivity or preferences, which are hard to observe. Alternatively, the sum of indirect effects could be absorbed by including σ_{in} as defined in (3) into the regression. A similar approach is adopted by Njike (2021). However, once the indirect effects are controlled for, the VA trade cost elasticity becomes identical to the trade cost elasticity of gross trade. Hence, a standard gravity equation is sufficient to estimate this parameter.

4 Quantification of Heterogeneity and Bias

4.1 Methodology

In this section, we demonstrate the quantitative importance of the abovementioned issues in a controlled simulation setting where A1 - A4 hold. We use a variant of the model of Aichele and Heiland (2018) to simulate the exact partial and general equilibrium effects of a hypothetical RTA on gross trade and VA trade. The model satisfies A1 and A2, and we simulate trade cost shocks that satisfy A3 and A4. Specifically, we assume that the set of countries $B \subset N$ forms an RTA that reduces trade cost among members by 10% ($\delta = .9$) and a trade elasticity $\varepsilon = -5$. The model yields counterfactual changes $\hat{X}_{in} = X'_{in}/X^0_{in}$, where X^0_{in} (X'_{in}) is gross bilateral trade in the baseline (counterfactual) equilibrium, and, analogously, counterfactual changes in VA trade, $\widehat{VA}_{in} = VA'_{in}/VA^0_{in}$ for $i, n \in N$. We then show that, as predicted by gravity, we can recover the partial effect of the RTA on gross trade from the regression

$$ln\widehat{X}_{in} = \beta^X RTA_{in} + \mu_i + \mu_n + u_{in}, \qquad (14)$$

where RTA_{in} equals one for $n, i \in B, n \neq i$ and zero otherwise. β^X observes

$$e^{\beta^X} = \delta^{\varepsilon}$$

Similarly, we recover $\hat{\beta}^{VA}$ from the estimation of

$$\ln \hat{V}\hat{A}_{in} = \beta^{VA}RTA_{in} + \mu_i + \mu_n + \varepsilon_{in}.$$
(15)

In what follows, we study how $\hat{\beta}^{VA}$ varies across different simulated scenarios to assess the importance of our theory-based concerns around this estimation equation.

4.2 Results

First, we focus on the extent of heterogeneity that is concealed by the average partial effect (issue 1). To that end, we simulate the following scenario:

Scenario 1 ("BRICS"). We assume that the BRICS countries (Brazil, Russia, India, China, and South Africa) form an RTA that leads to a trade cost reduction of 10% for all trade flows between RTA members.

To quantify the heterogeneity, we calculate the distribution of the partial VA trade effects of the RTA across all possible quadruples with one treated pair. Starting with gross trade as a reference point, A1 implies

$$\ln\left(\frac{\widehat{X}_{in}/\widehat{X}_{ij}}{\widehat{X}_{kn}/\widehat{X}_{kj}}\right) = \beta^X \quad \text{if} \quad RTA_{in} = 1, RTA_{ij}, RTA_{kn}, RTA_{kj} \neq 1.$$
(16)

The partial trade effect is constant across members of the RTA and independent of the composition of the control group. I.e., no matter which RTA member we compare to which non-member, the partial trade effect is always the same. The same is not true for VA trade. Every RTA member experiences a different partial trade effect, and so does every non-member. Hence, the distribution of

$$\ln\left(\frac{\widehat{VA}_{in}/\widehat{VA}_{ij}}{\widehat{VA}_{kn}/\widehat{VA}_{kj}}\right) \quad \text{for} \quad RTA_{in} = 1, RTA_{ij}, RTA_{kn}, RTA_{kj} \neq 1 \quad (17)$$

is non-degenerate. Figure 1 (blue line) shows the distribution of the RTA effects across quadruples as defined in (17). By construction, the partial effect on gross trade is constant. The partial VA effects are, on average, smaller than the partial effect on gross trade but span a wide range. The 10th to 90th percentile range is 0.38 - 0.48. In a few cases, the VA changes even exceed the gross trade change.

Second, we quantify the indirect effects on the control group (issue 2). Figure 2 demonstrates the distribution of the RTA effects on the control groups, calculated as

$$\ln\left(\frac{\widehat{VA}_{in}/\widehat{VA}_{ij}}{\widehat{VA}_{kn}/\widehat{VA}_{kj}}\right) \quad \text{for} \quad RTA_{in}, RTA_{ij}, RTA_{kn}, RTA_{kj} \neq 1.$$
(18)

As implied by (11), the effects are non-zero and heterogeneous across pairs.

Table 1 presents the estimates of β^X from (14) and β^{VA} from (15) in columns 1 and 2, respectively. The second row shows the implied relative partial (VA) trade changes. The partial gross trade change is $(e^{\beta^X} - 1) * 100\% = 69.35\%$, the average partial VA trade



Figure 2: BRICS, Effects on Non-members



Figure 1: BRICS, Effects on RTA-members vs. Non-members

	1.BRICS		2.BRICS + TTIP		$3.BRICS_{2001}$		4.BRICS + US	
	\widehat{X}_{in}	\widehat{VA}_{in}	\widehat{X}_{in}	\widehat{VA}_{in}	\widehat{X}_{in}	\widehat{VA}_{in}	\widehat{X}_{in}	\widehat{VA}_{in}
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$\beta^X \text{ or } \beta^{VA}$	0.5268	0.4381	0.5268	0.4475	0.5268	0.4476	0.5268	0.4402
$e^{\beta^X} \text{ or } e^{\beta^{VA}}$	1.6935	1.5497	1.6935	1.5643	1.6935	1.5645	1.6935	1.5523

Note: In all four scenarios, the simulated partial trade effect is $\delta^{\varepsilon} = 1.6935$

Table 1: Heterogeneity and biases under different scenarios

change is $(e^{\beta^{VA}} - 1) * 100\% = 54.97\%.$

As discussed in Section 3, an implication of issue 1 and issue 2 is that the estimate of the VA trade cost elasticity depends on the composition of the estimation sample, even in a controlled environment without noise. To illustrate the importance of this problem, we analyze two additional scenarios. In scenario 2, we change the set of countries joining an RTA. In scenario 3, we shift the baseline calibration to a different year.

Scenario 2: "BRICS + TTIP". We assume that in parallel with the formation of the BRICS agreement as defined in Scenario 1, another RTA (called "TTIP") is formed between the U.S. and all EU27 members, which also reduces trade costs between members by 10%.

Scenario 3: " $BRICS_{2001}$ ". Like in Scenario 1, we assume that the BRICS countries form an RTA, but now we calibrate the model baseline with data from 2001 instead of 2018.

Columns 3-4 and 5-6 of Table 1 present the results from the BRICS + TTIP and $BRICS_{2001}$ scenarios, respectively. In both cases, we find partial average VA effects that differ from those in Scenario 1, with the effects being approximately 1.5 percentage points larger than in the baseline scenario. By construction, the partial effect on gross trade is the same in all scenarios.

Finally, we turn to the issue of omitted variables bias (issue 3). To that end, we study

a fourth scenario in which, concurrently with the BRICS RTA, a massive infrastructure improvement occurs in the U.S..

Scenario 4: "BRICS + US". We assume that in addition to the BRICS agreement as in Scenario 1, a positive infrastructure shock occurs in the USA. This infrastructure shock results in a 50% decline in trade costs between the U.S. and all destinations (including the U.S. itself).

Columns 7 and 8 present the results from the BRICS + US scenario. As suggested by (13), the estimated partial VA trade effect of BRICS is affected by the infrastructure shock occurring elsewhere in the world. The difference is about .3 percentage points. This occurs despite the fact that the direct effect on BRICS countries' and non-BRICS countries' VA trade with the US is absorbed by the country fixed effects in (15). In contrast, in the gross trade regression, the country fixed effects perfectly control for the U.S.-specific shock.

5 Discussion

Our simulation analysis has shown that the theoretically founded concerns surrounding the estimation of VA gravity equations are non-negligible. The issue of heterogeneity undermines external validity and comparability across agreements and samples. Comparisons of coefficients obtained for different agreements are complicated by the fact that the heterogeneity can either be due to different impacts of the agreements on trade cost or to differences in the incidence of these trade cost changes. The same challenge applies to comparisons of estimates for the same agreements across different time periods or samples. In our controlled setting, all heterogeneity is due to differences in incidence. Changing the time period or the set of countries joining otherwise similar RTAs affected the estimated partial trade effect by a small but non-negligible amount. This issue of heterogeneity also implies that estimated partial effects have no predictive power for future agreements.

The issue of indirect effects on non-members means that the effect on the treated country pairs cannot be isolated from the effect on the non-treated ones. Consequently, the coefficient on RTA in the VA gravity equation cannot be interpreted as a measure of the RTAs effectiveness. For example, a very effective RTA can result in a small coefficient if a large amount of third-country VA passes through the RTA members, implying large positive indirect effects on the control group.

The issue of the bias appears to be the most concerning. If only issue 1 and issue 2 were present, one could appeal to the internal validity of the estimate and interpret the estimated β^{VA} as the average effect on the VA trade between members relative to nonmembers for a given agreement and time period and a possibly complete set of countries. However, the omitted variables problem implies that even this conservative interpretation is rarely valid. Due to the unique structure of countries' GVCs, third-country shocks – such as productivity changes – have non-trivial effects on bilateral VA trade. Unlike the gross trade gravity equation, these third-country effects cannot be fully absorbed by fixed effects in the VA gravity equation. This is a crucial distinction. As a consequence, the coefficient on RTA in the VA gravity equation will pick up the effects of any concurrent third-country shock to which, for possibly spurious reasons, the country pairs treated by the RTA are differentially exposed compared to the control pairs. Our simulation illustrates how an infrastructure change in a third country can confound the RTA effect on VA trade between other countries. The bias issue is even more concerning because the set of potential confounding variables is vast. In principle, any variable affecting the trade share π between any two countries elsewhere in the world or any country's value-added coefficient v_h is a potential confounder.

Our analysis focuses on the VA exports as defined by Johnson and Noguera (2012). However, the logic outlined above extends to other bilateral measures of value-added trade, such as the domestic VA content of exports or imports. Finally, we would like to discuss the assumptions underlying our framework. A3 is a widespread and fairly harmless log-linearity assumption. A4, in contrast, is unreasonably strong and will fail when confronted with real-world data. However, we adopt this exogeneity assumption for practical purposes only, because we want to demonstrate the challenges associated with VA gravity estimates for variables whose effects on gross trade can be cleanly identified in a fully saturated fixed effects model. In our simulated data, A4 holds true. Whether RTAs are exogenous in the real world has no bearing on our analysis.

A1 and A2 warrant more discussion. By adopting A1, we have assumed away thirdcountry effects on bilateral gross trade. However, A1 can be justified by a range of theoretical models. In contrast, we are not aware of any non-trivial theoretical model that predicts a gravity equation for VA flows where other countries' trade cost and other trade determinants enter only via *multilateral* resistance terms. Moreover, we do not intend for our analysis to suggest that gross trade gravity equations are correct and VA gravity equations are not. Instead, we want to point out that the use of reduced-form VA gravity equations should not be justified by referencing the theoretical and empirical merits of gravity equations for gross trade. Our analysis demonstrates that when intermediate and final gross trade flows follow gravity equations exactly, VA gravity equations are misspecified.

A2 is also very strong. It implies, among other things, that the VA composition of exported goods is identical across destinations, effectively ruling out the possibility that different inputs are used for different destination markets. However, since actual VA flows are unobservable, variants of A2 (aka "proportionality assumptions") underly all empirical measures of VA trade that aim at global coverage. Empirical measures of VA trade, such as those available in the OECD TiVA database, are derived from international IO tables constructed using proportionality assumptions. Similarly, CGE models featuring global IO linkages, such as GTAP or the model employed in Aichele and Heiland (2018), are calibrated based on these assumptions.

Arguably, international IO tables, such as the OECD ICIO database or the World Input-Output Database (WIOD), employ weaker versions of A2 than our paper. These tables are based on proportionality assumptions at the sector level rather than the aggregate level, which reduces aggregation bias and weakens the implications of the proportionality assumption on trade shares.⁶ However, the issues with empirical VA gravity equations discussed in this paper do not hinge on A2 in any major way. Suppose real data on VA flows at the country-pair was available, capturing correctly the aggregate of all firms' unique GVCs. Then, RTAs would still have country-pair specific effects on member countries and indirect effects on the control group. Also, treated pairs would still be exposed to other third-country shocks via their unique GVCs, resulting in potential biases in the estimated RTA effects. The only difference that the real data would make is that the degree of pair-specific exposure to the treatment or other shocks would be accurately measured, rather than approximated by A2. More broadly, relaxing the proportionality assumptions embedded in A2 would only increase the heterogeneity in exposure to third-country shocks, making it even less likely that these effects are captured by fixed effects. By making A2 as strong as possible in terms of the assumed proportionality, we have imposed a high degree of similarity on countries' GVCs. Nevertheless, we find heterogeneous exposure to shocks within and across pairs of countries, causing the empirical issues outlined above. In sum, we are confident that our conclusions do not hinge on the restrictive assumptions we have employed to illustrate the issues surrounding empirical VA gravity equations in a parsimonious way.

We would like to conclude the discussion with a more optimistic note regarding the potential of VA trade analysis. The third-country effects that we have tagged as prob-

⁶Some international IO tables also account for differences in trade shares across use categories, whereas in our setup, trade shares are the same for intermediate and final goods. Additionally, international IO tables that capture other dimensions of heterogeneity in inputs and outputs are currently under development Fortanier et al. (2020).

lematic, are, in fact, highly interesting from an economic perspective. Understanding how a country's VA is affected by shocks occurring elsewhere in the world is important, not least since the recent geopolitical turbulences have reinforced policymakers' focus on trade-based dependencies. Our analysis suggests that a structural approach to quantifying the naturally heterogeneous impact of local trade cost shocks on global VA trade patterns is preferable. New quantitative trade models featuring both intermediate and final goods trade, such as the model by Caliendo and Parro (2015), lend themselves to such analyses.

6 Conclusions

In this paper, we scrutinize empirical gravity equations for value-added (VA) trade. VA gravity equations are often justified by referencing the theoretical and empirical merits of traditional gravity equations for gross trade. Contrary to this rationale, we demonstrate that if bilateral gross trade follows gravity, bilateral VA trade does not. In other words, when the gross trade gravity equation is correctly specified, the VA gravity equation is misspecified.

We point out three specific issues that researchers need to consider when interpreting coefficients from VA gravity equations. First, the theoretical general gravity equation for VA trade implies that the partial effect on trade cost proxies, such as RTA indicators, are heterogeneous across pairs. As a result, estimated coefficients on RTAs and other trade cost proxies are not comparable across samples, agreements, and time periods, and, hence, not informative for future agreements. Second, trade cost changes affect third countries in a non-trivial manner. Unlike structural gravity equations for gross trade, these thirdcountry effects on the control group cannot be absorbed by fixed effects in VA gravity equations. Third, changes in trade cost or other trade determinants occuring elsewhere in the world will bias the RTA estimate unless both members' and non-members' GVCs are equally exposed to the third country shock, which is unlikely.

We employ the simplest possible theoretical model of gross trade and VA trade to illustrate these issues and conduct simulation exercises to quantify their importance in a controlled setting. Our simulation results confirm the relevance of the theoretical mechanisms and suggest that VA gravity estimates in real-world settings are difficult to interpret. As a remedy, we recommend adopting a structural approach to quantifying the heterogeneous effects of trade agreements and other trade cost shifters on bilateral trade in value added. **Declaration of generative AI and AI-assisted technologies in the writing pro-cess.** During the preparation of this work the authors used ChatGPT-4 to improve the language. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

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Appendix

Derivation of Equation (3)

We use $B = (1 - a) = \sum_{m=0}^{\infty} a^m$ to rewrite b_{hn} as

$$b_{hn} = I_{i=h} + \sum_{h_1} \alpha_{ih_1} b_{h_1h}, \tag{19}$$

where $I_{i=h} = 1$ if i = h and zero otherwise. Inserting (19) in (2) yields

$$VA_{in} = v_i \sum_{h} \left(I_{i=h} + \sum_{h} \sum_{h1} a_{ih_1} b_{h_1 h} \right) \pi_{hn} C_n$$
(20)

A2 and A1 together imply that $a_{in} = \frac{A_{in}}{Y_{in}} = (1 - v_n)\pi_{in}$. Inserting a_{in} in (20) yields

$$VA_{in} = v_i \left(\pi_{in} + \sum_{h} \sum_{h1} v_i \pi_{ih_1} b_{h_1 h} \pi_{hn} \right) C_n$$
(21)

Inserting $\pi_{in} = \tau_{in}^{-\varepsilon} / (\Psi_i \Phi_n)$ and reorganizing terms yields Equation (3).

List of Academic Papers and Policy Reports Estimating Gravity Equations with Value Added Trade Flows

Academic Papers

Blind et al. (2018)Boffa et al. (2019)Böhmecke-Schwafert and Blind (2023) Chen et al. (2022)Díaz-Mora et al. (2022)Doan and Le (2021)Fertő et al. (2024)Hayakawa and Mukunoki (2023) Johnson and Noguera (2017) Kang and Gapay (2024) Laget et al. (2020)Le et al. (2022)Lee (2019) Lu and Wolszczak-Derlacz (2024) Mulabdic et al. (2017)Njike (2021)

Olczyk and Kordalska (2017) Pahl and Timmer (2019) Sanguinet et al. (2022)Sharma et al. (2023)Thang et al. (2021)Tokas (2021)Tokas (2022)Wang and Thangavelu (2021) Wolszczak-Derlacz and Lu (2022) Yang (2022) Yang (2023) Zaninović (2022) Zaninović and Bugarčić (2023) Zaninović et al. (2024)Zhao (2022) Zhong et al. (2022)

Policy Reports

Cadestin et al. (2016) Jouanjean et al. (2017) Moïsé and Sorescu (2015) OECD (2021)