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Bilateral Trade Imbalances

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If sectoral trade flows obey structural gravity, countries' bilateral trade imbalances are the result of macro trade imbalances, "triangular trade", or pairwise asymmetric trade barriers. Using data for 40 major economies and the Rest of the World, we show that large and pervasive asymmetries in trade barriers are required to account for most of the observed variation in bilateral imbalances. A dynamic quantitative trade model suggests that eliminating these asymmetries would significantly reduce bilateral (but not macro) imbalances and have sizeable impacts on welfare. We provide evidence that the asymmetries we measure are in part related to the policy environment: trade inside the European Single Market appears to be subject to more bilaterally symmetric frictions. Extending the same symmetry to all parts of the global economy would give a large boost to the real incomes of several non-E.U. countries.

Key words: Trade imbalances, Trade wedges, Gravity

JEL codes: F15, F20, F32, F40, F62

1. INTRODUCTION

It is a well-known fact that the U.S. trade balance has been in deficit every year since 1992. In the 5 years between 2010 and 2014, that deficit amounted to 3% of GDP on average. What is perhaps less well known is that the overall U.S. deficit masks significant heterogeneity of its bilateral trade balance with individual partner economies. The vertical bars in Figure 1 represent the U.S. trade balance (as a percentage of U.S. GDP) vis-à-vis 39 other economies and the "Rest of the World" (RoW) over the period 2010–14.[1] There is significant variation in U.S. bilateral net exports around their average value, represented by the thick horizontal line.[2] The U.S. runs large bilateral deficits with China, and its NAFTA partners Mexico and Canada—but it also runs small trade surpluses with, among others, Ireland, the Netherlands, and France.

1. The figure is based on data from the 2016 release of the World Input–Output Database (WIOD), the latest currently available. Section 2.2.1 discusses this data source in detail.
2. Since the data represented in Figure 1 covers the total value of all U.S. exports and imports divided across 40 economies/regions, the average bilateral trade balance equals the overall U.S. trade balance divided by 40.

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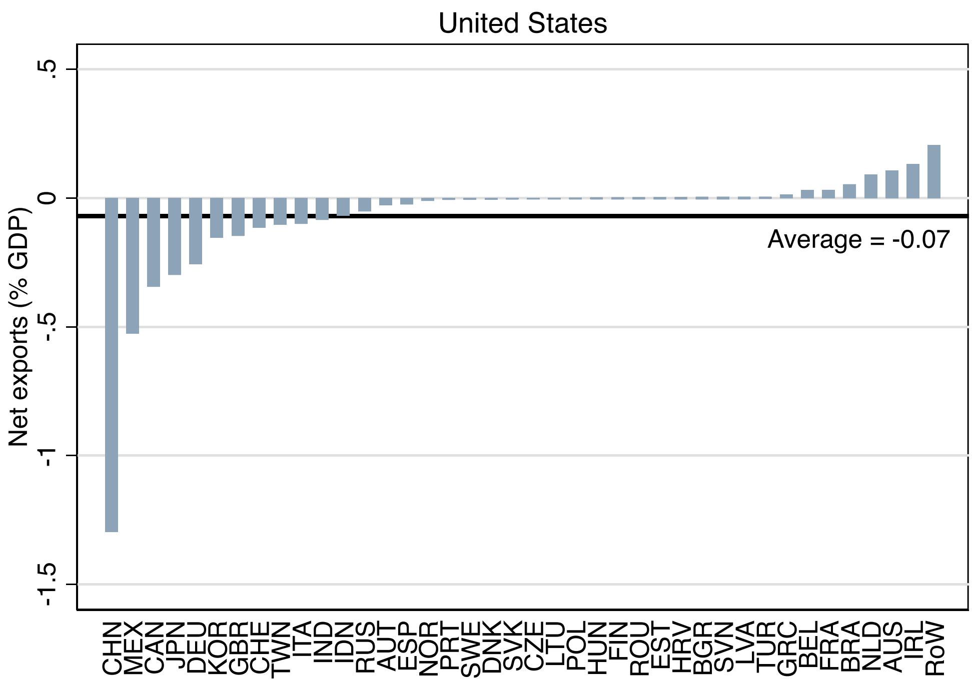


FIGURE 1

U.S. bilateral net exports, 2010–14

Note: "Net exports (% GDP)" refers to the net exports of goods and services by the U.S. to the horizontal-axis economy, expressed as a percentage of U.S. GDP. All data are based on WIOD (2016 release), average for the years 2010–14.

Such dispersion in a country's bilateral balances with its trade partners is not peculiar to the U.S. case. Yet, so far there exists no systematic study that accounts for the large observed variation in bilateral trade balances across country pairs—despite the fact that individual examples of major imbalances between trade partners are a recurrent trigger of political controversies.[3] Our article seeks to fill this gap in the literature. We do so by means of three specific contributions. First, we demonstrate that the drivers of bilateral trade imbalances can be understood in a simple framework underpinned by few, fairly general assumptions. Second, we take this framework to the data and document that one of these drivers—pairwise asymmetries in trade frictions—accounts for most of the variation in bilateral imbalances. Embedding our findings in a dynamic many-country, many-sector quantitative trade model, we use counterfactuals to confirm that eliminating all bilateral trade-cost asymmetries would not only cause most of the variation in bilateral imbalances to disappear but also have sizeable effects on macroeconomic outcomes. Third, we provide some evidence of the extent to which measured pairwise asymmetries in trade frictions (and through them, bilateral imbalances) may be shaped by the trade-policy environment.

We start from the assumption that sector-level bilateral trade flows can be modelled by means of a standard structural gravity equation (Anderson and van Wincoop, 2003). This assumption,

3. In the last three decades, the U.S. trade deficit vis-à-vis Japan (Janow, 1994), China (Feenstra *et al.*, 1998; Hughes, 2005) and, most recently, Germany (Swanson, 2017; Krugman, 2017) has been in the spotlight as a possible symptom of "unfair" trade practices on the part of these countries against American producers.

commonly made in empirical studies of international trade, is compatible with the microfoundations of many popular quantitative trade models.[4] Aggregating across sectors, it implies that there exist *exactly three sources* of bilateral trade imbalances between countries.

"Macro" (unilateral) trade balances are the first source: by definition, economies with a deficit in their macro trade balance—such as the U.S.—will have a deficit with their average trade partner; macro-surplus economies—such as China—will have a surplus. Everything else constant, we would thus expect a deficit–surplus pair to have a larger bilateral trade imbalance than two surplus or two deficit economies.

Differences in sectoral expenditure and production patterns are the second source: if a large portion of Dutch expenditure is dedicated to U.S. goods, a large portion of German expenditure to Dutch goods, and a large portion of U.S. expenditure to German goods, the resulting "triangular trade" give rise to *bilateral* imbalances even if trade is completely balanced at the macro level.

The third source is asymmetric obstacles to trade between two economies that penalize bilateral trade flows in one direction more than in the other. Our analytical expression for bilateral trade imbalances represents a generalization of a formula first derived by Davis and Weinstein (2002). Taking a first-order approximation, it permits a linear decomposition of the sources of variation in *proportional bilateral imbalances*—bilateral trade balances relative to the geometric average of bilateral trade flows. We perform this variance decomposition using data on 40 economies and the Rest of the World from the WIOD, and backing out unobserved (asymmetries in) bilateral trade frictions as "residuals" from a theory-consistent gravity estimation. We find that differences in macro trade balances on their own account for a small share of the variation in proportional bilateral imbalances (roughly 2%). The individual contribution of "triangular trade" is sizeable (roughly 12%), but the largest individual share is due to asymmetries in trade frictions (roughly 84%).

While this finding is suggestive, it may overstate the importance of asymmetric trade barriers in a number of ways. It relies on a linear approximation and abstracts from general equilibrium effects (such as the effect changes in trade barriers might have on expenditure patterns or macro trade balances). Moreover, even if trade imbalances are a symptom of asymmetric trade frictions, this is of interest only to the extent that such asymmetries have meaningful macroeconomic and welfare consequences. To address these issues, we set up a dynamic many-country, many-sector quantitative trade model.

Our model makes assumptions that deliver sector-level structural gravity equations. In its steady state, macro trade imbalances arise from differences in economies' technologies and rates of time preference; differences in production and spending patterns are the result of differences in countries' technologies and ideal consumption baskets; and generic "trade wedges" govern country-pair-sector variation in trade flows. We calibrate the deep parameters of the model so as to match the corresponding objects in our data perfectly and in a manner consistent with the assumptions of our aforementioned variance decomposition. We then perform counterfactuals that allow us to investigate changes in the distribution of bilateral trade balances and macroeconomic outcomes in response to changes in model parameters.[5]

4. Head and Mayer (2014) survey the use of structural gravity models in empirical studies of international trade. Costinot and Rodríguez-Clare (2014) provide an overview of the common analytical properties of "gravity class" quantitative trade models.

5. A popular trick in quantitative trade modelling, going back to Dornbusch *et al*. (1977), is to introduce macro trade imbalances as exogenous international transfers into an otherwise static model. We set up a dynamic model in which macro trade imbalances are an endogenous steady-state outcome that is independent of initial conditions. This

Our counterfactuals confirm that, in a hypothetical world economy with fully bilaterally symmetric trade wedges, 75% of the variation in proportional bilateral imbalances would disappear. By contrast, the disappearance of macro trade imbalances in counterfactual financial autarky would only reduce the variation in imbalances by 15%. Beyond its impact on trade patterns, a move to global trade-wedge symmetry would raise the median country's real GDP and consumption level by 8.5%. This highlights that measured trade-wedge asymmetries have meaningful implications for the global macroeconomy and makes the case for subjecting their nature and origins to further study.

Since we obtain bilateral (asymmetries in) trade wedges as a "residual", they capture all determinants of sector-level bilateral trade patterns that elude our gravity framework. These could include the pairwise asymmetric impact on trade barriers of structural factors such as preferences, technologies, or geography as well as asymmetric policy barriers to trade. We investigate the properties of our measured bilateral trade-wedge asymmetries at the aggregate and sectoral levels, and show that they are sizeable but not obviously related to sector characteristics. However, we obtain some evidence that the policy environment matters: asymmetries appear to be smaller among member countries of the European Single Market (SM), and countries that join the E.U. see their trade-wedge asymmetries vis-à-vis other members decline. We use our model to simulate the global impact of extending this bilateral trade-wedge-levelling effect of E.U. membership to all economies in our data and find that it would significantly reduce bilateral imbalances and lead to large increases in the long-run incomes of Mexico (38%), South Korea (20%), and Turkey (19%). Each of these countries currently enjoys a close trade relationship with major markets in its respective region short of a SM environment.

Until recently, bilateral trade imbalances had received surprisingly little attention in academic research. Two notable exceptions are Feenstra *et al*. (1998) and Davis and Weinstein (2002). Feenstra *et al*. (1998) focus exclusively on the case of the U.S. trade deficit with China, whereas Davis and Weinstein (2002) analyse bilateral imbalances for a large sample of countries. Their work is most closely related with ours. The authors provide calculations of gravity-predicted bilateral imbalances, based on a semi-structural gravity equation and discover that actual imbalances dramatically exceed their predictions: the "mystery of excess trade balances". Our article can be understood as embedding their analysis in a fully structural model which allows for theory-consistent variance decompositions and counterfactuals. We recover the "mystery" in a new guise: a structural gravity model requires large black-box bilateral asymmetries in trade frictions to explain why some country pairs have bigger imbalances than others.[6]

Our focus on structural gravity in the first part of the article speaks to a large and active empirical literature, sparked by Anderson (1979) and Anderson and van Wincoop (2003), that uses this framework to quantify the drivers of the variation in bilateral trade flows across country pairs.[7] We confirm that structural gravity is also helpful in understanding the drivers of variation

allows us to derive a dynamic block of exact-hat equations which is modular to the exact-hat algebra often employed to perform counterfactuals in static trade models.

6. Two recent papers re-visit the question what explains observed bilateral imbalances. The first, by Felbermayr and Yotov (2021), re-estimates the gravity model of Davis and Weinstein (2002) and suggest that the inclusion of theory-consistent multilateral resistance terms goes some way in resolving the "mystery" as originally conceived. As we show in Section 2.2.3, this conflates the well-documented success of empirical gravity in explaining the variation in bilateral trade flows with its ability to explain pairwise imbalances in these flows. The second recent paper, by Eugster *et al*. (2020), focuses on *changes* in bilateral imbalances over time. Consistently with our finding that bilateral trade-wedge asymmetries are fairly persistent, they find that these changes are primarily driven by macro factors (such as the macro trade balance).

7. Carrère *et al*. (2020) summarize some of the main facts established and remaining open questions in this literature, including in relation to bilateral trade balances.

in *imbalances*. Expressed as part of a unified formal framework, the drivers of imbalances are theoretically and quantitatively distinct from the drivers of (average) bilateral trade flows. In taking our analysis to the data, we rely crucially on recent insights about the theory-consistent estimation of structural gravity models by Santos Silva and Tenreyro (2006) and Fally (2015).

The second part of our article introduces additional assumptions to cast our baseline structural gravity equation as the steady-state outcome of a dynamic quantitative trade model. This part of our work connects with a strand of research, reaching back to Eaton and Kortum (2002), that employs calibrated quantitative models of international trade to analyse the relationship between countries' sector-level productivities, bilateral trade costs, and real incomes. Several papers in this literature—including Dekle *et al*. (2007, 2008), Eaton *et al*. (2016b), and Cuñat and Zymek (2018)—explore the impact of (changes in) *aggregate* trade imbalances on countries' incomes. Some analyse the impact of (changes in) trade costs on *aggregate* trade imbalances—following on from the classic paper by Obstfeld and Rogoff (2000).[8] Yet to the best of our knowledge, none explore the determinants of *bilateral* trade balances; and few investigate the prevalence and macroeconomic implications of asymmetric trade barriers.[9]

A notable exception is Waugh (2010), who shows that asymmetric trade barriers between rich and poor countries can help better reconcile quantitative trade models with countries' observed aggregate import shares. He demonstrates that removing them would potentially reduce international income differences significantly. Our findings are complementary with Waugh's analysis (2010), which abstracts from trade imbalances, insofar as they illustrate that trade-wedge asymmetries are also required to account for a portion of observed bilateral trade surpluses and deficits. Moreover, we find that such asymmetries appear to be influenced by the trade policy environment, shrinking among countries that opt for the deep integration of a Single Market.

2. BILATERAL BALANCE ACCOUNTING WITH GRAVITY

2.1. *Structural gravity and bilateral trade imbalances*

2.1.1. Bilateral imbalances through the lens of structural gravity. Consider a set of N economies, denoted by $n=1,\ldots,N$. These countries trade in S sectors, denoted by $s=1,\ldots,S$.[10] We assume that sector-level trade flows obey a structural gravity equation of the form

$$M_{sn'n} = \left(\frac{\tau_{sn'n}}{O_{sn'}P_{sn}}\right)^{-\theta_s} \frac{D_{sn'}E_{sn}}{D_s}, \tag{1}$$

8. Reyes-Heroles (2016) studies the contribution of trade globalization to the emergence of current account imbalances. Eaton *et al*. (2016a) and Ravikumar *et al*. (2019) perform trade policy experiments in dynamic models that permit trade imbalances. Sposi (2022) shows that bilateral trade barriers influence how a shock that causes a current-account imbalance in one country is reflected in the current accounts of its trade partners.

9. Since we restrict our analysis to a comparison of steady states, it primarily speaks to the long-run drivers of trade balances. In a recent paper, Alessandria and Choi (2021) employ a similar decomposition to the one we develop below to investigate the drivers of short-run *changes* in the U.S. trade balance in the period 1980–2015. They find that a significant role for asymmetric movements in trade barriers in explaining these changes.

10. In principle, these sectors could represent very narrowly defined goods or services. In our data application, they will correspond to broad sectors at the two-digit level of ISIC, *e.g.* "Transport equipment". At that level of aggregation, the output of a given sector is likely to comprise both intermediate and final goods, and expenditure flows will represent a combination of value chain and final trade.

where $M_{sn'n}$ is the dollar value of expenditure by country n on country-n' output in sector s; $\tau_{sn'n}$ is a measure of the ad-valorem-equivalent trade frictions applying to this flow;[11] θ_s is the trade elasticity; $D_{sn'}$ is the dollar value of country-n' output in sector s; E_{sn} is the dollar value of country-n expenditure on sector-s output; D_s is an arbitrary, potentially sector-specific "normalizer"; and P_{sn} and $O_{sn'}$ are respectively the inward and outward multilateral resistance terms (MRTs), defined as follows:

$$P_{sn} \equiv \left[\sum_{n'=1}^{N} \left(\frac{\tau_{sn'n}}{O_{sn'}} \right)^{-\theta_s} \frac{D_{sn'}}{D_s} \right]^{-\frac{1}{\theta_s}}, \quad O_{sn'} \equiv \left[\sum_{n=1}^{N} \left(\frac{\tau_{sn'n}}{P_{sn}} \right)^{-\theta_s} \frac{E_{sn}}{D_s} \right]^{-\frac{1}{\theta_s}}. \tag{2}$$

The MRTs embody the key insight that bilateral trade flows between any two economies not only depend on the direct bilateral trade frictions between them but also on the extent of the importer's access to all possible import sources (captured by the inward MRT, P_{sn}) and the extent of the exporter's access to all possible export destinations (captured by the outward MRT, $O_{sn'}$).

The structural gravity equation described by (1) and (2) has been used in a wide range of quantitative applications since its debut in Anderson and van Wincoop (2003).[12] Two sufficient conditions for obtaining it are:

1. The share of spending by country n on country n' output in sector s, $\upsilon_{sn'n} \equiv M_{sn'n}/E_{sn}$, can be expressed in the following multiplicatively separable form:

$$\upsilon_{sn'n} = \frac{F_{sn'}}{D_s} \left(\frac{\tau_{sn'n}}{P_{sn}} \right)^{-\theta_s}, \quad P_{sn}^{-\theta_s} D_s \equiv \sum_{n'=1}^{N} F_{sn'} \tau_{sn'n}^{-\theta_s}, \tag{3}$$

   where $F_{sn'}$ is some measure of the multilateral attractiveness of n' as a source of imports in sector s.
2. There is market clearing for each origin country:

$$D_{sn'} = \sum_{n=1}^{N} M_{sn'n} = F_{sn'} \sum_{n=1}^{N} \left(\frac{\tau_{sn'n}}{P_{sn}} \right)^{-\theta_s} \frac{E_{sn}}{D_s} \equiv F_{sn'} O_{sn'}^{-\theta_s}. \tag{4}$$

Equations (1) and (2) are obtained by using (4) to substitute for $F_{sn'}$ in (3).

These two conditions are sufficiently general to be compatible with many quantitative models of international trade. While Condition 2 is satisfied in any general-equilibrium model, Condition 1 is more restrictive. Nevertheless, Head and Mayer (2014) show that it is satisfied in the Armington (1969), Krugman (1980), and Eaton and Kortum (2002) models, as well as certain many-country incarnations of Melitz (2003).[13] This makes the structural gravity equation above a natural starting point for the analysis of bilateral trade imbalances.

11. As we illustrate in our formal model in Section 3.1, $\tau_{sn'n}$ might reflect a combination of trade barriers arising from physical and policy barriers to the delivery of sector-s output from country n' to n, and biases in sector-s spending by country n in relation to other economies' outputs (*e.g.* home bias). Therefore, $\tau_{sn'n}$ can be thought of more generally as an ad-valorem equivalent *trade wedge* that captures the country-pair-specific forces shaping sector-level bilateral expenditure patterns.

12. See Anderson (2011), Costinot and Rodríguez-Clare (2014), and Head and Mayer (2014) for surveys of this literature.

13. The compatibility of structural gravity with key assumptions of the Melitz (2003) model also implies a point of connection with the literature on buyer–seller interactions in cross-border production networks. That literature has been using Melitz-style assumptions in combination with micro data to model cross-border trade and production from the bottom up. See Antràs *et al*. (2017), Bernard and Moxnes (2018), and Bernard *et al*. (2022).

The sector-s bilateral imbalance between n' and n is given by $M_{snn'} - M_{sn'n}$. Summing across all sectors and using (1) yields an expression for the aggregate bilateral trade imbalance between n' and n:

$$M_{nn'} - M_{n'n} = D_n \left(D_{n'} - NX_{n'}\right) \sum_{s=1}^{S} \left(\frac{\tau_{snn'}}{O_{sn} P_{sn'}}\right)^{-\theta_s} \frac{d_{sn} e_{sn'}}{D_s} - D_{n'} \left(D_n - NX_n\right) \sum_{s=1}^{S} \left(\frac{\tau_{sn'n}}{O_{sn'} P_{sn}}\right)^{-\theta_s} \frac{d_{sn'} e_{sn}}{D_s}, \quad (5)$$

where $M_{n'n} \equiv \sum_s M_{sn'n}$; NX_n is the macro (unilateral) trade balance of country n; $d_{sn} \equiv D_{sn}/D_n$; $e_{sn} \equiv E_{sn}/E_n$; and $D_n \equiv \sum_s D_{sn}$ and $E_n \equiv \sum_s E_{sn}$ are country-n aggregate output and spending, respectively. National-accounting definitions imply $D_n = E_n + NX_n$. For the remainder of the article, we normalize D_s to equal world gross output in sector s. This is a purely presentational choice, with no material impact on any of our findings.

Equations (5) and (2) can be used to describe the underlying determinants of net exports by country n to n'—that is, the trade surplus of country n with n'. Everything else constant, this bilateral trade surplus is larger...

1. ...the smaller the aggregate net exports of country n'; and the larger the aggregate net exports of country n.
2. ...the more country n' spends in sectors which account for much country-n output; and the less country n spends in sectors which account for much country-n' output.
3. ...the smaller country-n' importing frictions from country n; and the larger country-n importing frictions from country n'.

Equation (5) generalizes an expression for bilateral trade imbalances first derived in Davis and Weinstein (2002).[14] There the authors abstract from intermediate inputs and from trade barriers or home bias giving rise to trade frictions (setting $\tau_{sn'n} = 1$ for all s, n' and n). Under these assumptions they show that bilateral trade imbalances are the result of macroeconomic imbalances and "triangular trade", corresponding to Points 1 and 2 above. Point 3 highlights a third potential determinant of bilateral imbalances made apparent by our generalization: bilateral asymmetries in trade frictions.

In turn, equation (5) shows that under standard structural-gravity assumptions, macroeconomic imbalances, triangular trade, and asymmetries in trade frictions are the *only* determinants of bilateral trade imbalances. If all macro trade balances were zero ($NX_n = 0$ for all n), if production and spending shares were the same across economies ($d_{sn} = e_{sn} = d_s = e_s$ for all s and n), and if trade frictions were symmetric ($\tau_{sn'n} = \tau_{snn'}$ for all s, n and n'), all trade would be balanced bilaterally.[15]

2.1.2. Bilateral imbalances in levels and proportional imbalances. Equation (5) provides an expression for the value the bilateral trade imbalance between n and n' in some common

14. See Davis and Weinstein (2002), p. 171: equation (5).
15. Note that this follows because $P_{sn} = O_{sn}$ for all s and n in this case.

currency, typically the U.S. dollar. Henceforth, we will refer to it as the *bilateral imbalance in levels*. It can be decomposed as follows:

$$M_{n'n} - M_{nn'} = M_{n'n}^{\frac{1}{2}} M_{nn'}^{\frac{1}{2}} \times \frac{M_{n'n} - M_{nn'}}{M_{n'n}^{\frac{1}{2}} M_{nn'}^{\frac{1}{2}}}. \tag{6}$$

Equation (6) shows that we can think of bilateral trade imbalances in levels as reflecting two components: the geometric average of the value of bilateral trade flows, and the term $(M_{n'nt} - M_{nn't})/(M_{n'nt}^{1/2} M_{nn't}^{1/2})$, which we will describe as the *proportional bilateral imbalance*.

By way of illustration, we decompose the U.S. bilateral trade balances in levels from Figure 1 (as a percentage of U.S. GDP) into the two components on the right-hand side of equation (6): the geometric average of bilateral trade flows with each corresponding trading partner (as a percentage of U.S. GDP) is shown in Figure 2A; and the proportional bilateral imbalance is shown in Figure 2B. The figure highlights why it is insightful to decompose in-levels imbalances in this way.

Variation in the value of geometric-average bilateral trade flows across U.S. trade relationships clearly reflects empirically well-established "gravity" forces such as distance and market size. However, the existence, sign, and ultimate magnitude of the observed in-levels imbalances is determined by the corresponding proportional bilateral imbalances. In turn, these proportional imbalances appear to be uncorrelated with the geometric-average bilateral trade flows, suggesting that they are driven by factors that are largely orthogonal to the drivers of the level of trade flows.[16]

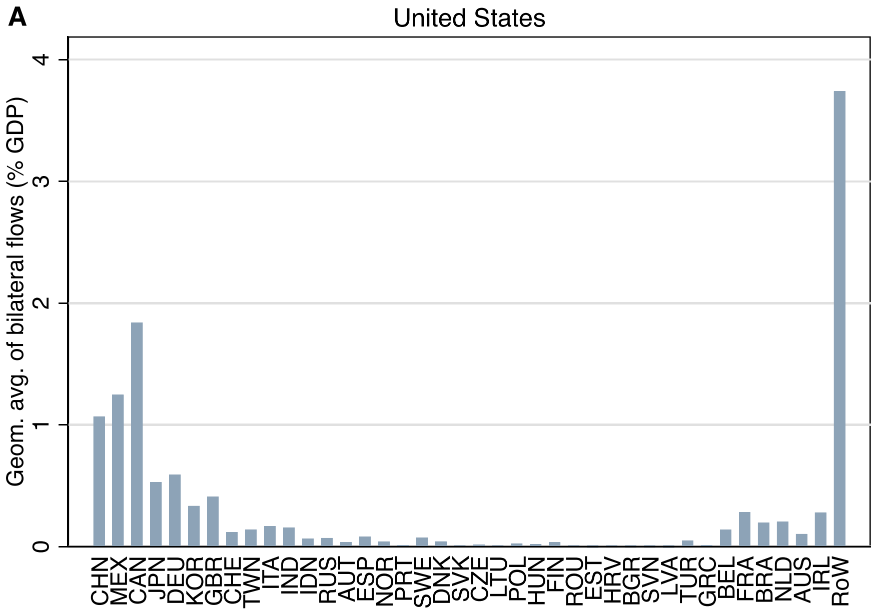
In Appendix A.1, we use equation (1) to show that, to a first-order approximation, proportional bilateral imbalances can be decomposed as follows:

$$\begin{aligned} \frac{M_{n'n} - M_{nn'}}{M_{n'n}^{\frac{1}{2}} M_{nn'}^{\frac{1}{2}}} \simeq \sum_{s=1}^{S} \left(\frac{M_{sn'n} M_{snn'}}{M_{n'n} M_{nn'}} \right)^{\frac{1}{2}} \Bigg[& \ln \left(\frac{1 - NX_n/D_n}{1 - NX_{n'}/D_{n'}} \right) + \ln \left(\frac{d_{sn'} e_{sn}}{d_{sn} e_{sn'}} \right) \\ & - \theta_s \ln \left(\frac{\tau_{sn'n}}{\tau_{snn'}} \right) - \theta_s \ln \left(\frac{O_{sn} P_{sn'}}{O_{sn'} P_{sn}} \right) \Bigg]. \end{aligned} \tag{7}$$

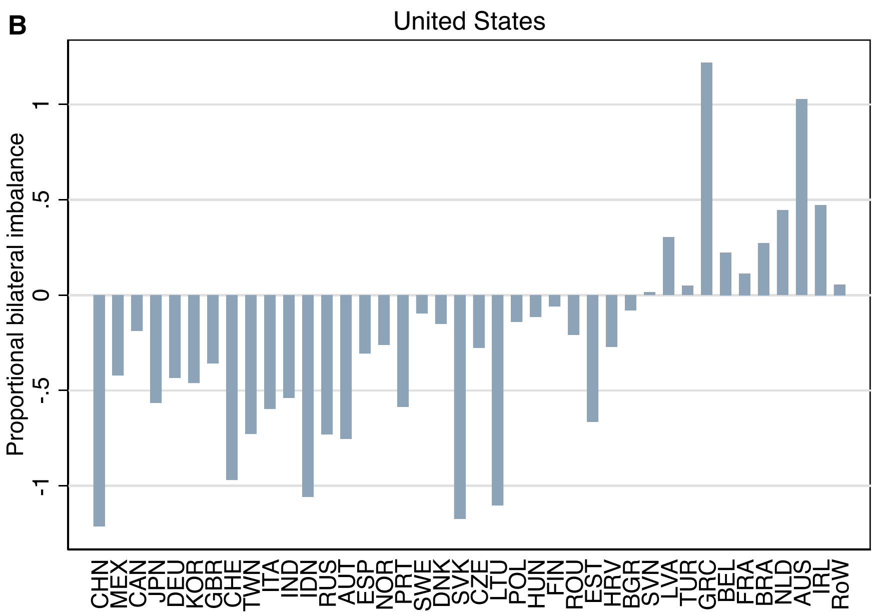
The first of the four right-hand side terms represents differences in economies' macro trade balances; the second represents differences in production and spending patterns giving rise to triangular trade; the third represents bilateral asymmetries in trade frictions. The fourth and final term captures differences in the two economies' ratios of outward and inward MRTs. It follows from the discussion in Section 2.1.1 that the last term would be zero if the first three terms were zero for n and n' vis-à-vis all their trading partners. Therefore, we can loosely think of the final term as arising from the "interaction" of macro trade imbalances, triangular trade and asymmetric frictions encountered by n and n' across their set of trade partners.

Equation (7) shows that proportional bilateral imbalances comprehensively encapsulate the theoretical determinants of bilateral imbalances consistent with standard structural gravity described in Section 2.1.1, as distinct from the much more commonly studied drivers of bilateral trade levels. For this reason, we will focus on the drivers of the variation in proportional bilateral imbalances in most of our analysis below.

16. Across all country pairs in our sample, the correlation between geometric average bilateral trade flows and the absolute value of proportion bilateral imbalances is negative and small in magnitude at −0.22.



Geometric average of bilateral trade flows (as % of GDP) with given trading partner



Proportional bilateral imbalance with given trade partner

FIGURE 2

Proportional imbalances in U.S. bilateral net exports

Notes: The “geometric average of bilateral flows (% GDP)” refers to the geometric average value of U.S. imports of goods and services from the horizontal-axis economy and U.S. exports of goods and services to the horizontal-axis economy, expressed as a percentage of U.S. GDP. The “proportional bilateral imbalance” refers to U.S. net exports to the horizontal-axis economy, expressed as a share of the geometric average of bilateral flows. All data are based on WIOD (2016 release), average for the years 2010–14.

2.1.3. Estimating trade wedges and multilateral resistance terms. Equation (7) provides a framework for assessing the approximate contribution of different drivers of imbalances to the observed variation in proportional bilateral imbalances. However, the right-hand side of equation (7) features some objects that are directly observable and others that are not. We can compute the trade weights, macro trade balances, outputs, and output and spending shares from readily available data. However, the sectoral bilateral trade frictions $\{\tau_{sn'n}\}_{s,n',n}$ and MRTs $\{P_{sn}, O_{sn}\}_{s,n}$ are unobserved.

So as to be able to recover these unobserved objects, we need to impose additional assumptions. A sufficient restriction is:

$$E\left[M_{sn'n}|n',n\right]=\frac{D_{sn'}E_{sn}/D_s}{(O_{sn'}P_{sn})^{-\theta_s}}, \tag{8}$$

i.e. the expected value of sectoral spending by economy n on economy-n' output reflects "country effects" from the economic-mass variables and MRTs.

The restriction in (8) has two significant advantages. First, it treats bilateral trade frictions as a "residual" that only explains the variation in sectoral bilateral expenditures that cannot be explained by country-specific factors. This amounts to minimizing the variance in unobserved bilateral trade frictions required to explain observed bilateral expenditure patterns. In turn, it works against finding an outsized role of asymmetries in such frictions in explaining proportional bilateral imbalances.

The second advantage of a restriction in the form of (8) is that we can leverage the results of Fally (2015) to obtain measures of trade frictions and the MRTs through a straightforward PPML estimation of

$$M_{sn'n}=\exp\{\Omega_{sn'}+\Pi_{sn}\}\,\varepsilon_{sn'n}, \tag{9}$$

where $\Omega_{sn'}$ is an economy-n'-sector-s-exporter fixed effect; Π_{sn} is a economy-n-sector-s-importer fixed effect; and $\varepsilon_{sn'n}$ is an error term.[17] Since the set of importer and exporter fixed effects is not of full rank, the restriction $\Pi_{sN}=0$ must be imposed for a benchmark economy N.

Fally (2015) shows that, if (9) is estimated by PPML, the properties of the estimator ensure that

$$P_{sn}^{-\theta_s}=\frac{E_{sn}}{E_{sN}}\exp\left\{-\hat{\Pi}_{sn}\right\},\qquad O_{sn'}^{-\theta_s}=E_{sN}\frac{D_{sn'}}{D_s}\exp\left\{-\hat{\Omega}_{sn'}\right\}, \tag{10}$$

In turn, this implies

$$\tau_{sn'n}^{-\theta_s}=\hat{\varepsilon}_{sn'n}. \tag{11}$$

Equations (10) and (11) give us all the necessary information to compute bilateral trade frictions and MRTs from available data under the assumption in (8). In the next subsection, we use the approach outlined here to account for the observed variation in proportional bilateral imbalances across a large number of trade-partner pairs.

2.2. *Bilateral balance accounting*

2.2.1. Data. Our analysis in this section, and the rest of the article, relies on data from the World Input Output Database (WIOD 2016 release; Timmer *et al.*, 2015). The utility of

17. Note that a key requirement is that the estimation is performed on a full matrix of bilateral expenditures, including economies' expenditures on their *own* outputs in sector s, $\{M_{snn}\}_{s,n}$.

TABLE 1
Bilateral trade flows and imbalances: 40 economies and Rest of the World

Variables	No. of obs.	Mean	SD	10th pctl.	med.	90th pctl.
$\lvert M_{n'n} - M_{nn'} \rvert$	820	4.2bn	13.9bn	0.0bn	0.6bn	10.3bn
$M_{n'n}^{1/2} M_{nn'}^{1/2}$	820	11.5bn	45.0bn	0.1bn	1.5bn	22.3bn
$\left\lvert \frac{M_{n'n} - M_{nn'}}{M_{n'n}^{1/2} M_{nn'}^{1/2}} \right\rvert$	820	0.645	0.620	0.081	0.463	1.441
$\left\lvert \text{App.}\left(\frac{M_{n'n} - M_{nn'}}{M_{n'n}^{1/2} M_{nn'}^{1/2}} \right) \right\rvert$	820	0.447	0.398	0.048	0.357	0.997

Notes: $M_{n'n}$ represents the total spending by economy n on output from n' (in current U.S.$). "App. $(M_{n'nt} - M_{nn't}/(M_{n'nt}^{1/2} M_{nn't}^{1/2}))$" refers to the linearly approximated proportional bilateral imbalance as described by equation (7). All data are based on WIOD (2016 release), averaged for the years 2010–14. The data cover 40 individual economies and the Rest of the World.

WIOD for the purposes of our study is that it provides a carefully integrated data set covering sector-level production, expenditure, and trade that satisfies the adding-up constraints required by structural gravity models and is consistent with key macro aggregates such as nominal GDP and the trade balance for a large group of major economies.

For all data taken from this source, we calculate a 5-year average of the reported values in our period of interest. We do this so as to average out short-run fluctuations in the values of trade balances, output, and expenditure shares. Our baseline analysis uses data for the five most recent years available, 2010–14.

The 2016 release of WIOD consists of annual global input–output tables covering 43 economies and the "Rest of the World", with spending broken down into 56 sectors at the two-digit level of ISIC (Rev. 4). Out of the 43 economies, three have populations of less than 1 million (Cyprus, Luxembourg, and Malta). We merge these with the "Rest of the World" totals to focus on larger and more diversified economies. We also aggregate sectors to obtain 16 broad manufacturing sectors and 15 service sectors. We do this in order to make the data consistent with available information on sectoral trade elasticities (see Table A3 and Appendix A.6). The resulting global input–output table covers 40 economies and the "rest of the world", with spending broken down into 31 sectors. Tables A1 and A2 in the Appendix give an overview of our aggregation of regions and sectors relative to the original WIOD data.[18]

For each of the 31 sectors, the data provide us with the value of economy-n spending on economy-n' output $\{M_{sn'nt}\}_{s,n',n}$.[19] Taking the difference between sector-level bilateral flows and summing across sectors yields $(41 \times 40/2 =)$ 820 distinct bilateral trade balances. Table 1 presents summary statistics for the absolute dollar value of these imbalances, $|M_{n'nt} - M_{nn't}|$, the dollar value of geometrically averaged bilateral flows, $M_{n'nt}^{1/2} M_{nn't}^{1/2}$, and the corresponding proportional imbalances: $|M_{n'nt} - M_{nn't}|/(M_{n'nt}^{1/2} M_{nn't}^{1/2})$. The median proportional imbalance is equal to 0.46, and there is significant variation: the smallest proportional imbalance is (nearly) 0, while the largest is 5.01.

18. For simplicity, we will refer to the 41 "economies" in our data from now on, instead of the more accurate "40 economies and one region". None of the stylized facts presented throughout the rest of the article are sensitive to dropping the Rest of the World, and reporting statistics for only the 40 genuine economies (or the corresponding 780 trade-partner pairs) instead.

19. For our sample of economies, and our chosen level of sectoral aggregation, zero-valued flows are very uncommon. Out of a total of $(31 \times 41 \times 41 =)$ 52,111 sector-country-pair flows, less than 2% are zero-valued.

TABLE 2
Proportional bilateral imbalances: linear decomposition terms

Panel A: Summary statistics

Term	No. of obs.	Mean	SD	10th pctl.	med.	90th pctl.
Macro NX	820	0.027	0.022	0.004	0.021	0.058
Prod./spend.	820	0.095	0.082	0.012	0.073	0.208
Trade frictions	820	0.396	0.343	0.062	0.302	0.879
MRTs	820	0.000	0.000	0.000	0.000	0.000

Panel B: Pairwise correlations

Covariances (No of obs. = 1,681)	Macro NX	Prod./spend.	Trade frictions	MRTs
Macro NX	0.001			
Prod./spend.	0.002	0.015		
Trade frictions	0.005	0.026	0.268	
MRTs	−0.000	−0.000	−0.000	0.000

Notes: "Macro NX" refers to the first right-hand side term in equation (7). "Prod./spend." refers to the second right-hand side term in equation (7). "Trade frictions" refers to the third right-hand side term in equation (7). "MRTs" refers to the fourth right-hand side term in equation (7). Summary statistics in Panel A are based on the 820 unique absolute values of these terms. Covariances in Panel B are computed for all 1,681 bilateral trade balances. All data are based on WIOD (2016 release), averaged for the years 2010–14. The data cover 40 individual economies and the Rest of the World.

Economy-n spending on sector s is given by $E_{sn} = \sum_{n'} M_{sn'n}$. Economy-$n$ output in sector s is given by $D_{sn} = \sum_{n'} M_{snn'}$. The macro trade balance is $NX_n = \sum_s \sum_{n' \neq n} (M_{snn'} - M_{sn'n})$. As with any input–output table, these numbers can easily be calculated by summing across the relevant columns and rows. Finally, sector-level bilateral trade frictions and MRTs are derived as described in Section 2.1.3. Table 2 provides summary statistics for the four component terms of the approximated proportional imbalances from equation (7) in Panel A and covariances between these terms in Panel B.

2.2.2. Variance decomposition for proportional bilateral imbalances. Figure 3 plots the approximated proportional bilateral imbalances against their data counterparts. As the figure shows, the correlation between the two is high: the R^2 with respect to the 45° line is 0.90, and there are only a handful significant outliers. We can thus meaningfully decompose proportional bilateral imbalances for the large majority of economy pairs using our approximation.

In Figure 4, we plot each of the four terms in (7) against our approximated proportional bilateral imbalances. In each panel, the red line represents the line of best fit. The slope of this line, also shown in red, corresponds to the share of the variation in trade imbalances which can be attributed to each term. By construction, the four slope coefficients add up to 1.[20] As can be seen from the figure, variation in macro trade balances accounts for the smallest share of the variation in bilateral trade imbalances—a mere 2%. Differences in production and spending patterns account for 12% of the variation, and asymmetric trade wedges account for 85%. The ratio of inward to outward MRTs, which reflects the interaction of the three imbalance drivers, displays hardly any variation, and consequently accounts for a negligible share of the variation

20. To see this, note that the slope of a univariate linear regression of x_i on y is $Cov(x_i, y)/Var(y)$; and that for $y \equiv \sum_i x_i$, we can write $Var(y) = \sum_i Cov(x_i, y)$. Note further that $Cov(x_i, y) = Var(x_i) + \sum_{j \neq i} Cov(x_i, x_j)$, so this approach amounts to defining the share of the variance of y explained by x_i as the share explained by the variance of x_i and its covariance with all other determinants of y.

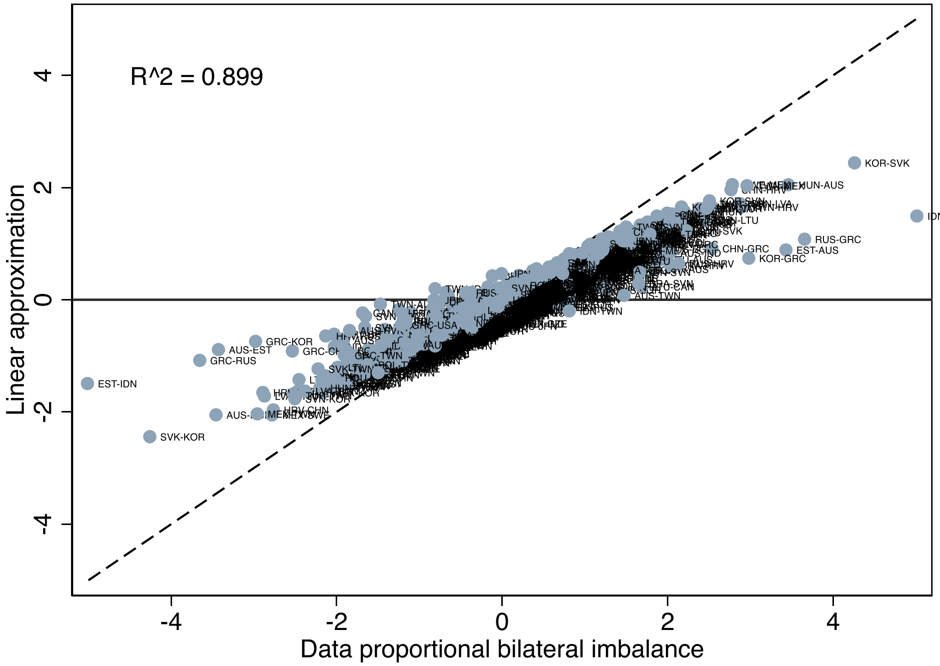


FIGURE 3

Approximated and actual trade imbalances

Notes: "Data proportional bilateral imbalance" refers to $(M_{n'n} - M_{nn'})/(M_{n'n}M_{nn'})^{1/2}$, where $M_{n'n}$ represents the total spending by economy n on output from n'. "Linear approximation" is the first-order linear approximation of this term, described in expression (7). All data are based on WIOD (2016 release), averaged for the years 2010–14. The data cover 40 individual economies and the Rest of the World.

in imbalances. This makes the interpretation of the findings from our variance decomposition very straightforward.[21,22]

There are three main takeaways. First, overall trade surpluses and deficits explain only a vanishingly small portion of the variation in proportional bilateral imbalances across trade-partner pairs. This is striking because macroeconomic imbalances are frequently cited as a key driver of bilateral imbalances in the public discourse. Our results suggest that this emphasis may be misplaced. Second, a significantly greater share of the variation is explained by differences in production and spending patterns ("triangular trade"). Such differences are a natural determinant of trade patterns from the vantage point of trade theory, yet they are rarely acknowledged in popular discussions.

Third and finally, we recover the "mystery" uncovered by Davis and Weinstein (2002) in a different guise: large bilateral asymmetries in trade frictions are required to explain why some

21. By construction, identifying restrictions that differ from (8) only affect the split of the share of the variance attributed to trade-wedge asymmetries and MRTs. Imposing instead that $E[\ln M_{sn'n}|n',n] = \ln[(D_{sn'}/D_s)E_{sn}/(O_{sn'}P_{sn})^{-\theta_s}]$ and estimating (9) in logs using OLS results in 39% of the variance in proportional bilateral imbalances being attributed to asymmetric trade wedges, still making them the largest individual contributor. However, it also assigns 46% of the variance to the MRT ratios. We focus on restriction (8) as it is more compatible with the structural-gravity approach underpinning our analysis.

22. In Appendix A.2, we repeat our variance decomposition with data from the 1995 to 1999 period, the earliest for which WIOD data are available, and obtain virtually the same results.

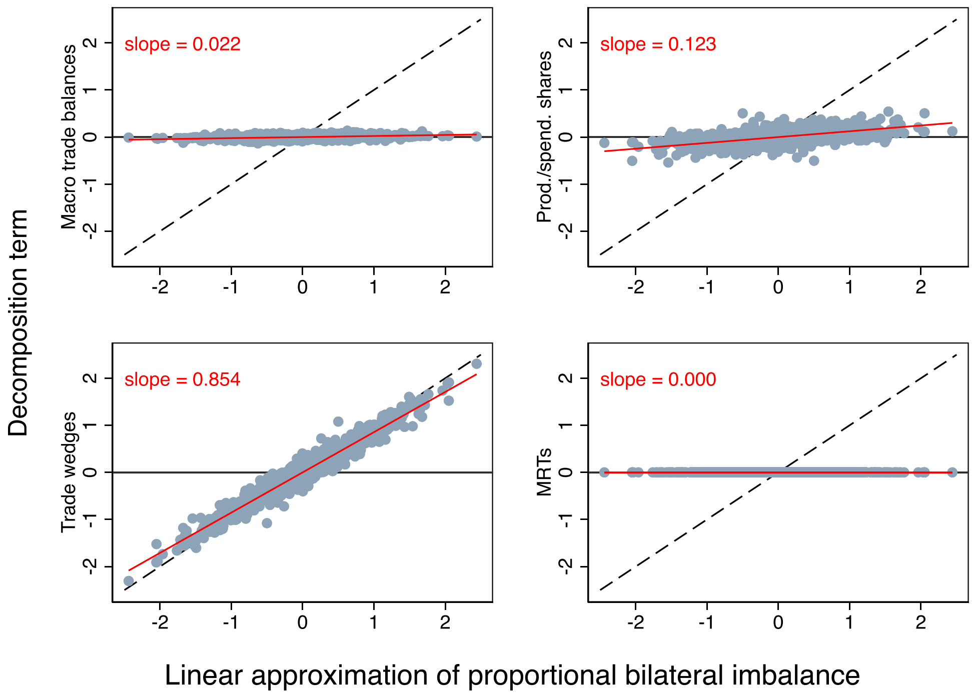


FIGURE 4
Variance decomposition

Notes: In each panel, the horizontal-axis variable is the first-order linear approximation of $(M_{n'n} - M_{nn'})/(M_{n'n}M_{nn'})^{1/2}$ from Equation (7), where $M_{n'n}$ represents the total spending by economy n on output from n'. The vertical-axis variable is one each of the four right-hand-side terms in expression (7). Each panel also shows the line of best fit, whose slope is printed in the top-left corner. All data are based on WIOD (2016 release), averaged for the years 2010–14. The data cover 40 individual economies and the Rest of the World.

country pairs have bigger proportional imbalances than others. Since the restriction in (8) ensures that these frictions are recovered as an economy-pair residual, we can think of the resulting asymmetries in bilateral frictions as reflecting the portion of the variation in proportional imbalances we cannot account for through economy-specific observables, such as aggregate trade balances or production and spending shares. This portion amounts to 85%.[23]

In line with this finding, Appendix A.3 illustrates that the trade-wedge asymmetries implied by our estimation are sizeable. It defines a measure of the "average" import wedge from economy n' to economy n across sectors. For the median pair of economies, the average import wedge in one direction is 0.08 log points (roughly 8%) higher than in the other direction. For 10% of pairs, this gap is larger than 0.20 log points (roughly 22%).[24] The appendix also shows

23. A possible concern is that small-value bilateral trade flows may be more prone to measurement error, and that our measure of *proportional* imbalances gives the imbalances calculated from such flows an outsized weight in the variance decomposition. To address this concern, we repeat the variance decomposition for only the proportional imbalances associated with the top 50% of country pairs by the geometric-average value of their bilateral trade flows. The results we obtain are almost identical: macro trade balances account for 3% of the variation; differences in production and spending patterns account for 12%; and asymmetric trade wedges for 85%.

24. For reference, we can also compute the "average" ratio of external to internal trade wedges across sectors for the median country pair, which yields an ad-valorem tariff-equivalent trade barrier of 156%. By construction, this value is similar to the findings of previous studies that have quantified the implied magnitude of trade barriers using a gravity framework (see Anderson and van Wincoop, 2004).

that five out of the 31 sectors in Table A5 (“Electrical and optical equipment”, “Chemicals and chemical products”, “Basic metals and fabricated metal”, “Transport equipment”, “Machinery, nec”) on their own account for 70% of the cross-pair variation in average trade-wedge asymmetries. However, this is only because they make up a relatively large share of overall bilateral trade flows, not because they are characterized by especially large sectoral trade-wedge asymmetries.

2.2.3. Variance decomposition for bilateral imbalances in levels. We can transform equation (6) to obtain

$$\ln|M_{n'n}-M_{nn'}| = \ln\left(M_{n'n}^{\frac{1}{2}}M_{nn'}^{\frac{1}{2}}\right) + \ln\left|\frac{M_{n'n}-M_{nn'}}{M_{n'n}^{\frac{1}{2}}M_{nn'}^{\frac{1}{2}}}\right|. \tag{12}$$

This allows us to quantify how much of the variation in the absolute value of bilateral imbalances in levels is due to variation in geometric average trade flows, and how much is due to variation in the absolute value of proportional imbalances. Proceeding as in Section 2.2.2, we find that the former accounts for 82% of the variation, and the latter for 18%.

This second-layer decomposition illustrates that a quantitative understanding of the drivers of variation in bilateral trade levels across country pairs goes a long way towards explaining variation in the absolute value of bilateral imbalances *in levels*. Explaining the sources of variation in bilateral trade levels has been the focus of a large empirical gravity literature reaching back to Tinbergen (1962) including, implicitly, earlier papers on bilateral imbalances.[25] However, an assessment of the relative quantitative importance of the distinct sources of the size and sign of bilateral net exports requires a decomposition of *proportional* bilateral imbalances, as in the previous subsection.

3. DYNAMIC QUANTITATIVE TRADE MODEL

3.1. *Model assumptions*

To move beyond accounting, this section assesses whether more bilaterally symmetric trade frictions would indeed lead to significantly smaller imbalances after general-equilibrium effects have played out, and what impact trade-wedge symmetry would have on global welfare. To this end, we introduce a dynamic many-country, many-sector model of international trade.

In the model, final consumption and investment require tradable inputs from many sectors. Economies differ in their reliance on, and productivity in, these sectors. In addition, sectoral inputs are differentiated by their country of origin, as in Armington (1969).[26] This creates a motive for international trade between and within sectors.

25. Davis and Weinstein (2002) model $M_{n'n}$ empirically using a semi-structural gravity equation that assumes no intermediate input trade. Felbermayr and Yotov (2021) show that the inclusion of a full set of theory-consistent fixed effects dramatically improves the ability of empirical gravity models to explain $M_{n'n}$ and, as a result, the variation of bilateral imbalances in levels.

26. This particular microfoundation of a sector-level gravity equation is not crucial for our purposes: we could obtain the same results by microfounding sector-level trade using the assumptions of Eaton and Kortum (2002). Increasing-returns models such as Krugman (1980) and Chaney (2008) would also deliver the same structural gravity equation. However, the presence of market-size effects in the latter class of models makes an analysis of model dynamics more intricate. The extent of the isomorphisms between different gravity-class trade models is discussed in detail in Costinot and Rodríguez-Clare (2014).

Forward-looking agents make consumption and savings decisions, and international asset trade is permitted. However, agents' lifespans are not infinite, as in the Ramsey model but may end each period with a constant probability, as in Blanchard (1985). Agents whose life ends are replaced by a cohort of newly borns. In this setting, differences in economies' rate of time preference give rise to a non-degenerate cross-country distribution of assets and trade balances in steady state, independent of initial conditions.[27] We exploit this property of the model to derive expressions that facilitate the analysis of counterfactual steady states as a generalization of the exact-hat algebra often employed to compute counterfactuals in static trade models.

3.1.1. Preferences and endowments. There are many economies, denoted by $n = 1, \ldots, N$. Time lasts forever, and there is no aggregate uncertainty. Individual agents face a constant probability of death, ξ, each period. There is a unit mass of agents in each economy; each period an exogenous mass ξ of agents is born in n, so that net population growth is zero in all economies.[28] Agents in n discount the future at rate ρ_n and are endowed with H_{nt} units of human capital, which they supply inelastically in domestic labour markets at wage w_{nt}. H_{nt} grows exogenously at gross rate γ for all n: $H_{nt+1} = \gamma H_{nt}$. Agents are born without wealth but can accumulate it through savings. Actuarially fair life insurance is available: agents in n choose to pay their wealth to the life insurance company if they die, and in return have $1 + \xi/(1-\xi) = 1/(1-\xi)$ times their wealth if they live. There is no bequest motive, and negative bequests are prohibited.

Agents' period utility is logarithmic in final consumption each period, and we denote by $C_{nt}(t')$ the final consumption in period t of an agent in economy n who was born in period t'. The optimal-savings problem of an agent born in period t' can be expressed as

$$\max_{\{C_{nt}(t')\}_{t=t'}^{\infty}} \sum_{t=t'}^{\infty} \left(\frac{1-\xi}{1+\rho_n} \right)^{t-t'} \ln C_{nt}\left(t'\right) \tag{13}$$

subject to

$$P_{nt} C_{nt}\left(t'\right) + A_{nt+1}\left(t'\right) = w_{nt} H_{nt} + \frac{R_t}{1-\xi} A_{nt}\left(t'\right), \;\; A_{nt'}\left(t'\right) = 0, \tag{14}$$

where P_{nt} denotes the price of final consumption in economy n and period t; R_t is the return to wealth, which is equal across economies (as we discuss below); and $A_{nt}(t')$ is the wealth that a cohort-t' member has at the beginning of period t, before the uncertainty about their death has been resolved.[29] We describe the solution to this problem in Appendix A.4. Aggregate final consumption in n is a weighted average of the final consumption of all members of country-n cohorts alive in period t:

$$C_{nt} = \sum_{t'=-\infty}^{t} \xi \left(1-\xi\right)^{t-t'} C_{nt}\left(t'\right). \tag{15}$$

27. In a similar spirit, Matsuyama (1987) uses an open-economy version of the Blanchard model in order to analyse the current-account dynamics of a small open economy whose rate of time preference differs from the world interest rate.

28. However, note that we allow for exogenous human capital growth below which could be re-interpreted as reflecting combined population and productivity growth.

29. After this uncertainty is resolved, the wealth of a surviving cohort-t' member in period t is $A_{nt}(t')/(1-\xi)$.

3.1.2. Technologies. In each country n, firms assemble a non-traded aggregate "all-purpose" good by using inputs from many sectors, $s = 1, \ldots, S$:

$$X_{nt} = \prod_{s=1} \left(\frac{X_{snt}}{\sigma_{sn}} \right)^{\sigma_{sn}}, \tag{16}$$

where $\sigma_{sn} \in (0, 1)$; $\sum_s \sigma_{sn} = 1$; X_{nt} is the output of the good; and X_{snt} is the quantity of sector-s inputs used. The sector-s input is also non-tradable, but firms assemble it from tradable, place-specific varieties:

$$X_{snt} = \left(\sum_{n'=1}^{N} \omega_{sn'n}^{\frac{1}{1+\theta_s}} x_{sn'nt}^{\frac{\theta_s}{1+\theta_s}} \right)^{\frac{1+\theta_s}{\theta_s}}, \tag{17}$$

where $\theta_s \geq 0$; $\omega_{sn'n} \geq 0$; and $x_{sn'nt}$ represents the use of the economy-n' variety in the production of the sector-s input by economy n. The economy-n variety in sector s is produced with the Cobb–Douglas technology

$$Q_{snt} = z_{sn} \left(\frac{K_{snt}^{\alpha_n} H_{snt}^{1-\alpha_n}}{1 - \mu_{sn}} \right)^{1-\mu_{sn}} \left(\frac{J_{snt}}{\mu_{sn}} \right)^{\mu_{sn}}, \tag{18}$$

where $\alpha_n, \mu_{sn} \in (0, 1)$. K_{snt} and H_{snt}, respectively represent the capital and efficiency units of labour used; J_{snt} denotes the use of the economy-n final good as intermediate input in s; and shifter z_{sn} describes the economy-sector-specific efficiency of production.

The non-traded aggregate good in n can be used to provide one unit of final consumption, one unit of intermediate input for one of the economy-sector-specific varieties, J_{snt}, or $1/\eta_n > 0$ units of investment, I_{nt}: $X_{nt} = C_{nt} + \eta_n I_{nt} + \sum_s J_{snt}$. Parameter η_n thus captures (inversely) the investment efficiency of economy n. Investment adds to the economy's capital stock according to:

$$K_{nt+1} = I_{nt} + (1 - \delta) K_{nt}, \tag{19}$$

where $\delta \in (0, 1)$; K_{nt} is the capital stock of n in period t.

3.1.3. Market structure. All markets are perfectly competitive. International trade is subject to iceberg transport costs: $\kappa_{sn'n} \geq 1$ units of the economy-n', sector-s variety must be shipped for one unit to arrive in country n. Production factors can move freely between activities within economies but cannot move across borders.

Agents in all economies can trade in a one-period international riskless bond (which is in zero net supply) in a competitive global bond market. One unit of bond holdings at the end of period t pays a nominal return of R_t. The wealth that a cohort-t' member has at the beginning of period t is $A_{nt}(t') \equiv \eta_n P_{nt-1} K_{nt}(t') + B_{nt}(t')$.

3.1.4. Steady state. Throughout the remainder of the article, we will focus exclusively on steady states of the model. For a given set of parameters, the model has a unique steady state in which all aggregate variables – C_{nt}, I_{nt}, K_{nt}, B_{nt}, and Y_{nt}—grow at the constant rate γ. Consequently all prices are constant, as are the ratios $C_{nt}/H_{nt} \equiv c_n$, $I_{nt}/H_{nt} \equiv i_n$, $K_{nt}/H_{nt} \equiv k_n$, $B_{nt}/H_{nt} \equiv b_n$, and $Y_{nt}/H_{nt} \equiv y_n$.

As per the discussion in Section 2.1.1, the assumption that the world economy is in steady state is not necessary for trade flows in a given period to obey a gravity equation of the form given in (1). However, it *is* key when exploring changes in prices, capital stocks, and macro trade balances in response to changes in model parameters. We are content to rely on this assumption in for two reasons. First, it allows us to perform illustrative counterfactuals about the long-run impact of parameter changes that are in the spirit of typical static trade counterfactuals—but do not require us to assume that capital stocks and trade balances are exogenously given. Second, the calibrated steady state of our model turns out to be consistent with two widely acknowledged observations about aggregate trade balances: (1) high-savings economies are more likely to run trade surpluses and (2) overall trade surpluses and deficits are fairly persistent over time.[30]

Steady-state prices are given by

$$P_n^C = P_n^J = \frac{P_n^I}{\eta_n} = \prod_{s=1}^{S} \left[\sum_{n'=1}^{N} \left(\tau_{sn'n} p_{sn'} \right)^{-\theta_s} \right]^{-\frac{\sigma_{sn}}{\theta_s}} \equiv P_n, \tag{20}$$

where P_{nt}^C, P_{nt}^I, and P_{nt}^I respectively denote the final-consumption price, the intermediates price, and the investment price; and

$$p_{sn} = \frac{1}{z_{sn}} f_n^{1-\mu_{sn}} P_n^{\mu_{sn}}, \quad f_n \equiv \left(\frac{r_n}{\alpha_n} \right)^{\alpha_n} \left(\frac{w_n}{1-\alpha_n} \right)^{1-\alpha_n} \tag{21}$$

where f_n is the factor cost in economy n, and $\tau_{sn'n} \equiv \omega_{sn'n}^{-1/\theta_s} \kappa_{sn'n}$. We can thus think of $\tau_{sn'n}$ as the ad-valorem tax equivalent of all factors—trade costs and possible country biases (including home biases) in preferences or technologies—which may impede sectoral trade between pairs of economies. For this reason, we will refer to $\tau_{sn'n}$ as a "trade wedge" from now on.

Equalization of the returns to physical capital and the riskless bond yields

$$R = \frac{\alpha_n}{\eta_n} \frac{f_n}{P_n} k_n^{\alpha_n - 1} + 1 - \delta. \tag{22}$$

The steady-state ratio of aggregate net exports to GDP of n is

$$\frac{NX_{nt}}{f_n k_n^{\alpha_n} H_{nt}} = 1 - \frac{\alpha_n \left(1 - \frac{1-\delta}{\gamma}\right)}{\frac{R}{\gamma} - \frac{1-\delta}{\gamma}} - \frac{\xi \left(\rho_n + \xi\right) \frac{R}{\gamma} \left(1 - \alpha_n\right)}{\left[1 + \rho_n - \frac{R}{\gamma}\left(1 - \xi\right)\right] \left[\frac{R}{\gamma} - \left(1 - \xi\right)\right]}. \tag{23}$$

This ratio depends negatively on the capital share α_n. An economy with a large capital share will have a higher share of investment expenditure and a lower share of next exports in GDP, everything else constant. If $\gamma > R$, it also depends negatively on the discount rate of ρ_n. An economy with a high discount rate will have negative holdings of the international bond; if $\gamma > R$, the value of new international liabilities it incurs each period outstrips the interest payments it must make on past liabilities in steady state. As a result, its steady-state expenditure exceeds its steady-state GDP, causing a trade deficit. Conversely, an economy with a low discount rate will run a trade surplus in steady state.[31]

30. Ravikumar *et al*. (2019) develop a framework for the analysis of the macroeconomic impact of trade-cost changes in a world of financially integrated economies in steady state as well as along the transition path.

31. In our calibration below, $\gamma > R$ turns out to be the relevant case. If $\gamma < R$, the interest payments an impatient country makes in steady-state outstrip its new international liabilities. In this case, the country's steady-state GDP exceeds expenditure, causing a trade surplus. Conversely, a patient country will run a trade deficit in steady state.

Applying Shephard's Lemma in equation (20) yields the value of sector-s imports by n from n':

$$M_{sn'nt} = \frac{(\tau_{sn'n} p_{sn'})^{-\theta_s}}{\sum_{n''=1}^{N} (\tau_{sn''n} p_{sn''})^{-\theta_s}} \sigma_{sn} \left(\sum_{s=1}^{S} p_{sn} Q_{snt} - NX_{nt} \right). \tag{24}$$

Market clearing implies

$$p_{sn} Q_{snt} = \sum_{n'=1}^{N} M_{snn't}; \quad f_n k_n^{\alpha_n} H_{nt} = \sum_{s=1}^{S} (1-\mu_{sn}) p_{sn} Q_{snt}; \quad \sum_{n=1}^{N} NX_{nt} = 0. \tag{25}$$

Equations (25) and (24) respectively ensure that conditions 1 and 2 from Section 2.1.1 are satisfied in any period of the model and, therefore, spending by economy n on economy-n' output in sector s in steady state can be characterized by means of a gravity equation of the form shown in (1):

$$M_{sn'nt} = \left(\frac{\tau_{sn'n}}{O_{sn'} P_{sn}} \right)^{-\theta_s} \frac{D_{sn't} E_{snt}}{D_{st}}, \tag{26}$$

$$P_{sn} \equiv \left[\sum_{n'=1}^{N} \left(\frac{\tau_{sn'n}}{O_{sn'}} \right)^{-\theta_s} \frac{D_{sn't}}{D_{st}} \right]^{-\frac{1}{\theta_s}}, \quad O_{sn'} \equiv \left[\sum_{n=1}^{N} \left(\frac{\tau_{sn'n}}{P_{sn}} \right)^{-\theta_s} \frac{E_{snt}}{D_{st}} \right]^{-\frac{1}{\theta_s}}, \tag{27}$$

where $D_{snt} \equiv p_{sn} Q_{snt}$; $E_{snt} = \sigma_{sn} (\sum_s p_{sn} Q_{snt} - NX_{nt})$; and $D_{st} = \sum_n D_{snt}$.

For given model parameters, there is a unique vector of equilibrium factor costs, $\{f_n\}_n$, up to a normalization, which satisfies pricing conditions (20) and (21) and market-clearing conditions (24) and (25). Finally, we can express the steady-state real GDP per effective worker of n as

$$y_{nt} \equiv \frac{Y_{nt}}{H_{nt}} \equiv \frac{f_n}{P_n} k_n^{\alpha_n} = Z_n k_n^{\alpha_n} \times \prod_{s=1}^{S} \left(\frac{M_{snnt}}{\sum_{n'=1}^{N} M_{sn'nt}} \right)^{-\frac{1}{\theta_s} \frac{\sigma_{sn}}{1-\sum_s \sigma_{sn}\mu_{sn}}}, \tag{28}$$

where $Z_n \equiv \prod_{s=1}^{S} (z_{sn}/\tau_{snn})^{\sigma_{sn}/(1-\sum_s \sigma_{sn}\mu_{sn})}$. Equation (28) shows that steady-state real GDP per effective worker can be written as a function of an aggregate productivity term, the per-effective-worker capital stock, and an aggregator of sectoral "own spending" shares in line with familiar results from gravity-class trade models by Arkolakis *et al.* (2012) and Ossa (2015).

3.2. *Counterfactual parameter changes and calibration*

3.2.1. Exact-hat algebra. In the following, we use the model to explore two types of counterfactual parameter changes by means of exact-hat algebra. The first relates to changes in inter-economy trade wedges, $\{\tau_{sn'n}\}_{s,n' \neq n}$ which can be thought to result from changes in the iceberg trade costs, $\{\kappa_{sn'n}\}_{s,n' \neq n}$. The system of equations needed to analyse this counterfactual is provided in Appendix A.5.2. It has the same basic structure as the exact-hat algebra that can be performed to explore counterfactuals in static gravity-class quantitative trade models (see Costinot and Rodríguez-Clare, 2014). However, this basic structure is complemented by three new equations that reflect the impact of parameter changes via international asset markets and capital accumulation on the steady-state world interest rate and macro trade balances.

The second type of counterfactual we explore relates to changes in an implicit parameter: the barriers to international asset trade. In our model setup, we have assumed that such barriers are negligible. In Appendix A.5.3, we derive exact-hat algebra for the specific case in which

TABLE 3
Calibration overview

Object	Data
ξ	$=0.13$ (life expectancy: 60 years)
δ	$=0.06$
γ	$=1.044$ (PWT: 1985–2014)
R	$=1.030$ (King and Low, 2014: 1985–2014)
$\{\rho_n\}_n$	Match $\{NX_{nt}/f_n k_n^{\alpha_n} H_{nt}\}_n$ (WIOD)
$\{\alpha_n\}_n$	Match 1$-$ country-n labour share (PWT)
$\{\eta_n\}_n$	Match $\{k_n\}_n$ (PWT)
$\{\sigma_{sn}\}_{s,n}$	Match country-n, sector-s spending share (WIOD)
$\{\mu_{sn}\}_{s,n}$	Match country-n, sector-s input share (WIOD)
$\{\theta_s\}_s$	Match trade elasticities (Caliendo and Parro, 2015; Costinot and Rodríguez-Clare, 2014): Table A2
$\{\tau_{sn'n}\}_{s,n',n}$	Match $\{\hat{\varepsilon}_{sn'n}\}_{s,n',n}$ from PPML estimation: Section 2.1.3
$\{z_{sn}/z_{sN}\}_{s,n}$	Match $\{\hat{\Omega}_{sn}-\hat{\Omega}_{sN}\}_{s,n}$ from PPML estimation: Section 2.1.3
$\{Z_n\}_n$	Match $\{y_n\}_n$ (PWT)

Notes: For parameter definitions, see Section 3.1. The data sources and calibration strategy are described in detail in Sections 2.2.1 and 3.2.2, and Appendix A.6.

these barriers go from negligible to prohibitive for *all* economies ("financial autarky"). One consequence of this change is that all macro trade balances are zero in the new steady state, which allows us to explore the consequences of balanced trade at the economy level for pairwise trade imbalances.[32]

3.2.2. Calibration. Appendix A.6 details how the model above can be calibrated consistently with the assumptions underlying our variance decomposition in Section 2 to interpret all variables of interest in the global economy as endogenous steady-state outcomes. Table 3 gives an overview of the calibration strategy. However, using the exact-hat algebra in Appendices A.5.2 and A.5.3 to perform counterfactuals does not require this full calibration. It only relies on countries' trade shares, sectoral spending shares, and world GDP contributions (all of which are taken from WIOD as in Section 2.2.1), and a more limited set of parameters to be specified. Critically, we impose that the trade-wedge asymmetry for any n, n', and s can be identified from $\tau_{sn'n}/\tau_{snn'}=(\hat{\varepsilon}_{sn'n}/\hat{\varepsilon}_{snn'})^{-\theta_s}$, where $\{\hat{\varepsilon}_{sn'n}\}_{s,n,n}$ is derived from the same PPML estimation as discussed in Section 2.1.3.

3.3. *Global trade-wedge symmetry*

3.3.1. Assumptions. Our variance decomposition in Section 2.2.2 suggested that most of the cross-pair variation in proportional bilateral imbalances must be attributed to pairwise asymmetric trade frictions. We now use our fully fledged quantitative model to re-visit this finding. Specifically, we adjust model trade wedges from a calibration that is consistent with our variance decomposition by reducing the higher of any two pairwise wedges to equal the lower, and

32. The exact-hat algebra introduced in Appendix A.5 extends results from Dekle *et al.* (2007, 2008). Their papers explore trade counterfactuals in the presence of unbalanced trade by treating macro trade balances as exogenous parameters in an otherwise static model. The model we have derived above makes it possible to perform counterfactuals in which macro trade balances are steady-state outcomes that change endogenously in response to changes in underlying structural parameters.

we investigate (1) the effect on proportional bilateral imbalances and (2) the broader impacts on macroeconomic outcomes and international integration.

Starting from the model calibration described in Section 3.2.2 we impose new inter-economy trade wedges, $\{\tilde{\tau}_{sn'n}\}_{s,n'\neq n}$, such that

$$\hat{\tau}_{sn'n} = \min\left\{1, \frac{\tau_{snn'}}{\tau_{sn'n}}\right\} \quad \text{for all } s, n' \neq n, \tag{29}$$

where $\hat{\tau}_{sn'n} \equiv \tilde{\tau}_{sn'n}/\tau_{sn'n}$. That is, for any sector s and pair n' and n, we set the higher of the two bilateral trade wedges to equal the lower wedge. This counterfactual scenario of complete global bilateral trade-wedge symmetry is admittedly extreme, but it illustrates the extent to which bilateral asymmetries in frictions may shape outcomes in the global economy.[33] In Section 4.4, we explore counterfactual changes in bilateral trade barriers that trade policy could more realistically effect.

3.3.2. Impact on trade patterns. Figure 5 plots the remaining proportional bilateral imbalances in the counterfactual new steady state of the world economy against the original (actual) proportional imbalances. In the counterfactual steady state, there is a lot less variation in bilateral imbalances: the slope of the line of best fit between the new and the original imbalances is only 0.24. In line with the discussion in Section 2.2.2, it suggests that asymmetric trade wedges account for by far the greatest share of variation in proportional bilateral imbalances. Yet, Figure 5 also shows that, once non-linearities and general-equilibrium effects are taken into account, the remaining variation in proportional imbalances in a world of trade-wedge symmetry is somewhat larger than what the simple variance decomposition in Section 2.2.2 would suggest.

As can be seen in Column 5 of Table 4 below, the move towards trade-wedge symmetry has almost no impact on macro trade balances. This is because the new set of trade barriers leaves the world interest rate almost unchanged, and without significant changes in the world interest rate there are no changes in macro trade balances via equation (23).

3.3.3. Impact on macro outcomes and the global economy. The move to bilaterally symmetric trade wedges, by lowering the higher of the two bilateral wedges, has very sizeable effects on real incomes. For the median economy in Column 1 of Table 4 per-worker real GDP increases by 8.5%. This effect arises from two channels. First, lower trade barriers raise the purchasing power of domestic income. This enters Equation (28) via smaller shares of spending on domestically produced output, as described in Arkolakis *et al.* (2012) and Ossa (2015). Second, the presence of international capital mobility in our dynamic model amplifies this effect through Equation (22): lower trade barriers raise an economy's marginal product of capital and, for a given world interest rate, this results in a higher steady-state per-worker capital stock. Columns

33. Alternatively, we could impose proportional changes in inter-economy trade wedges, $\{\hat{\tau}_{sn'n}\}_{s,n'\neq n}$, such that

$$\hat{\tau}_{sn'n} = \left(\frac{\tau_{snn'}}{\tau_{sn'n}}\right)^{\frac{1}{2}} \quad \text{for all } s, n' \neq n,$$

i.e. for any sector s and pair n' and n, we set bilateral trade wedges to equal their geometric average. The main results presented below are also obtained in this alternative counterfactual. In particular, (1) most proportional bilateral imbalances vanish; (2) macro trade balances remain almost unchanged; and (3) per-worker real income and consumption changes primarily reflects the changes in import wedges that economies experience. However, in this scenario, import wedges rise for some countries (causing real income and consumption losses), while they fall for others (bringing real-income and consumption gains).

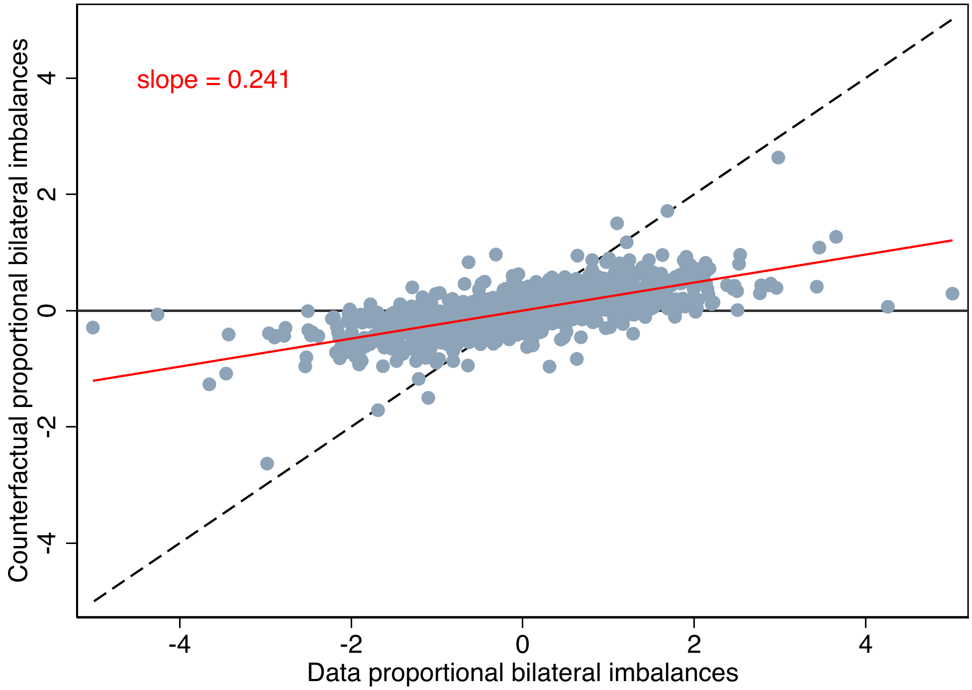


FIGURE 5
Proportional bilateral imbalances under global trade-wedge symmetry

Notes: "Data proportional bilateral imbalance" refers to $(M_{n'nt} - M_{nn't})/(M_{n'nt}M_{nn't})^{1/2}$, where $M_{n'nt}$ represents the total spending by economy n on output from n'. "Counterfactual imbalances" refers to the corresponding term in the counterfactual steady state in which all bilateral trade wedges are made symmetric, as described in Section 3.3. The figure also shows the line of best fit, whose slope is printed in the top-left corner. All data are based on WIOD (2016 release), average for the years 2010–14. The data cover 40 economies and the Rest of the World.

2 and 3 of Table 4 report the changes in these two components of real GPD from equation (28). Unsurprisingly, they are highly correlated: economies whose reliance on domestic output declines more also experience a greater increase in their capital stocks.[34]

In principle, an economy could increase its reliance on foreign output either as a result of lower trade barriers or due to general-equilibrium changes in relative prices. Column 4 of Table 4 shows the weighted average decline in import trade wedges for each economy. The correlation with changes in economies' own-spending terms in Column 2 is 0.91. Therefore, to a first order, we can think of the magnitude of economies' gains from our counterfactual exercise as deriving from the decline in import trade wedges they experience. In turn, this reflects the extent to which their imports were exposed to higher bilateral wedges than their exports. Our counterfactual leaves the world interest rate, and with it macro trade balances, virtually unchanged. Consequently, the changes in real GDP are accompanied by almost one-for-one changes in real aggregate consumption—a more meaningful measure of aggregate welfare.

In sum, our counterfactual confirms not only that trade-wedge asymmetries could explain most of the variation in economies' bilateral imbalances but also that the existence of such

34. In Appendix A.7, we show that global trade-wedge symmetry would deliver the same reduction in the variation of bilateral imbalances in a static trade model, but with smaller real-GDP effects due to the absence of endogenous capital accumulation and allocation.

TABLE 4
Macroeconomic impacts of global trade-wedge symmetry

Country	(1) $\hat{y}_n$ %	(2) $\hat{\upsilon}_{nn}$ %	(3) $\hat{k}_n$ %	(4) $\hat{\tau}_n$ %	(5) $\tilde{nx}_n - nx_n$ ppt.	(6) $\hat{c}_n$ %
AUS	2.4	−1.2	2.7	−0.1	0.0	2.1
AUT	12.6	−6.6	12.9	−1.6	0.0	12.3
BEL	10.2	−5.8	10.5	−1.3	0.0	9.8
BGR	11.1	−5.1	11.5	−0.9	−0.1	11.1
BRA	2.4	−1.2	2.7	−0.2	−0.1	2.3
CAN	4.0	−2.2	4.3	−0.4	0.0	3.8
CHE	7.0	−4.2	7.3	−0.7	0.1	6.5
CHN	6.0	−3.1	6.3	−0.2	0.0	5.7
CZE	30.1	−12.6	30.4	−2.5	0.0	29.4
DEU	12.6	−7.0	13.0	−1.3	0.1	12.2
DNK	6.9	−4.1	7.2	−0.8	0.1	6.5
ESP	6.7	−3.7	7.1	−0.9	−0.1	6.6
EST	15.6	−8.1	16.0	−1.7	0.0	15.4
FIN	6.8	−3.8	7.1	−0.6	0.0	6.6
FRA	6.0	−3.5	6.3	−0.6	−0.1	5.9
GBR	6.5	−3.7	6.8	−0.7	−0.1	6.4
GRC	3.5	−1.6	3.8	−0.2	−0.2	3.6
HRV	8.4	−5.1	8.7	−0.9	−0.1	8.3
HUN	19.6	−10.1	20.0	−2.3	0.0	19.2
IDN	4.1	−1.6	4.4	−0.3	−0.1	3.7
IND	4.7	−2.1	5.0	−0.3	−0.1	4.5
IRL	19.0	−8.0	19.4	−1.9	0.0	17.8
ITA	6.3	−3.1	6.7	−0.6	0.0	6.1
JPN	7.8	−4.3	8.1	−0.5	−0.1	7.6
KOR	21.2	−9.2	21.6	−0.7	0.0	20.6
LTU	14.8	−6.2	15.2	−0.9	0.0	14.4
LVA	9.2	−4.8	9.5	−0.9	−0.1	9.1
MEX	16.1	−5.5	16.4	−1.2	−0.1	15.6
NLD	9.7	−5.2	10.0	−1.2	0.1	9.1
NOR	5.2	−2.5	5.5	−0.4	0.1	4.5
POL	11.7	−6.0	12.1	−1.5	0.0	11.5
PRT	8.1	−4.4	8.4	−0.7	−0.1	8.1
ROU	14.9	−6.1	15.2	−1.1	−0.1	14.7
RUS	2.3	−1.5	2.6	−0.3	−0.2	4.6
RoW	4.5	−2.2	4.8	−0.3	−0.2	4.6
SVK	44.3	−18.0	44.7	−2.5	0.0	43.8
SVN	19.6	−11.2	19.9	−2.1	0.0	19.4
SWE	10.9	−5.5	11.2	−1.0	0.0	10.4
TUR	11.8	−4.6	12.1	−0.8	−0.1	11.4
TWN	12.8	−5.5	13.2	−0.9	0.0	12.0
U.S.	2.4	−1.3	2.7	−0.2	−0.1	2.3

Notes: For each steady-state outcome x, define $\tilde{x}$ as the new outcome after the counterfactual parameter change, and $\hat{x} \equiv \tilde{x}/x$. y_n is real GDP per effective worker; k_n is real capital stock per effective worker; $nx_n \equiv NX_n/(f_n k_n^{\alpha_n} H_{nt})$; c_n is real aggregate consumption per effective worker; all as formally defined in Section 3.1. $\upsilon_{nn} \equiv \prod_s (M_{snnt}/\sum_{n'} M_{sn'nt})^{\sigma_{sn}/\theta_s/(1-\sum_s \sigma_{sn}\mu_{sn})}$; and $\hat{\tau}_n \equiv \sum_s \sum_{n'} M_{sn'n}\hat{\tau}_{sn'n}/\sum_s \sum_{n'} M_{sn'n}$.

asymmetries might have substantive implications for macro outcomes.[35] This makes the case for subjecting the nature and origins of bilateral trade-wedge asymmetries to further study. In Section 4, we explore some ways in which they might be shaped by the trade-policy environment.

3.4. *Financial autarky*

3.4.1. Assumptions. Before we turn to a more detailed analysis of bilateral trade-wedge asymmetries, we briefly explore another counterfactual that speaks to the drivers of the observed variation in (proportional) bilateral imbalances. Starting from the baseline steady state of the model in which agents can freely trade a riskless bond in international financial markets, we let the barriers to international asset trade become prohibitive so that economies exist in financial autarky in the new steady state. All macro trade balances are zero in the new steady state, which allows us to investigate the impact on bilateral trade imbalances of the disappearance of macroeconomic imbalances.

3.4.2. Impact on trade patterns. Figure 6 plots the remaining proportional bilateral imbalances in the counterfactual financial-autarky steady state against the actual proportional imbalances. The slope of the line of best fit between the new and the original imbalances is .84: there is somewhat less variation in proportional imbalances, but the bulk remains. The reduction in the variation in proportional imbalances in a world of counterfactual financial autarky is moderately larger than the variance decomposition in Section 2.2.2 suggests.

In addition to the effect of counterfactual financial autarky on trade patterns, it has a major impact on economies' real incomes, capital stocks, and real aggregate consumption levels. For completeness, these impacts are described in Appendix A.8.

4. TRADE-COST ASYMMETRIES IN A SM

4.1. *Role of the trade policy environment*

At least some trade-wedge asymmetries likely arise from the (asymmetric) impact on trade barriers of deep structural factors such as geography, technologies, and preferences. In the remainder of this section, we instead assemble some evidence on the extent to which the *trade-policy environment* might realistically impact bilateral trade-cost asymmetries and, through them, bilateral imbalances. The aim is to provide a more realistic benchmark for policy counterfactuals than the elimination of *all* trade-wedge asymmetries we analysed for illustrative purposes in Section 3.3.

One straightforward way in which trade policy could give rise to pliable trade-cost asymmetries is through pairwise asymmetries in bilateral import tariffs. However, the sample of economies in our data is heavily biased towards economies with low or zero tariffs. Out of 40 individual sample economies, 24 were E.U. members in the 2010–14 period.[36] Therefore, out of the 820 trade-partner pairs in our data, about a third are not subject to tariffs at all.

35. Even in a more limited global symmetry counterfactual, in which we apply (29) only to the five sectors we identified in Section 2.2.2 as contributing 70% of the variation in average bilateral asymmetries, about half of the variation in proportional bilateral imbalances disappears. This is equivalent to roughly two thirds of the effect of full global trade-wedge symmetry. The distribution of macroeconomic impacts across economies is qualitatively similar to our baseline global symmetry counterfactual, but the magnitude of impacts is commensurately smaller.

36. Note that Croatia only joined the E.U. in 2013, and that we group Cyprus, Luxembourg, and Malta with the "rest of the world" as discussed in Section 2.2.1.

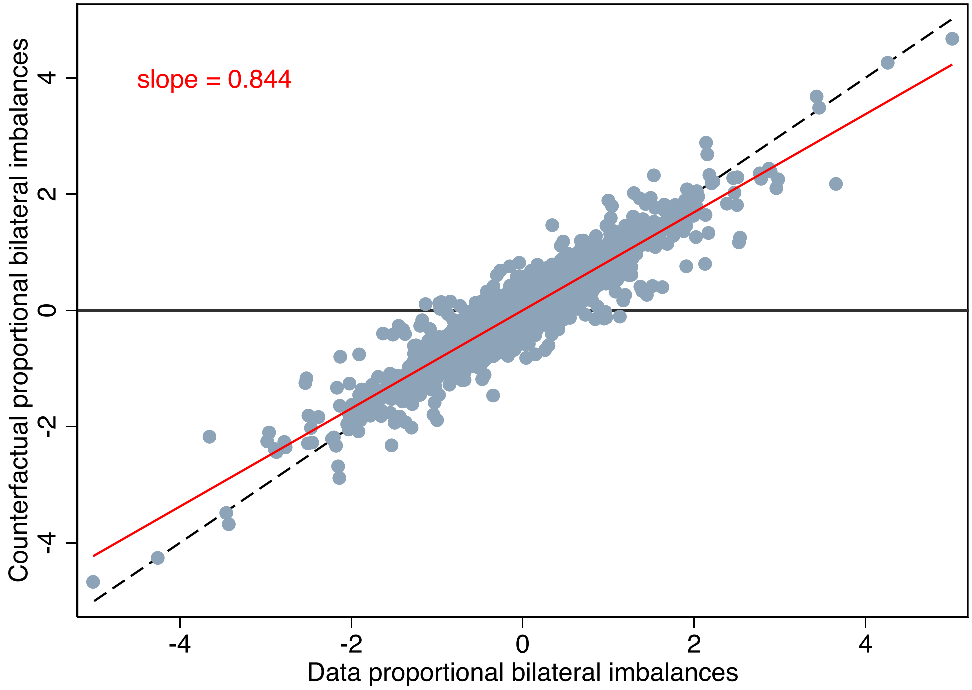


FIGURE 6
Proportional bilateral imbalances under financial autarky

Notes: "Data proportional bilateral imbalance" refers to $(M_{n'nt} - M_{nn't})/(M_{n'nt}M_{nn't})^{1/2}$, where $M_{n'nt}$ represents the total spending by economy n on output from n'. "Counterfactual imbalances" refers to the corresponding term in the counterfactual steady state in which economies exist in financial autarky, as described in Section 3.4. The figure also shows the line of best fit, whose slope is printed in the top-left corner. All data are based on WIOD (2016 release), average for the years 2010–14. The data cover 40 economies and the Rest of the World.

Based on WDI data (2021 edition), the E.U.'s weighted average external tariff rate was 1.7% in the 2010–14 period, and the weighted average tariff rate for the median non-E.U. economy in our sample was 2.6%. This means that pairwise asymmetries in tariffs can at best account for a small fraction of the magnitude of trade-wedge asymmetries implied by our calculations above.

We thus take a broader view and ask to what extent membership in a SM that eliminates both tariffs *and* non-tariff barriers to trade appears to reduce trade-cost asymmetries. Focusing on this question has two advantages. First, it allows us to exploit the over-representation of E.U. member countries in our baseline data for the 2010–14 period, as well as the fact that 11 countries that are both in our 1995–999 and 2010–14 datasets joined the European SM between these two periods. Second, it casts a spotlight on the experience of an economic union created with express purpose of eliminating trade barriers so as to level the playing field between suppliers from different member countries within its boundaries.[37]

37. For example, Zuleeg (2020) notes that "the E.U.'s SM has been built around the concept of a level playing field, going further than the rules which exist to govern global interactions. There is an extensive body of law that ensures that European companies face the same conditions no matter which member state's markets they enter, with EU institutions executing supranational implementation, arbitration, and enforcement."

4.2. *Cross-sectional evidence on the SM effect*

4.2.1. An alternative measure of trade-wedge asymmetries. As a first step, we turn to a useful measure of sectoral symmetries in bilateral trade barriers, first employed by Caliendo and Parro (2015). This measure has the benefit of imposing very little structure on trade wedges. In particular, it does not rely on our restriction (8) and only requires that sectoral trade flows are governed by structural gravity as described by equations (1) and (2). Suppose we can generically write

$$\ln \tau_{sn'n} = \ln \tau^{E}_{sn'} + \ln \tau^{I}_{sn} + \ln \bar{\tau}_{sn'n} + \ln \vec{\tau}_{sn'n}. \tag{30}$$

$\tau^{E}_{sn'}$ captures trade-wedge determinants in sector s that are specific to n' as exporter; τ^{I}_{sn} captures determinants that are specific to n as importer; $\bar{\tau}_{sn'n}$ represents the pairwise symmetric component of trade costs ($\bar{\tau}_{sn'n} = \bar{\tau}_{snn'}$ for all s, n' and n); and $\vec{\tau}_{sn'n}$ is the component that is pairwise asymmetric ($\vec{\tau}_{sn'n} \neq \vec{\tau}_{snn'}$ for all s, n', and n). Then Caliendo and Parro (2015) show that, given (1) and (2),

$$\left| \ln \frac{M_{sn''n'} M_{sn'n} M_{snn''}}{M_{sn''n} M_{snn'} M_{sn'n''}} \right| = \left| -\theta_s \ln \left(\frac{\vec{\tau}_{sn''n'} \vec{\tau}_{sn'n} \vec{\tau}_{snn''}}{\vec{\tau}_{sn''n} \vec{\tau}_{snn'} \vec{\tau}_{sn'n''}} \right) \right| \tag{31}$$

for any s, n'', n', and n.

Equation (31) provides a measure of the extent of *pairwise* asymmetries in trade wedges by location triplets (n,n',n''). The further away from zero the measure, the larger the extent of pairwise asymmetries.[38] Panel A of Table 5 describes the distribution of this measure across the 10,660 unique triplets of economies that can be formed based on our 2010–14 data, for each of the 15 goods-producing sectors.[39] The distribution of the asymmetry measure is captured by the 10th percentile, median, and 90th percentile value for each sector.

4.2.2. EU membership and trade-wedge asymmetries. Panel B of Table 5 now divides the triplets of economies for which we compute the measure in (31) into three groups. The first group contains only triplets involving at most one E.U. member country, so *none* of the 6 bilateral trade flows constitute intra-E.U. flows. The second group is made up of triplets with *exactly two* E.U. countries, so two out of six bilateral trade flows are intra-E.U. The third group is made up of triplets comprising *exactly three* E.U. countries.

As the summary statistics for the different bins show, relative to the group with at most one E.U. country per triplet, the distribution of the Caliendo-Parro asymmetry measure is shifted towards zero in the group with exactly two E.U. countries per triplet. This is true for all sectors. It is shifted further towards zero still in the group with exactly three E.U. countries per triplet, again with remarkable consistency across all sectors. Note that, by virtue of the properties of

38. Allen and Arkolakis (2016) define trade wedges of the form

$$\tau_{sn'n} = \tau^{E}_{sn'} \tau^{I}_{sn} \bar{\tau}_{sn'n}$$

as "quasi-symmetric". Note that quasi-symmetric wedges would still give rise to bilateral asymmetries of the form

$$\ln \tau_{sn'n} - \ln \tau_{snn'} = \left(\ln \tau^{E}_{sn'} - \ln \tau^{E}_{sn} + \ln \tau^{I}_{sn} - \ln \tau^{I}_{sn'} \right).$$

However, such asymmetries, which derive purely from *country*—not *pair* − effects cancel in the triple ratio of trade flows in (31).

39. Appendix A.3 shows that these 15 good-producing sectors make up 90% of the overall variation in bilateral trade-wedge asymmetries. Note that three of them ("Mining and quarrying", "Wood and products of wood and cork", and "Coke, refined petroleum, and nuclear fuel") have fewer than 10,660 trade-flow triplets as a result of zero-valued trade flows.

TABLE 5

Caliendo and Parro (2015) measure of sectoral trade-wedge asymmetries

Panel A: Trade-cost asymmetries in the full sample

$|\ln[(M_{sn''n'}M_{sn'n}M_{snn''})/(M_{sn''n}M_{snn'}M_{sn'n''})]|$

Sector code	Sector name	Obs.	$p(10)$	$p(50)$	$p(90)$
1	Agriculture, hunting, forestry, and fishing	10,660	0.275	**1.491**	4.130
2	Mining and quarrying	10,583	0.383	**2.017**	5.365
3	Food, beverages, and tobacco	10,660	0.188	**1.018**	2.869
4	Textiles and textile products;...	10,660	0.173	**0.993**	2.594
5	Wood and products of wood and cork	10,621	0.222	**1.196**	3.207
6	Pulp, paper; paper, printing, and publishing	10,660	0.215	**1.212**	3.605
7	Coke, refined petroleum, and nuclear fuel	10,224	0.362	**1.946**	5.655
8	Chemicals and chemical products	10,660	0.174	**0.973**	2.696
9	Rubber and plastics	10,660	0.147	**0.845**	2.380
10	Other non-metallic, mineral products	10,660	0.188	**1.027**	2.734
11	Basic metals and fabricated metal	10,660	0.179	**1.064**	3.105
12	Electrical and optical equipment	10,660	0.143	**0.813**	2.283
13	Machinery, nec	10,660	0.162	**0.905**	2.456
14	Transport equipment	10,660	0.208	**1.155**	3.137
15	Manufacturing, nec; recycling	10,660	0.169	**0.952**	2.654

Panel B: Trade-cost asymmetries by E.U. membership status

$|\ln[(M_{sn''n'}M_{sn'n}M_{snn''})/(M_{sn''n}M_{snn'}M_{sn'n''})]|$

	<2 E.U. members				2 E.U. members				3 E.U. members			
Sector code	Obs.	$p(10)$	$p(50)$	$p(90)$	Obs.	$p(10)$	$p(50)$	$p(90)$	Obs.	$p(10)$	$p(50)$	$p(90)$
1	3,944	0.321	**1.723**	4.708	4,692	0.302	**1.517**	4.049	2,024	0.190	**1.081**	0.2966
2	3,912	0.438	**2.224**	5.873	4,647	0.368	**2.018**	5.286	2,024	0.334	**1.701**	4.680
3	3,944	0.227	**1.241**	3.321	4,692	0.199	**1.068**	2.873	2,024	0.123	**0.641**	1.735
4	3,944	0.195	**1.190**	3.064	4,692	0.167	**0.959**	2.371	2,024	0.144	**0.797**	2.064
5	3,928	0.260	**1.402**	3.665	4,669	0.212	**1.184**	3.150	2,024	0.176	**0.905**	2.322
6	3,944	0.295	**1.584**	4.154	4,692	0.216	**1.186**	3.561	2,024	0.154	**0.793**	2.319
7	3,754	0.427	**2.327**	6.585	4,468	0.370	**1.954**	5.512	2,002	0.261	**1.496**	4.021
8	3,944	0.212	**1.171**	3.030	4,692	0.188	**1.003**	2.676	2,024	0.110	**0.636**	1.857
9	3,944	0.194	**1.041**	2.718	4,692	0.150	**0.867**	2.368	2,024	0.095	**0.565**	1.602
10	3,944	0.218	**1.162**	2.881	4,692	0.203	**1.050**	2.790	2,024	0.134	**0.770**	2.158
11	3,944	0.244	**1.350**	3.748	4,692	0.192	**1.103**	2.982	2,024	0.112	**0.624**	1.919
12	3,944	0.171	**0.978**	1.753	4,692	0.147	**0.821**	2.204	2,024	0.101	**0.581**	1.625
13	3,944	0.197	**1.064**	2.680	4,692	0.171	**0.929**	2.526	2,024	0.111	**0.648**	1.723
14	3,944	0.252	**1.366**	3.487	4,692	0.220	**1.182**	3.167	2,024	0.143	**0.822**	2.181
15	3,944	0.221	**1.226**	3.129	4,692	0.165	**0.922**	2.484	2,024	0.114	**0.647**	1.769

Notes: $M_{sn'nt}$ represents spending by economy n on sector-s output from n' during period t. "Obs." refers to the number of observations; "$p(10)$", "$p(50)$" and "$p(90)$" refer to the values at the 10th, 50th and 90th percentiles, respectively. Median (50th percentile) values are highlighted in bold. All data are based on WIOD (2016 release), averaged for the years 2010–14. The data cover 40 individual economies and the Rest of the World.

the Caliendo-Parro measure of asymmetries, differences in economies' attributes or symmetric elements of geography between these groups are effectively "controlled for" in Table 5. Therefore, the table offers simple yet compelling evidence that trade wedges in intra-E.U. trade are characterized by greater pairwise symmetry.

4.3. *Longitudinal evidence on the single-market effect*

4.3.1. Impact of E.U. accessions on trade-wedge asymmetry. Given the findings in the previous section, we now ask whether trade-wedge asymmetries appear to *decline* when countries join the E.U. SM. To answer the question, we use the fact that 10 countries that are both in our 1995–99 and 2010–14 datasets (Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Slovakia, Slovenia, Bulgaria, and Romania) became E.U. members between these two periods. We run a regression of the form

$$\triangle\left(\ln\tau_{sn'n}-\ln\tau_{snn'}\right)=\Psi_s+\psi_s\triangle EU_{n'n}+\upsilon_{n'n}, \tag{32}$$

where $(\ln\tau_{sn'n}-\ln\tau_{snn'})$ is the change in measured trade-wedge asymmetries between 1995–99 and 2010–14 computed as,

$$\begin{aligned}&\triangle\left(\ln\tau_{sn'n}-\ln\tau_{snn'}\right)\\&=\left[\ln\left(\frac{\hat{\varepsilon}_{sn'n10-14}}{\hat{\varepsilon}_{snn'10-14}}\right)^{-\frac{1}{\theta_s}}-\ln\left(\frac{\hat{\varepsilon}_{sn'n95-99}}{\hat{\varepsilon}_{snn'95-99}}\right)^{-\frac{1}{\theta_s}}\middle|\left(\frac{\hat{\varepsilon}_{sn'n95-99}}{\hat{\varepsilon}_{snn'95-99}}\right)^{-\frac{1}{\theta_s}}>1\right];\end{aligned} \tag{33}$$

$\hat{\varepsilon}_{sn'nt}$ is derived from the PPML estimation in Section 2.1.3 performed for period $t\in\{1995-19;\,2010-14\}$; θ_s is our calibrated sector-s trade elasticity; $\triangle EU_{n'n}$ is a dummy variable taking value 1 if n' and n are both E.U. members in period 2010–14 but at least one of them was not in 1995–99; and $\upsilon_{n'n}$ is the error term.[40] We are testing if $\psi_s<0$, *i.e.* if joining the E.U. between the two periods was associated with a decline in new members' trade-wedge asymmetries vis-à-vis other members in sector s.

4.3.2. Estimation results. Our estimates of ψ_s for each of the 15 goods-producing sectors, along with standard errors and the regression fit are shown in Table 6. As can be seen there, we find a statistically significant negative association across all goods sectors. In a handful of these sectors, the "SM effect" on its own accounts for more than 10% of the over-time change in trade-wedge asymmetries.

The above suggests that intra-E.U. trade is not only characterized by smaller bilateral trade-wedge asymmetries, but that countries that join the E.U. see their trade-wedge asymmetries with other E.U. members decline. To the best of our knowledge, this effect of E.U. Single Market membership has not been documented before. It is separate from, and additional to, the well documented reduction in the average level (rather than pairwise asymmetries) of bilateral trade barriers from E.U. membership.[41]

4.4. *Extending the SM effect*

4.4.1. Assumptions. We now assess whether the trade-wedge-levelling effect of E.U. membership is economically meaningful, by exploring a counterfactual that extends it to all non-E.U.

40. We exclude the "Rest of the World" from these regressions because its definition differs between the two datasets. See Appendix A.3 for a description of the properties of the 1995–99 data. After excluding the "Rest of the World", we have 40 individual economies in our 2010–14 data, but only 38 of these are also in our 1995–99 data. This leaves ($38\times37/2=$) 666 unique pairs on which to perform the regression in (32). In line with (33) we define unique pairs such that their 1995–99 trade-wedge gap is positive, and we can thus assess by means of (32) if E.U. membership shrinks this gap.

41. See Mayer *et al*. (2019) for a discussion of the literature on the trade-promoting effects of E.U. membership as well as updated estimates.

TABLE 6
Estimated impact of E.U. accession on sectoral trade-wedge asymmetries

Sector code	Sector name	$\hat{\psi}_s$	R^2	Obs.
1	Agriculture, hunting, forestry, and fishing	−0.108*** (0.012)	0.06	664
2	Mining and quarrying	−0.100*** (0.012)	0.08	604
3	Food, beverages, and tobacco	−0.351*** (0.040)	0.08	663
4	Textiles and textile products;...	−0.097*** (0.017)	0.04	664
5	Wood and products of wood and cork	−0.039*** (0.009)	0.02	661
6	Pulp, paper; paper, printing, and publishing	−0.091*** (0.011)	0.06	664
7	Coke, refined petroleum, and nuclear fuel	−0.025*** (0.003)	0.05	619
8	Chemicals and chemical products	−0.154*** (0.018)	0.08	666
9	Rubber and plastics	−0.642*** (0.055)	0.13	664
10	Other non-metallic, mineral products	−0.320*** (0.038)	0.10	665
11	Basic metals and fabricated metal	−0.096*** (0.009)	0.07	666
12	Electrical and optical equipment	−0.505*** (0.042)	0.09	664
13	Machinery, nec	−0.113*** (0.008)	0.19	628
14	Transport equipment	−3.749*** (0.307)	0.11	664
15	Manufacturing, nec; recycling	−0.175*** (0.020)	0.08	664

Notes: Estimates from the regression described in Section 4.3.1 for 15 goods-producing sectors. All data are based on WIOD (2013 and 2016 releases), taking 5-year averages to compare the 1995–99 and 2010–14 periods. The data used for the regressions cover 38 individual economies, including 11 countries (Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Slovakia, Slovenia, Bulgaria, and Romania) that joined the E.U. between 1995–99 and 2010–14.

sample economies. Starting from the model and calibration described in Sections 3.1 and 3.2, we impose proportional changes in inter-economy trade wedges for the period 2010–14, $\{\hat{\tau}_{sn'n}\}_{s,n'\neq n}$, such that

$$\hat{\tau}_{sn'n} = \begin{cases} \exp\left\{\hat{\psi}_s\right\} & \text{if } \tau_{sn'n} > \tau_{snn'} \\ 1 & \text{otherwise,} \end{cases} \tag{34}$$

for any goods-producing sector s, and any pair in which at least one of n' and n is *not* an E.U. member. That is, for all non-E.U. economies, we keep the lower of each bilateral goods trade wedge unchanged, and change the higher wedge in line with our estimate of the SM symmetry effect estimated in Section 4.3. All intra-E.U. and all service-sector trade wedges remain as they are.

This counterfactual only captures the trade-wedge-levelling effect of E.U. membership documented above, *not* the reduction in average bilateral trade barriers E.U. accession has been shown to bring about. It is also more limited than the global trade-wedge symmetry experiment from Section 3.3. Only extra-E.U. goods trade wedges are affected, and these only move towards symmetry in line with our estimates from Table 6, instead of becoming fully symmetric.

4.4.2. Impact on trade patterns and macro outcomes. Once again, Figure 7 plots the resulting counterfactual proportional bilateral imbalances against actual 2010–14 imbalances. As can be seen from the figure, the variation in proportional bilateral imbalances declines noticeably, equivalent to roughly one-third of the effect of full global trade-wedge symmetry. Given the more limited scope of the SM effect, and that it is imposed for the bilateral trade flows of the 17 non-E.U. economies in our data, this demonstrates that a SM-like trade policy environment could have substantive effects on bilateral imbalances.

Figure 8 gives a graphical overview of the impact of this counterfactual experiment on economies' real per-capita GDP and consumption levels. While these effects are smaller than under full global trade-wedge symmetry, they are still sizeable: the median economy experiences

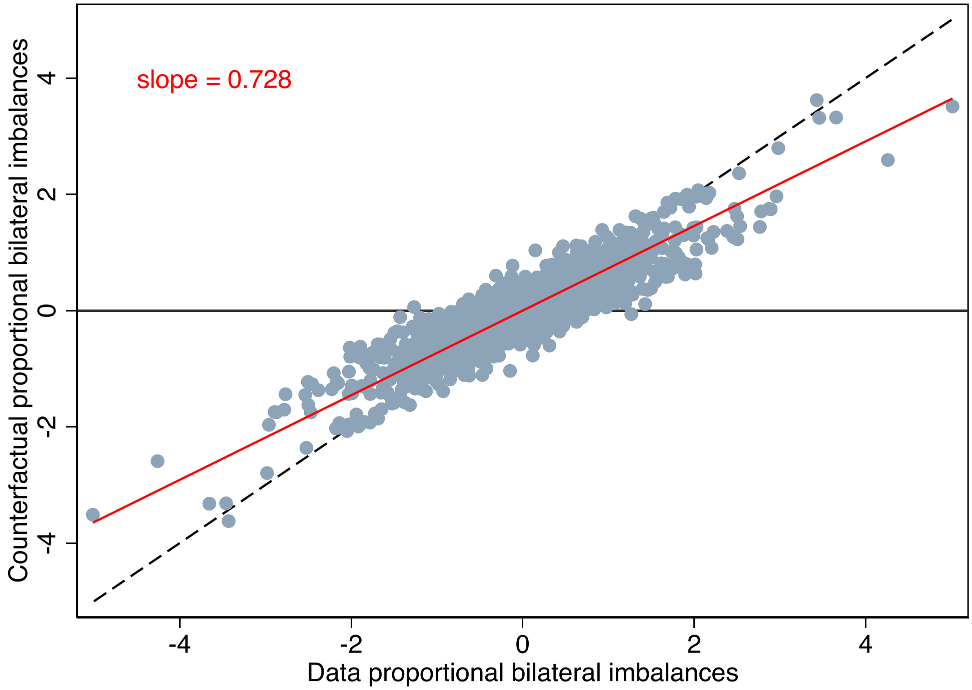


FIGURE 7
Proportional imbalances with E.U. trade-wedge symmetry in non-EU economies

Notes: "Data proportional bilateral imbalance" refers to $(M_{n'nt}-M_{nn't})/(M_{n'nt}M_{nn't})^{1/2}$, where $M_{n'nt}$ represents the total spending by economy n on output from n'. "Counterfactual imbalances" refers to the corresponding term in the counterfactual steady state in which non-E.U. economies' trade-wedge asymmetry declines in line with the estimated EU accession effect, as described in Section 4.4.1. The figure also shows the line of best fit, whose slope is printed in the top-left corner. All data are based on WIOD (2016 release), average for the years 2010–14. The data cover 40 economies and the Rest of the World.

a real GDP increase of more than 5%. One noteworthy aspect of these results is that the three biggest winners from in this counterfactual scenario are Mexico (38%), South Korea (20%), and Turkey (19%). Each of these countries currently enjoys a close trade relationship with major markets in its respective region short of a SM environment. As a result of the real-GDP gains in these middle-to-high-income countries, the top end of the international income distribution in our data narrows, even though the overall extent of international income differences remains broadly unchanged.

5. CONCLUSION

Under the common assumption that sectoral trade flows between economies obey a structural gravity equation, explaining the observed variation in bilateral trade balances requires large bilateral trade-wedge asymmetries—*i.e.* barriers between trade partners that are higher in one direction than the other. The structural-gravity assumption is compatible with many different trade models and sufficient to obtain this finding by means of a simple variance decomposition. However, the finding is confirmed in the general-equilibrium counterfactuals of a fully fledged dynamic quantitative trade model. These counterfactuals also show that eliminating trade-wedge asymmetries would have sizeable effects on welfare and the global economy.

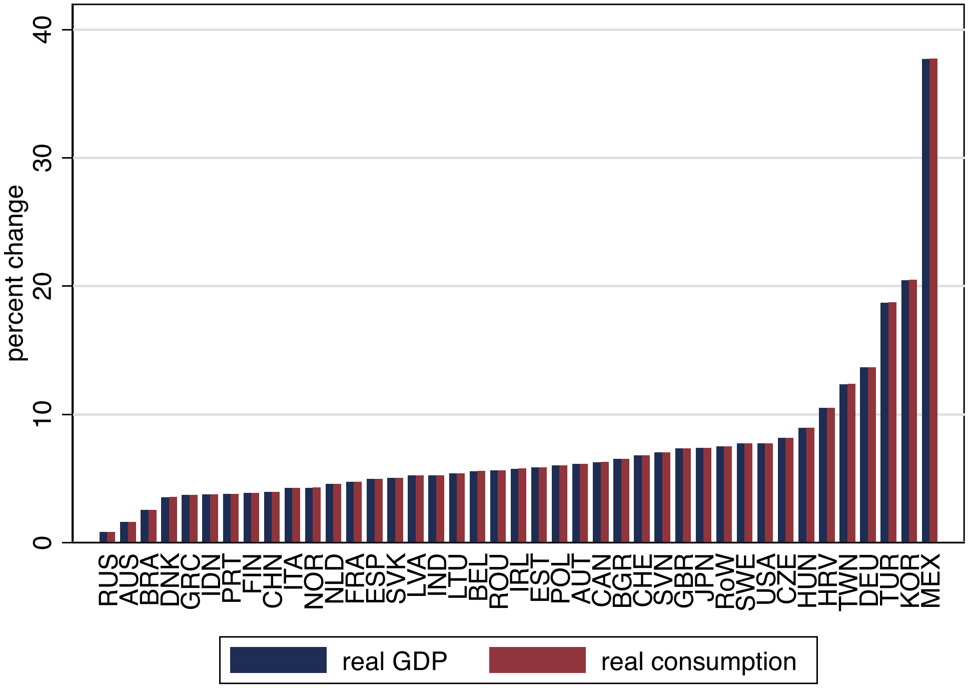


FIGURE 8

Macroeconomic impacts of E.U. trade-wedge symmetry in non-E.U. economies

Notes: Percent change in real per-capita GDP and consumption relative to data in a counterfactual steady in which non-E.U. economies' trade-wedge asymmetry declines in line with the estimated E.U. accession effect, as described in Section 4.4.1. Calibrations are based on data from PWT (edition 9.0) and WIOD (2016 release), average for the years 2010–14.

Measured trade-wedge asymmetries could reflect a host of factors. They may capture data errors or shortcomings of the standard structural gravity framework. They may also result from impacts of geography, technologies, and preferences on trade flows that are not yet well understood. While a full account of the origins of these measured asymmetries is beyond the scope of this paper, we have provided evidence that they are in part related to the trade policy environment. In particular, we have documented that member countries of the European SM appear to enjoy more bilaterally symmetric (in addition to lower) trade barriers. This might suggest that deep cross-border integration can facilitate a reduction in bilateral imbalances.

APPENDIX

A.1. *Approximating bilateral trade imbalances*

We can write the proportional bilateral imbalance between n and n' as:

$$\frac{M_{n'n} - M_{nn'}}{M_{n'n}^{\frac{1}{2}} M_{nn'}^{\frac{1}{2}}} = \sum_{s=1}^{S} \frac{M_{sn'n} - M_{snn'}}{M_{sn'n}^{\frac{1}{2}} M_{snn'}^{\frac{1}{2}}} \left(\frac{M_{sn'n} M_{snn'}}{M_{n'n} M_{nn'}} \right)^{\frac{1}{2}}. \tag{35}$$

Note from (1) that

$$\frac{M_{sn'n}}{M_{sn'n}^{\frac{1}{2}}M_{snn'}^{\frac{1}{2}}}=e^{\frac{1}{2}\left[\ln\left(\frac{1-NX_n/D_n}{1-NX_{n'}/D_{n'}}\right)+\ln\left(\frac{d_{sn'}e_{sn}}{d_{sn}e_{sn'}}\right)-\theta_s\ln\left(\frac{\tau_{sn'n}}{\tau_{snn'}}\right)-\theta_s\ln\left(\frac{O_{sn}P_{sn'}}{O_{sn'}P_{sn}}\right)\right]}. \tag{36}$$

The first-order Taylor-series expansion of (36) centred at $\ln(1-NX_n/D_n)=0$ for all n, $\ln d_{sn}=\ln e_{sn}=\ln(D_s/D)$ for all s and n, and $\ln\tau_{sn'n}^{-\theta_s}=\ln\tau_{snn'}^{-\theta_s}=\ln\bar{\tau}_{sn'n}^{-\theta_s}$ for all s, n' and n yields[42]

$$\frac{M_{sn'n}}{M_{sn'n}^{\frac{1}{2}}M_{snn'}^{\frac{1}{2}}}\simeq\frac{1}{2}\left[\ln\left(\frac{1-NX_n/D_n}{1-NX_{n'}/D_{n'}}\right)+\ln\left(\frac{d_{sn'}e_{sn}}{d_{sn}e_{sn'}}\right)\right.$$
$$\left.-\theta_s\ln\left(\frac{\tau_{sn'n}}{\tau_{snn'}}\right)-\theta_s\ln\left(\frac{O_{sn}P_{sn'}}{O_{sn'}P_{sn}}\right)\right]. \tag{37}$$

and, hence,

$$\frac{M_{n'n}-M_{nn'}}{M_{n'n}^{\frac{1}{2}}M_{nn'}^{\frac{1}{2}}}\simeq\sum_{s=1}^{S}\left(\frac{M_{sn'n}M_{snn'}}{M_{n'n}M_{nn'}}\right)^{\frac{1}{2}}\left[\ln\left(\frac{1-NX_n/D_n}{1-NX_{n'}/D_{n'}}\right)+\ln\left(\frac{d_{sn'}e_{sn}}{d_{sn}e_{sn'}}\right)\right.$$
$$\left.-\theta_s\ln\left(\frac{\tau_{sn'n}}{\tau_{snn'}}\right)-\theta_s\ln\left(\frac{O_{sn}P_{sn'}}{O_{sn'}P_{sn}}\right)\right]. \tag{38}$$

A.2. *Variance decomposition for 1995–99*

A.2.1. Data. To compile the data for 1995–99 decomposition of the variation in bilateral imbalances, we proceed as described in Sections 2.1 and 2.2—with one exception: we use the 2013 release of WIOD (whose data tables start in 1995), instead of the 2016 release (whose data tables start in 2000). The data allow us to aggregate trade and spending values to the same 31 sectors as described in Section 2.2 (and shown in Table A2). However, in the 2013 release Croatia, Norway, and Switzerland are not covered as individual economies but grouped with the "Rest of the World". For this reason, the 1995–99 data only cover 37 individual economies and the Rest of the World, which yields ($38\times 37/2=$) 703 distinct bilateral trade imbalances.

Figure A1 correlates the bilateral imbalances available in both periods with one another, using only the 703 surpluses for 1995–99. The figure indicates that there is a fairly high degree of persistence: the correlation of the 1995–99 surplus with the 2010–14 value of the same trade balance is .036. Moreover, more than two thirds of the bilateral balances which were in surplus in 1995–99 were still in surplus in 2010–14.

A.2.2. Variance decomposition. Figure A2 is the analogue for the 1995–99 period of Figure 4 in the main text. The quantitative results of the variance decomposition are remarkably similar.

Variation in economies' aggregate trade balances accounts for 3% of the variation in bilateral trade imbalances. Differences in production and spending patterns ("triangular trade") account for 9% of the variation, and asymmetric trade wedges account for the remaining 88%.

42. Note from our definitions that $d_{sn}=\frac{D_s}{D}\quad\Leftrightarrow\quad\frac{D_{sn}}{D_s}=\frac{D_n}{D},\quad e_{sn}=\frac{D_s}{D}\quad\Leftrightarrow\quad\frac{E_{sn}}{D_s}+e_{sn}\frac{NX_n}{D_n}\frac{D_n}{D_s}=\frac{D_n}{D}$.

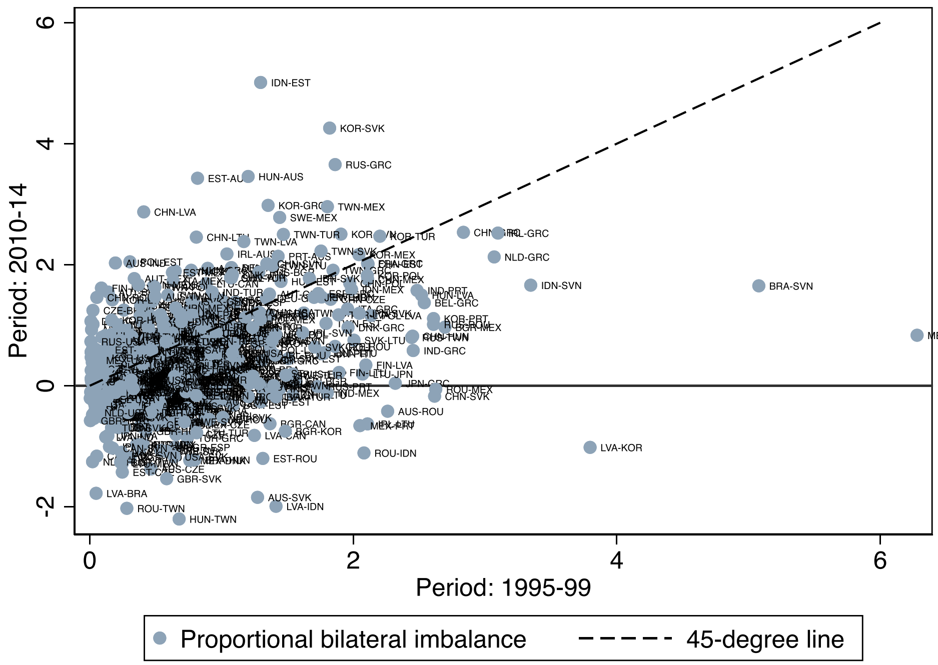


FIGURE A1
Proportional bilateral imbalances, 2010–14 versus 1995–99

Note: "Proportional bilateral imbalance" refers to $(M_{n'nt} - M_{nn't})/(M_{nnt}M_{n'n't})^{1/2}$, where $M_{n'nt}$ represents the total spending by economy n on goods and services from n' in period t. On the horizontal axis, all values are the average for the 2010–14 period. On the vertical axis, all values are the average for the 1995–99 period. The 2010–14 data are based on WIOD (2016 release), the 1995–99 data on WIOD (2013 release). The chart covers 37 individual economies.

A.3. *Properties of aggregate and sectoral asymmetries*

A.3.1. Aggregate trade-wedge asymmetries. Define the log difference between "average" trade wedge from economy n' to n and "average" wedge from economy n to n' as

$$\ln\left(\frac{\tau_{n'n}}{\tau_{nn'}}\right) \equiv \sum_{s=1}^{S}\left(\frac{M_{sn'nt}M_{snn't}}{M_{n'nt}M_{nn't}}\right)^{\frac{1}{2}}\frac{\theta_s}{\theta}\ln\left(\frac{\tau_{sn'n}}{\tau_{snn'}}\right)$$
$$= \frac{1}{\theta}\sum_{s=1}^{S}\left(\frac{M_{sn'nt}M_{snn't}}{M_{n'nt}M_{nn't}}\right)^{\frac{1}{2}}\ln\left(\frac{\hat{\varepsilon}_{snn'}}{\hat{\varepsilon}_{sn'n}}\right), \quad (39)$$

where θ is the aggregate trade elasticity; and $\{\hat{\varepsilon}_{sn'n}\}_{s,n',n}$ are the residuals from the estimation described in Section 2.1.3. The larger is $\ln(\tau_{n'n}/\tau_{nn'})$, the more difficult it is to sell goods and services from n' in n relative to selling goods and services from n in n'.

Equation (39) is a natural measure of aggregate trade-wedge asymmetries in the context of our analysis because—up to the value of θ—it corresponds to the contribution of these asymmetries in our approximate decomposition of bilateral imbalances in (7). We choose $\theta = 4$ in this section, in keeping with Simonovska and Waugh's (2014) estimate of the aggregate trade elasticity, and because it is close to the median of our sectoral trade elasticities in Table A3. Given

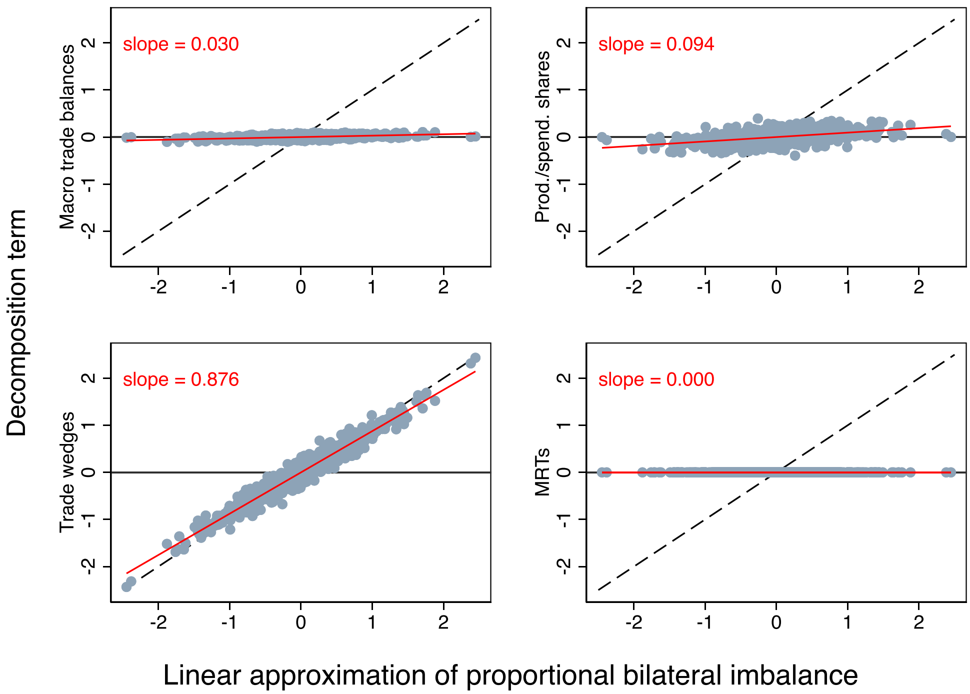


FIGURE A2
Variance decomposition for 1995–99

Notes: In each panel, the horizontal-axis variable is the first-order linear approximation of $(M_{n'n} - M_{nn'})/(M_{n'n}M_{nn'})^{1/2}$ from equation (7), represents the total spending by economy n on output from n'. The vertical-axis variable is one each of the four right-hand side terms in expression (7). Each panel also shows the line of best fit, whose slope is printed in the top-left corner. All data are based on WIOD (2013 release), averaged for the years 1995–99. The data cover 37 individual economies and the Rest of the World.

this parameter choice, Table A4 reports summary statistics for the 820 distinct absolute values of $|\ln(\tau_{n'n}/\tau_{nn'})|$ from our data for the 2010–14 period.[43]

The table highlights the size of trade-wedge asymmetries required for a structural-gravity framework to fit sectoral trade flows perfectly. For the median economy pair, the average import wedge in one direction is 0.08 log points (roughly 8%) higher than in the other direction. For 10% of economy pairs, this gap is larger than 0.20 log points (roughly 22%).

A.3.2. Sectoral trade-wedge asymmetries. In Table A5, we dig deeper to assess the role of different sectors in the aggregate trade-wedge asymmetries described above. The table reports a measure of the contribution of each of the 31 sectors in our baseline 2010–14 data to the cross-pair variation in aggregate trade-wedge asymmetries as defined in equation (39).

The top 5 of the 31 sectors in Table A5 ("Electrical and optical equipment", "Chemicals and chemical products", "Basic metals and fabricated metal", "Transport equipment", "Machinery, nec") on their own account for 70% of the aggregate variation. The 15 goods-producing sectors together account for 90%. For each sector, the table also lists the median weight of each sector in economy pairs' bilateral trade flows, $M_{sn'n}^{1/2}M_{snn'}^{1/2}/M_{n'n}^{1/2}M_{nn'}^{1/2}$, and the magnitude of the sector's

43. Note that we only need to choose a value of the parameter θ for expositional reasons, so as to be able to interpret the numbers in Table A4 in terms of ad-valorem trade costs.

median estimated bilateral asymmetry, $|\ln(\hat{\varepsilon}_{sn'n}/\hat{\varepsilon}_{snn'})|$. These numbers suggest that the sectors that contribute most of the variation in aggregate trade-wedge asymmetries do so because they make up a relatively large share of bilateral trade flows, not because they are characterized by especially large sectoral trade-wedge asymmetries.

By way of a cross-check, for the 15 goods-producing sectors the median sectoral trade-wedge asymmetry reported in Table A5 is highly correlated with the median Caliendo-Parro measure of asymmetries in Panel A of Table 5, with a correlation coefficient of 0.86. Both these measures thus appear to capture largely the same "residual" pairwise asymmetries in sectoral trade flows.

A.4. *Dynamic model*

A.4.1. Agents' optimality. The utility maximization problem of an agent born in t' can be written as

$$\max_{\{C_{nt}(t')\}_{t=t'}^{\infty}} \sum_{t=t'}^{\infty} \left(\frac{1-\xi}{1+\rho_n}\right)^{t-t'} \ln C_{nt}\left(t'\right) \tag{40}$$

subject to

$$P_{nt}^{C} C_{nt}\left(t'\right) + P_{nt}^{I} I_{nt}\left(t'\right) + B_{nt+1}\left(t'\right) = w_{nt} H_{nt} + \frac{r_{nt}}{1-\xi} K_{nt}\left(t'\right) + \frac{R_t}{1-\xi} B_{nt}\left(t'\right), \tag{41}$$

$$K_{nt+1}\left(t'\right) = I_{nt}\left(t'\right) + (1-\delta) K_{nt}\left(t'\right), \tag{42}$$

$$K_{nt'}\left(t'\right) = B_{nt'}\left(t'\right) = 0, \tag{43}$$

where $I_{nt}(t')$ is the agent's investment in t; $B_{nt}(t')$ denotes bond holdings; $K_{nt}(t')$ denotes capital holdings; P_{nt}^{C} is the final-consumption price level; P_{nt}^{I} is the investment price level; w_{nt} is the wage rate; and r_{nt} is the rental rate of capital in n. The resulting Euler equation is

$$\frac{C_{nt+1}\left(t'\right)}{C_{nt}\left(t'\right)} = \frac{P_{nt}^{C}}{P_{nt+1}^{C}} \frac{R_{t+1}}{1+\rho_n}, \tag{44}$$

and the optimal portfolio requires

$$\frac{r_{nt+1} + P_{nt+1}^{I}(1-\delta)}{P_{nt}^{I}} = R_{t+1}. \tag{45}$$

A.4.2. Steady-state optimal savings. We can analytically characterize the steady-state consumption and savings decisions of an agent born in period t' as a function of their period-t asset and human wealth:

$$P_n C_{nt}\left(t'\right) = \frac{\rho_n + \xi}{(1-\xi)(1+\rho_n)} R A_{nt}\left(t'\right) + \frac{R(\rho_n+\xi)}{\left[R - \gamma(1-\xi)\right](1+\rho_n)} w_n H_{nt}, \tag{46}$$

$$A_{nt+1}\left(t'\right) = \frac{1}{1+\rho_n} R A_{nt}\left(t'\right) + \frac{\left[R - \gamma(1+\rho_n)\right](1-\xi)}{\left[R-\gamma(1-\xi)\right](1+\rho_n)} w_n H_{nt}. \tag{47}$$

Define $A_{nt} \equiv (1-\xi)^{-1} \sum_{t'=-\infty}^{t} \xi(1-\xi)^{t-t'} A_{nt}(t')$. Then,

$$a_{nt+1} = \frac{1-\xi}{\gamma}\left[\frac{R}{1+\rho_n} a_{nt} + \frac{R - \gamma(1+\rho_n)}{\left[R-\gamma(1-\xi)\right](1+\rho_n)} w_n\right], \tag{48}$$

where $a_{nt} \equiv A_{nt}/H_{nt}$. There is a stationary distribution of assets in steady state as long as $\frac{1-\xi}{1+\rho_n}\frac{R}{\gamma} < 1$. Under this condition,

$$A_{nt} = \frac{(1-\xi)\left[R-\gamma\,(1+\rho_n)\right](1-\alpha_n)}{\left[\gamma\,(1+\rho_n)-R\,(1-\xi)\right]\left[R-\gamma\,(1-\xi)\right]} f_n K_{nt}^{\alpha_n} H_{nt}^{1-\alpha_n}, \tag{49}$$

$$P_n C_{nt} = \frac{\gamma\,\xi\,(\rho_n+\xi)\,R\,(1-\alpha_n)}{\left[\gamma\,(1+\rho_n)-R\,(1-\xi)\right]\left[R-\gamma\,(1-\xi)\right]} f_n K_{nt}^{\alpha_n} H_{nt}^{1-\alpha_n}. \tag{50}$$

A.4.3. Steady-state net exports. In steady state,

$$K_{nt} = \frac{\alpha_n}{\eta_n P_n\,(R-1+\delta)} f_n K_{nt}^{\alpha_n} H_{nt}^{1-\alpha_n}. \tag{51}$$

This in turn implies

$$\eta_n P_n I_{nt} = \frac{\alpha_n\,(\gamma-1+\delta)}{R-1+\delta} f_n K_{nt}^{\alpha_n} H_{nt}^{1-\alpha_n}. \tag{52}$$

From the definition of GDP,

$$f_n K_{nt}^{\alpha_n} H_{nt}^{1-\alpha_n} = P_n C_{nt} + \eta_n P_n I_{nt} + NX_{nt}. \tag{53}$$

This, together with (50) and (52), gives us the steady-state trade balance-to-GDP ratio.

A.5. *Exact-hat algebra*

A.5.1. Key outcomes and "own spending" shares. In the spirit of Arkolakis *et al.* (2012), we can re-write a number of key conditions in terms of "own spending" shares. Specifically, from (20) to (28),

$$P_n = \frac{f_n}{Z_n} \prod_{s=1}^{S} \upsilon_{snn}^{\frac{1}{\theta_s}\frac{\sigma_{sn}}{1-\sum_s \sigma_{sn}\mu_{sn}}}, \tag{54}$$

$$p_{sn} = \frac{f_n}{z_{sn} Z_n^{\mu_{sn}}} \left(\prod_{s=1}^{S} \upsilon_{snn}^{\frac{1}{\theta_s}\frac{\sigma_{sn}}{1-\sum_s \sigma_{sn}\mu_{sn}}} \right)^{\mu_{sn}}, \tag{55}$$

$$\upsilon_{sn'n} = \left(\frac{\tau_{sn'n}\,p_{sn'}}{\tau_{snn}\,p_{sn}} \right)^{-\theta_s} \upsilon_{snn}, \tag{56}$$

$$R = \frac{\alpha_n}{\eta_n} \left(\prod_{s=1}^{S} \upsilon_{snn}^{-\frac{1}{\theta_s}\frac{\sigma_{sn}}{1-\sum_s \sigma_{sn}\mu_{sn}}} \right) Z_n k_n^{\alpha_n-1} + 1 - \delta, \tag{57}$$

where $\upsilon_{sn'n} \equiv M_{sn'n} \big/ \sum_{n'} M_{sn'n} = (\tau_{sn'n}\,p_{sn'})^{-\theta_s} \big/ \sum_{n'} (\tau_{sn'n}\,p_{sn'})^{-\theta_s}$ is the economy-n' trade share in economy-n expenditure in sector s.

A.5.2. Changes in trade costs. For any steady-state outcome x_n, define $\tilde{x}_n$ as the new outcome after a parameter change; and $\hat{x}_n \equiv \tilde{x}_n / x_n$. The only exogenous parameter changes we consider in this section are changes in $\{\tau_{sn'n}\}_{s,n'\neq n}$.

Then:

$$\hat{\upsilon}_{sn'n} = \frac{\left[\hat{\tau}_{sn'n}\hat{f}_{n'}\left(\prod_{s=1}^{S}\hat{\upsilon}_{sn'n'}^{\frac{1}{\theta_s}\frac{\sigma_{sn'}}{1-\sum_s \sigma_{sn'}\mu_{sn'}}}\right)^{\mu_{sn'}}\right]^{-\theta_s}}{\sum_{n'=1}^{N}\left[\hat{\tau}_{sn'n}\hat{f}_{n'}\left(\prod_{s=1}^{S}\hat{\upsilon}_{sn'n'}^{\frac{1}{\theta_s}\frac{\sigma_{sn'}}{1-\sum_s \sigma_{sn'}\mu_{sn'}}}\right)^{\mu_{sn'}}\right]^{-\theta_s}\upsilon_{sn'n}}, \tag{58}$$

$$\hat{f}_n\hat{k}_n^{\alpha_n}h_n = \sum_{s=1}^{S}(1-\mu_{sn})\sum_{n'=1}^{N}\hat{\upsilon}_{snn'}\upsilon_{snn'}\sigma_{sn'}\left(\tilde{q}_{n'} - \tilde{nx}_{n'}\right)\hat{f}_{n'}\hat{k}_{n'}^{\alpha_{n'}}h_{n'}, \tag{59}$$

$$\tilde{q}_n\hat{f}_n\hat{k}_n^{\alpha_n}h_n = \sum_{s=1}^{S}\sum_{n'=1}^{N}\hat{\upsilon}_{snn'}\upsilon_{snn'}\sigma_{sn'}\left(\tilde{q}_{n'} - \tilde{nx}_{n'}\right)\hat{f}_{n'}\hat{k}_{n'}^{\alpha_{n'}}h_{n'}, \tag{60}$$

$$\tilde{nx}_n = 1 - \frac{\alpha_n\left(1-\frac{1-\delta}{\gamma}\right)}{\frac{\tilde{R}}{\gamma}-\frac{1-\delta}{\gamma}} - \frac{\xi\left(\rho_n+\xi\right)\frac{\tilde{R}}{\gamma}\left(1-\alpha_n\right)}{\left[1+\rho_n-\frac{\tilde{R}}{\gamma}\left(1-\xi\right)\right]\left[\frac{\tilde{R}}{\gamma}-\left(1-\xi\right)\right]}, \tag{61}$$

$$\sum_{n=1}^{N}\tilde{nx}_n\hat{f}_n\hat{k}_n^{\alpha_n}h_n = 0, \tag{62}$$

$$\frac{\tilde{R}-1+\delta}{R-1+\delta} = \left(\prod_{s=1}^{S}\hat{\upsilon}_{snn}^{-\frac{1}{\theta_s}\frac{\sigma_{sn}}{1-\sum_s\sigma_{sn}\mu_{sn}}}\right)\hat{k}_n^{\alpha_n-1}, \tag{63}$$

$$\hat{y}_n = \left(\prod_{s=1}^{S}\hat{\upsilon}_{snn}^{-\frac{1}{\theta_s}\frac{\sigma_{sn}}{1-\sum_s\sigma_{sn}\mu_{sn}}}\right)\hat{k}_n^{\alpha_n}, \tag{64}$$

$$\hat{c}_n = \frac{\tilde{R}\left[\gamma\left(1+\rho_n\right)-R\left(1-\xi\right)\right]\left[R-\gamma\left(1-\xi\right)\right]}{R\left[\gamma\left(1+\rho_n\right)-\tilde{R}\left(1-\xi\right)\right]\left[\tilde{R}-\gamma\left(1-\xi\right)\right]}\hat{y}_n, \tag{65}$$

where $nx_n = NX_{nt}/f_nk_n^{\alpha_n}H_{nt}$ denotes the economy-n aggregate net exports to GDP ratio, $h_n \equiv f_nk_n^{\alpha_n}H_{nt}/\sum_n(f_nk_n^{\alpha_n}H_{nt})$ is the economy-n share in world nominal GDP, and $q_n \equiv \sum_s p_{sn}Q_{snt}/(f_nk_n^{\alpha_n}H_{nt})$ is the economy-n gross-output-to-GDP ratio.

Equations (58)–(60) describe the exact-hat algebra for our model conditional on given changes in trade balances and per-worker capital stocks, $\{\tilde{nx}_n, \hat{k}_n\}_n$. If factor endowments and trade balances were taken as exogenous as in static trade models of the kind used, for example, in Dekle *et al.* (2007, 2008), this set of equations would be sufficient to perform counterfactuals exploring the trade impact of changes in trade wedges (as well as the exogenous factor endowments and trade balances). In this sense, they represent the "static block" of our exact-hat algebra. Equations (61)–(63) reflect the endogeneity of trade balances and capital stocks—via asset-market clearing and portfolio optimality, respectively—in the steady state of our dynamic model. They represent the "dynamic block" of our exact-hat algebra. Finally, equations (64) and (65) translate the exogenous and endogenous changes in the combined static and dynamic blocks into real-GDP and consumption changes.

A.5.3. Financial autarky. We only consider the transition from our baseline assumption of perfectly integrated international asset markets (no barriers to international asset trade) to complete financial autarky (prohibitive barriers to international asset trade). The latter requires all net holdings of the international bond to be zero in equilibrium: $B_{nt} = 0$ for all n and t. Since economies differ in their production technologies and intertemporal preferences, each economy must have its "own" interest rate R_{nt} (instead of R_t) for this to be an equilibrium outcome.

Assuming an economy-specific interest rate R_{nt}, we can proceed as in Section A.3 to show that in steady state,

$$\frac{A_{nt}}{f_n K_{nt}^{\alpha_n} H_{nt}^{1-\alpha_n}} = \frac{(1-\xi)\left[R_n - \gamma\,(1+\rho_n)\right](1-\alpha_n)}{\left[\gamma\,(1+\rho_n) - R_n\,(1-\xi)\right]\left[R_n - \gamma\,(1-\xi)\right]}, \tag{66}$$

$$\frac{\eta_n P_n K_{nt}}{f_n K_{nt}^{\alpha_n} H_{nt}^{1-\alpha_n}} = \frac{\alpha_n}{R_n - 1 + \delta}, \tag{67}$$

where R_n is the new steady-state interest rate. Financial autarky requires $B_n = 0$, which implies $A_{nt} = \eta_n P_n K_{nt}$. Equating (66) and (67) yields a quadratic equation in permissible values of R_n.[44] This quadratic equation has only one positive root:

$$\frac{R_n}{\gamma} = (1+\rho_n)\left\{1 - \frac{1}{2}\left[1 - \frac{(1-\alpha_n)(1-\delta)}{\gamma\,(1+\rho_n)} - \alpha_n\left(\frac{1-\xi}{1+\rho_n} + \frac{\xi}{1-\xi}\right)\right]\right.$$
$$\left. + \frac{1}{2}\sqrt{\left[1 - \frac{(1-\alpha_n)(1-\delta)}{\gamma\,(1+\rho_n)} - \alpha_n\left(\frac{1-\xi}{1+\rho_n} + \frac{\xi}{1-\xi}\right)\right]^2 + 4\alpha_n \frac{\xi}{1-\xi}\frac{\xi+\rho_n}{1+\rho_n}}\right\}. \tag{68}$$

It is straightforward to show that $B_{nt} = 0$ implies $NX_{nt} = 0$ for all n and t.

The exact-hat algebra required to compute outcomes in the new financial-autarky steady state is now summarized by the following system of equations:

$$\hat{\upsilon}_{sn'n} = \frac{\left[\hat{f}_{n'}\left(\prod_{s=1}^{S} \hat{\upsilon}_{sn'n'}^{\frac{1}{\theta_s}\frac{\sigma_{sn'}}{1-\sum_s \sigma_{sn'}\mu_{sn'}}}\right)^{\mu_{sn'}}\right]^{-\theta_s}}{\sum_{n'=1}^{N}\left[\hat{f}_{n'}\left(\prod_{s=1}^{S} \hat{\upsilon}_{sn'n'}^{\frac{1}{\theta_s}\frac{\sigma_{sn'}}{1-\sum_s \sigma_{sn'}\mu_{sn'}}}\right)^{\mu_{sn'}}\right]^{-\theta_s}\upsilon_{sn'n}}, \tag{69}$$

$$\hat{f}_n \hat{k}_n^{\alpha_n} h_n = \sum_{s=1}^{S}(1-\mu_{sn})\sum_{n'=1}^{N}\hat{\upsilon}_{snn'}\upsilon_{snn'}\sigma_{sn'}\tilde{q}_{n'}\hat{f}_{n'}\hat{k}_{n'}^{\alpha_{n'}}h_{n'}, \tag{70}$$

$$\tilde{q}_n \hat{f}_n \hat{k}_n^{\alpha_n} h_n = \sum_{s=1}^{S}\sum_{n'=1}^{N}\hat{\upsilon}_{snn'}\upsilon_{snn'}\sigma_{sn'}\tilde{q}_{n'}\hat{f}_{n'}\hat{k}_{n'}^{\alpha_{n'}}h_{n'}, \tag{71}$$

$$\frac{R_n - 1 + \delta}{R - 1 + \delta} = \left(\prod_{s=1}^{S}\hat{\upsilon}_{snn}^{-\frac{1}{\theta_s}\frac{\sigma_{sn}}{1-\sum_s \sigma_{sn}\mu_{sn}}}\right)\hat{k}_n^{\alpha_n - 1}, \tag{72}$$

$$\hat{y}_n = \left(\prod_{s=1}^{S}\hat{\upsilon}_{snn}^{-\frac{1}{\theta_s}\frac{\sigma_{sn}}{1-\sum_s \sigma_{sn}\mu_{sn}}}\right)\hat{k}_n^{\alpha_n}, \tag{73}$$

$$\hat{c}_n = \frac{R_n\left[\gamma\,(1+\rho_n) - R\,(1-\xi)\right]\left[R - \gamma\,(1-\xi)\right]}{R\left[\gamma\,(1+\rho_n) - R_n\,(1-\xi)\right]\left[R_n - \gamma\,(1-\xi)\right]}\hat{y}_n, \tag{74}$$

where R_n is given in equation (68) and, from the reasoning above, $\tilde{nx}_n = 0$ for all n.

44. Note that $R_n \in [\gamma\,(1+\rho_n), \gamma\,(1+\rho_n)/(1-\xi)]$ is required for $A_{nt}/(f_n K_{nt}^{\alpha_n} H_{nt}^{1-\alpha_n})$ to be positive and finite.

A.6. *Full model calibration*

The full model calibration assumes that the 2010–14 averages of observed sectoral trade patterns, trade imbalances, real incomes, and capital stocks can be interpreted as steady-state outcomes of the model in Section 3. The WIOD data described in Section 2.2.1 and the Penn World Tables (PWT, edition 9.0; Feenstra *et al*., 2015) are the two main sources of data for the calibration. Unless otherwise specified, all data moments used to pin down model parameters are simple 5-year averages for the years 2010–14. Table 3 in the main text presents an overview of how all model parameters are calibrated.

Sectoral spending shares and intermediate input shares, $\{\sigma_{sn}, \mu_{sn}\}_{s,n}$, are set to match their empirical counterparts which can be computed straightforwardly from WIOD data. Capital shares and human capital stocks, $\{\alpha_n, H_{nt}\}_n$, are obtained from PWT.[45] Trade elasticities are taken from Caliendo and Parro (2015) and Costinot and Rodríguez-Clare (2014), as listed in Appendix Table A3. The probability of death for an individual agent is put at $\xi = 0.13$, yielding an expected lifespan of 60 years for an agent in our model. The capital depreciation rate is calibrated to be $\delta = 0.06$.

We set the steady-state growth rate to $\gamma = 1.044$ to match the average annual growth rate of world GDP during the 1985–2014 period from PWT. We then target a world interest rate of $R = 1.030$ based on estimates by King and Low (2014) of the real-world interest rate during the same period, and use $\{\eta_n\}_n$ to match per-effective-worker capital stocks from PWT using equation (22). Note that this calibration implies $\gamma > R$. The empirical analogue of the real risk-free world interest rate in our model is not obvious. However, it is reassuring that our model calibration implies that η_n is approximately equal to 1 for countries like Germany and Switzerland, so the calibrated risk-free world rate is approximately equal to the real marginal product of capital in countries that generally attract some of the lowest risk premia in real-world bond markets.[46]

Given R, we use the discount rates, $\{\rho_n\}_n$, to match macro trade balances from WIOD using equation (23). The resulting correlation between discount rates and aggregate trade balances is -0.75: more impatient economies tend to have trade deficits, while patient economies tend to have surpluses.

Finally, we impose

$$\tau_{sn'n}^{-\theta_s} = \hat{\varepsilon}_{sn'n}, \tag{75}$$

$$\left(\frac{z_{sN}}{z_{sn}} \frac{f_n^{1-\mu_{sn}} P_n^{\mu_{sn}}}{f_N^{1-\mu_{sN}} P_N^{\mu_{sN}}} \right)^{-\theta_s} = \exp\left\{ \hat{\Omega}_{sn} - \hat{\Omega}_{sN} \right\}, \tag{76}$$

where $\hat{\varepsilon}_{sn'n}$ and $\hat{\Omega}_{sn}$ are derived from the PPML estimation discussed in Section 2.1.3; and N is the arbitrary benchmark economy in that estimation. This ensures that the model perfectly matches sector-level bilateral trade patterns and is consistent with the restriction in (8). Moreover, it lends a new interpretation to that restriction in terms of our model parameters. For given $\{E_{snt}/D_{st}\}_{s,n}$ pinned down to a first order by $\{\sigma_{sn}\}_{s,n}$, the restriction amounts to explaining as much variation in sectoral bilateral expenditures as possible as the result of technological comparative advantages, $\{z_{sn}/z_{sN}\}_{s,n\neq N}$. This still leaves sufficiently many free parameters to set

45. Note that the labour share in PWT is computed as the share of labour income in GDP, which corresponds to $1 - \alpha_n$ in our model.

46. Note from equations (22) and (28) that $\eta_n > 1$ implies $\alpha_n y_n / k_n > R - 1 + \delta$, so despite the assumption of fully integrated international asset markets, our model is consistent with the observed differences in the marginal product of capital across economies. One interpretation of a "low investment efficiency" ($\eta_n > 1$) is that it captures frictions in the flow of capital to certain economies in a black-box fashion.

$\{Z_n\}_n$ so as to match economies' expenditure-side real GDPs from PWT for given steady-state prices and capital stocks.

A.7. *Global trade-wedge symmetry in a static model*

The exact-hat algebra for a dynamic trade model with international capital mobility and endogenous macro trade balances described in equations (58)–(65) is one innovation of this article. Nevertheless, a quantitative question of interest is whether our headline finding about the role of trade-wedge asymmetries in explaining bilateral imbalances could have been obtained using a more conventional static trade model with exogenous macro trade balances such as, for example, in Dekle *et al*. (2007, 2008).

To answer this question, we perform the counterfactual described in Section 3.3.1 using equations (58)–(60) and (64), and assuming

$$\hat{k}_n = 1, \tag{77}$$

$$\tilde{nx}_n = nx_n h_n \frac{\sum_{n=1}^{N} \hat{f}_n h_n}{\hat{f}_n h_n}, \tag{78}$$

for all n. Equation (77) amounts to assuming that, like labour, capital is an exogenously given production factor growing at rate γ.[47] Equation (78) imposes that countries' macro trade balances arise from exogenous international transfers whose value is constant as a share of world GDP.[48]

Performing this alternative, static counterfactual, we obtain virtually the same decline in the variation of bilateral trade imbalances as described in Section 3.3.2 and Figure 5. However, the welfare gains from global trade-wedge symmetry are much smaller, with real GDP per capita rising by only 5% for the median country. This primarily reflects the absence of endogenous capital accumulation and allocation, which amplifies the impact of trade-wedge changes in the dynamic model via equation (63).

A.8. *Macroeconomic impact of financial autarky*

Figure A3 gives a graphical overview of the macroeconomic impact of financial autarky across economies. The real-GDP and real-consumption changes primarily reflect a dramatic relocation of capital. Economies with net negative international bond holdings under full financial integration (towards the left-hand side of Figure A3) see their capital stocks and real income levels shrink in financial autarky. Meanwhile, economies with net positive bond holdings under financial integration (towards the right-hand side of Figure A3) see their capital stocks and real incomes grow. However, both economy groups experience a decline in their real consumption levels. This is because the former lose the benefit of higher wages supported by externally financed capital investments, while the latter lose the benefit of higher foreign investment returns.

The disappearance of macro trade surpluses and deficits also prompts changes in real incomes via the "transfer effect": expenditure shifts towards the output of former trade-surplus countries, which causes a terms-of-trade in their favour, raising their real incomes, and lowering the real

47. Equivalently, we could impose $\alpha_n = 0$ for all n.

48. The only restriction on these transfers required by the model is that they must sum to zero across n for all t. A constant value of transfers in levels would satisfy this restriction, but the international-currency value of transfers is not well defined within the model. For this reason, we opt for a constant value *relative* to world GDP in equation (78).

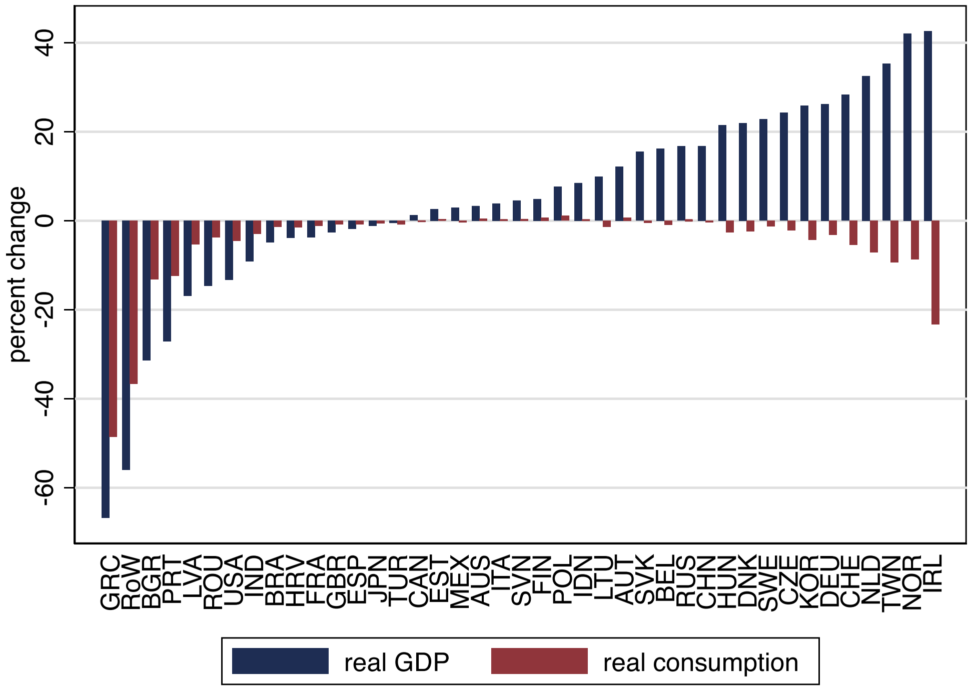


FIGURE A3

Impact of financial autarky on real GDP and consumption

Notes: Percent change in real per-capita GDP and consumption relative to data in the financial-autarky steady state, as described in Section 3.4 and Appendix A.8. Calibration on data from PWT (edition 9.0) and WIOD (2016 release), average for the years 2010–14.

incomes of former trade-deficit economies. However, as found in Dekle *et al*. (2007, 2008), these effects are quantitatively small, and they are dwarfed for most countries by the impact of financial autarky on their capital stocks.

A.9. *Appendix tables*

TABLE A1

Sample of economies

WIOD (2016)		Final data	
Economy	Code	Economy	Code
Australia	AUS	Australia	AUS
Austria	AUT	Austria	AUT
Belgium	BEL	Belgium	BEL
Brazil	BRA	Brazil	BRA
Bulgaria	BGR	Bulgaria	BGR
Canada	CAN	Canada	CAN
China	CHN	China	CHN
Croatia	HRV	Croatia	HRV
Cyprus	CYP	Rest of the World	RoW
Czech Republic	CZE	Czech Republic	CZE

(continued)

TABLE A1
Sample of economies

WIOD (2016)		Final data	
Economy	Code	Economy	Code
Denmark	DNK	Denmark	DNK
Estonia	EST	Estonia	EST
Finland	FIN	Finland	FIN
France	FRA	France	FRA
Germany	DEU	Germany	DEU
Greece	GRC	Greece	GRC
Hungary	HUN	Hungary	HUN
India	IND	India	IND
Indonesia	IDN	Indonesia	IDN
Ireland	IRL	Ireland	IRL
Italy	ITA	Italy	ITA
Japan	JPN	Japan	JPN
Korea	KOR	Korea	KOR
Latvia	LVA	Latvia	LVA
Lithuania	LTU	Lithuania	LTU
Luxembourg	LUX	Rest of the World	RoW
Malta	MLT	Rest of the World	RoW
Mexico	MEX	Mexico	MEX
Netherlands	NLD	Netherlands	NLD
Norway	NOR	Norway	NOR
Poland	POL	Poland	POL
Portugal	PRT	Portugal	PRT
Rest of the World	RoW	Rest of the World	RoW
Romania	ROU	Romania	ROU
Russia	RUS	Russia	RUS
Slovakia	SVK	Slovakia	SVK
Slovenia	SVN	Slovenia	SVN
Spain	ESP	Spain	ESP
Sweden	SWE	Sweden	SWE
Switzerland	CHE	Switzerland	CHE
Taiwan, Prov. of China	TWN	Taiwan, Prov. of China	TWN
urkey	TUR	Turkey	TUR
U.K.	GBR	U.K.	GBR
U.S.	U.S.	U.S.	U.S.

Notes: The “WIOD (2016)” column shows economies and regions as covered in the 2016 release of WIOD. The “Final data” column shows economies and regions as grouped for our analysis.

TABLE A2
Sector sample

WIOD (2016)		Final data
Sector	ISIC 2-dg.	New code
codeCrop and animal production. . .	1	1
Forestry and logging	2	1
Fishing and aquaculture	3	1
Mining and quarrying	5–9	2

(continued)

TABLE A2
Sector sample

WIOD (2016)		Final data
Sector	ISIC 2-dg.	New code
Manufacture of food products,…	10–12	3
Manufacture of textiles,…	13–15	4
Manufacture of wood and…	16	5
Manufacture of paper and…	17	6
Printing and reproduction…	18	6
Manufacture of coke and…	19	7
Manufacture of chemicals…	20	8
Manufacture of basic pharma…	21	8
Manufacture of rubber and…	22	9
Manufacture of other non-metal…	23	10
Manufacture of basic metals	24	11
Manufacture of fabricated metal…	25	11
Manufacture of computer,…	26	13
Manufacture of electrical equip…	27	13
Manufacture of machinery and…	28	12
Manufacture of motor vehicles,…	29	14
Manufacture of other transport…	30	14
Manufacture of furniture; other…	31–32	15
Repair and installation…	33	15
Electricity, gas, steam and…	35	16
Water collection, treatment…	36	16
Sewerage; waste collection,…	37–39	16
Construction	41–43	17
Wholesale and retail…	45	18
Wholesale trade, except…	46	18
Retail trade, except of…	47	19
Land transport and…	49	21
Water transport	50	22
Air transport	51	23
Warehousing and support…	52	24
Postal and courier activities	53	25
Accommodation and food…	55–56	20
Publishing activities	58	6
Motion picture, video and…	59–60	6
Telecommunications	61	25
Computer programming,…	62–63	28
Financial service activities,…	64	26
Insurance, reinsurance and…	65	26
Activities auxiliary to financial…	66	26
Real estate activities	68	27
Legal and accounting activities;…	69–70	28
Architectural and engineering…	71	28
Scientific research and…	72	28
Advertising and market research	73	28
Other professional, scientific…	74–75	28
Administrative and support…	77–82	28
Public administration and…	84	31
Education	85	29
Human health and social work…	86–88	30
Other service activities	90–96	31
Activities of households…	97–98	28
Activities of extraterritorial…	99	31

Notes: The “WIOD (2016)” column shows sector names and codes as covered in the 2016 release of WIOD. The “Final data” column shows the new codes for the sector groups created for our analysis.

TABLE A3
Sector sample and trade elasticities

Final data		
New code	Sector	Trade elasticity
1	Agriculture, hunting, forestry, and fishing	8.11
2	Mining and quarrying	15.72
3	Food, beverages, and tobacco	2.55
4	Textiles and textile products; leather, leather apparel, and footwear	5.56
5	Wood and products of wood and cork	10.83
6	Pulp, paper; paper, printing, and publishing	9.07
7	Coke, refined petroleum and nuclear fuel	51.08
8	Chemicals and chemical products	4.75
9	Rubber and plastics	1.66
10	Other non-metallic mineral products	2.76
11	Basic metals and fabricated metal	7.99
12	Electrical and optical equipment	10.60
13	Machinery, nec	1.52
14	Transport equipment	0.37
15	Manufacturing, nec; recycling	5
16	Electricity, gas, and water supply	5
17	Construction	5
18	Wholesale trade, commission trade, including motor vehicles and motorcycles	5
19	Retail trade, except of motor vehicles and motorcycles	5
20	Hotels and restaurants	5
21	Inland transport	5
22	Water transport	5
23	Air transport	5
24	Other supporting and auxiliary transport activities; activities of travel agencies	5
25	Post and telecommunications	5
26	Financial intermediation	5
27	Real estate activities	5
28	Other business activities	5
29	Education	5
30	Health and social work	5
31	Public admin, defence, social security, and other public services	5

Notes: "New code" shows the new codes for the sector groups created for our analysis. "Sector" shows the corresponding sector names. "Trade elasticity" shows the corresponding trade elasticities. Trade elasticities are based on Caliendo and Parro (2015) and Costinot and Rodríguez-Clare (2014).

TABLE A4
Aggregate asymmetries in trade wedges

Variable	No. of obs.	Mean	SD	10th pctl.	Median	90th pctl.
$\lvert \ln(\tau_{n'n}/\tau_{nn'}) \rvert$	820	0.099	0.086	0.015	0.076	0.220

Notes: $\tau_{n'n}$ represents the ad-valorem equivalent of the aggregate trade wedge applying to imports by economy n from n', as defined in equation (39). Calibrations are based on data from PWT (edition 9.0) and WIOD (2016 release), averaged for the years 2010–14. The data cover 40 individual economies and the Rest of the World.

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TABLE A5

Sectoral bilateral trade-wedge asymmetries and their contribution to aggregate asymmetries

Sector code	Sector name	Contribution to agg. asymmetries	Median $\frac{M^{1/2}_{sn'nt}M^{1/2}_{snn't}}{M^{1/2}_{n'nt}M^{1/2}_{nn't}}$	Median $\left\|\ln\left(\frac{\hat{\varepsilon}_{sn'n}}{\hat{\varepsilon}_{snn'}}\right)\right\|$
12	Electrical and optical equipment	0.307	0.073	0.778
8	Chemicals and chemical products	0.112	0.070	0.683
11	Basic metals and fabricated metal	0.110	0.059	0.654
14	Transport equipment	0.084	0.040	0.903
15	Machinery, nec	0.082	0.040	0.790
3	Food, beverages, and tobacco	0.042	0.034	1.015
18	Wholesale trade,...	0.040	0.024	1.407
4	Textiles and textile products;...	0.039	0.015	1.091
9	Rubber and plastics	0.039	0.020	0.777
15	Manufacturing, nec; recycling	0.029	0.020	0.778
28	Other business activities	0.027	0.037	0.640
6	Pulp, paper; paper, printing...	0.019	0.015	1.123
7	Coke, refined petroleum, and nuclear fuel	0.016	0.006	1.397
10	Other non-metallic, mineral	0.013	0.007	0.982
19	Retail trade, except of motor vehicles...	0.009	0.003	1.663
17	Construction	0.009	0.002	1.545
26	Financial intermediation	0.008	0.002	1.279
1	Agriculture, hunting, forestry, and fishing	0.007	0.011	1.356
5	Wood and products of wood and cork	0.006	0.004	1.328
23	Air transport	0.005	0.006	0.837
16	Electricity, gas and water supply	0.003	0.006	1.031
24	Other supporting transport activities;...	0.003	0.005	1.094
21	Inland transport	0.003	0.009	1.302
31	Public admin,...	0.002	0.003	1.167
30	Health and social work	0.001	0.000	1.555
25	Post and telecommunications	0.000	0.003	0.908
27	Real estate activities	0.000	0.000	1.983
22	Water transport	0.000	0.001	1.102
29	Education	−0.000	0.000	1.527
20	Hotels and restaurants	−0.001	0.000	1.193
2	Mining and quarrying	−0.006	0.005	1.711

Notes: The contribution of sector s to aggregate trade-wedge asymmetries is defined as $Cov[\ln(\tau_{sn'n}/\tau_{snn'})\theta_s M^{1/2}_{sn'nt}M^{1/2}_{snn't}/(\theta M_{n'nt}M_{nn't}), \ln(\tau_{n'n}/\tau_{nn'})]/Var[\ln(\tau_{n'n}/\tau_{nn'})]$. All variables and parameters are as defined in Sections 2.1 and 2.2. The data source is WIOD (2016 release), averaged for the years 2010–14. The data cover 40 individual economies and the Rest of the World.

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The data underlying this article are available on Zenodo, at: https://doi.org/10.5281/zenodo.7752647.

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