The Long and Short (Run) of Trade Elasticities*

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Abstract

We propose a novel approach to estimate the trade elasticity at various horizons. When countries change Most Favored Nation (MFN) tariffs, partners that trade on MFN terms experience plausibly exogenous tariff changes. The differential effects on imports from these countries relative to a control group – countries not subject to the MFN tariff scheme – can be used to identify the trade elasticity. We build a panel dataset combining information on product-level tariffs and trade flows covering 1995-2018, and estimate the trade elasticity at short and long horizons using local projections (Jordà, 2005). Our main findings are that the elasticity of tariff-exclusive trade flows in the year following the exogenous tariff change is about -0.76, and the long-run elasticity ranges from -1.75 to -2.25. Our long-run estimates are smaller than typical in the literature, and it takes 7-10 years to converge to the long run, implying that (i) the welfare gains from trade are high and (ii) there are substantial convexities in the costs of adjusting export participation.

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1 Introduction

The elasticity of trade flows to trade barriers – the "trade elasticity" – is the central parameter in international economics. Quantifications of the impact of shocks or trade policies on trade flows, trade balances, GDP, and welfare hinge on its magnitude. However, there is currently no consensus on the value of this parameter, with a variety of empirical strategies delivering a broad range of estimates.[1]

This paper develops and implements a novel approach to estimating trade elasticities. Following a long tradition in the literature, our empirical strategy exploits variation in tariffs. Our principal contributions are to simultaneously address (i) endogeneity due to possible reverse causality and omitted variables, and (ii) evolution across time horizons. The main results are as follows. First, our estimate of the long-run elasticity of trade values exclusive of tariff payments is -1.75 to -2.25, which is at the lower end of the range of existing estimates. This implies that the welfare-relevant (i.e., tariff-inclusive) long-run elasticity in most static trade models is around 1 in absolute value, and thus the gains from trade implied by these models are large. Second, the trade elasticity in the year following the initial tariff change is -0.76, and it takes several years for it to converge to the long-run value. The trade elasticity point estimates stabilize between years 7 and 10.

Our first contribution is to address the endogeneity of tariffs. Our estimating equations time-difference the data in order to account for omitted variables that vary by country-pair-product. However, differencing the data still leaves open the possibility that, for instance, changes in tariffs are caused by changes in trade flows. A surge in imports due to high productivity growth in the exporting country may intensify lobbying for protection and lead to higher tariffs. In this case, estimates that do not account for this reverse causality will be biased towards zero. Our identification strategy relies on the key institutional feature of the WTO system: the MFN principle. Under this principle, a country must apply the same tariffs to all its WTO member trade partners. We estimate the trade elasticity based on the response of minor exporters to an importer's MFN tariff change. The identifying assumption is that developments in the minor exporters do not affect a country's decision to change its MFN import tariffs. Our estimation procedure then compares the changes in minor exporters' trade flows to a control group of exporters to the same country to whom MFN tariffs do not apply. These are countries in preferential trade agreements with the importer. Addressing the reverse causality indeed produces larger elasticities in absolute value than OLS.

Our second contribution is to provide estimates over different time horizons, ranging from impact to 10 years. Because tariff changes can be autocorrelated, to estimate elasticities at longer horizons we use time series methods, namely local projections (Jordà, 2005). This approach takes into account the fact that tariffs themselves may have a nontrivial dynamic impulse response structure, implying

[1] Anderson and van Wincoop (2004) and Head and Mayer (2014) review available estimates.

the elasticities of trade flows at different horizons might depend on the autocorrelation patterns of tariffs. A key advantage of this approach is that we can compare short- and long-run elasticities obtained within the same estimation framework. It is well-known that trade elasticities estimated from cross-sectional variation in tariffs tend to be much higher than the short-run elasticities needed to fit international business cycle moments. Normally, this discrepancy is rationalized by assuming that the elasticities estimated from the cross-section essentially reflect the long run. However, existing estimates either use purely cross-sectional variation (e.g. Caliendo and Parro, 2015), or a time difference over only one horizon (e.g. Head and Ries, 2001; Romalis, 2007). In both cases it is unclear whether what is being estimated is a long-run elasticity, an elasticity over a fixed time horizon, or a mix of short- and long-run elasticities. Our exercise provides mutually consistent estimates of the short- and the long-run elasticities, as well as their full path over time.

In the process, we highlight the role of omitted variables. The theoretical foundations of the gravity equation emphasize the need to control for exporter and importer multilateral resistance terms, structurally (Anderson, 1979; Anderson and van Wincoop, 2003) or with appropriate fixed effects (e.g. Redding and Venables, 2004; Baldwin and Taglioni, 2006). We show that the traditional log-levels gravity specification with multilateral resistance fixed effects yields the conventional wisdom elasticities of -3 to -7. However, multilateral resistance terms do not absorb aggregate or product-specific bilateral taste shifters or other unobserved bilateral gravity variables. For instance, if buyers in a particular importing country have time-invariant idiosyncratically high tastes for a certain product from a certain country, the policymaker might respond by setting a low tariff. Omitting these unobservables can thus lead to large elasticity estimates. Indeed, once we time-difference the traditional gravity specification to remove bilateral, time-invariant, unobserved gravity variables and taste shifters, conventional OLS estimates fall sharply to around 1 in absolute value.[2]

Our analysis uses data on global international trade flows from BACI, and tariffs from UN TRAINS. The sample covers 183 economies, over 5,000 HS 6-digit categories, and the time period 1995-2018. These data also allow us to explore sectoral heterogeneity in trade elasticities. Across 11 broad HS sections, the long-run values range from -0.75 to -5.

Our empirical strategy is deliberately not tied to a particular theory, because we expect that our estimates can serve as targets for multiple theories. The mapping between our estimates and structural parameters in theoretical models will then depend on model structure. This is well-understood in the context of static trade models, as multiple microfoundations generate the gravity equation. To illustrate this in a dynamic setting, the final section of the paper presents a simple model, focus-

[2]While we are not the first to control for bilateral unobservables via time-differencing or fixed effects (see, e.g. Feenstra, 1994; Head and Ries, 2001; Lai and Trefler, 2002, and the literature that followed), this approach is not common practice in trade elasticity estimation, and the systematic implications for the value of the estimated elasticities have not been emphasized by this body of work.

ing on the minimal common structure required to (i) state the short- and long-run model-implied elasticities and the properties of their time path; (ii) deliver our empirical estimating equations to first order; and (iii) produce a sluggish adjustment of trade to trade cost shocks, consistent with the empirical estimates. The model yields analytical expressions for trade elasticities at all horizons that clarify the determinants of the adjustment dynamics. It nests dynamic versions of the Krugman (1980), Melitz (2003), and Arkolakis (2010) models, as well as extensions with pricing to market (e.g. Burstein, Neves, and Rebelo, 2003; Atkeson and Burstein, 2008). We also present a multi-country multi-sector general equilibrium extension to show that the time path of our estimated elasticities is a key input for quantifying the general-equilibrium responses of trade flows to tariff shocks.

Finally, we apply our elasticity estimates to the Arkolakis, Costinot, and Rodríguez-Clare (2012) gains from trade formula. To do that, we must account for the fact that our left-hand side variable is trade values exclusive of tariff payments, whereas the elasticity that enters gains from trade formulas is that of tariff-inclusive spending. Our estimates imply an elasticity relevant for computing the welfare gains from trade of about -1. Under this value, the gains from trade are 5-6 times larger than under the commonly used elasticity of -5.

More broadly, our elasticity estimates can inform a range of long-standing questions in international macroeconomics. The parameters governing the response of trade flows to relative price changes are crucial for understanding the impact of the exchange rate on the trade balance (e.g. Marshall, 1923; Lerner, 1944; Backus, Kehoe, and Kydland, 1994; Obstfeld and Rogoff, 2005; Imbs and Mejean, 2015). For instance, Backus, Kehoe, and Kydland (1994) illustrate the role of a low Armington elasticity in matching the response of the trade balance to terms-of-trade changes. Our short-horizon estimates can be used to discipline business-cycle substitution elasticities between home and foreign goods, and so can also be used in quantifications of business cycle shock transmission across countries (e.g. Backus, Kehoe, and Kydland, 1992; Heathcote and Perri, 2002; Kose and Yi, 2006; Johnson, 2014; Huo, Levchenko, and Pandalai-Nayar, 2020; Drozd, Kolbin, and Nosal, 2021). Finally, the trade elasticity is also important for international risk sharing (Cole and Obstfeld, 1991; Coeurdacier, 2009; Heathcote and Perri, 2013), among others. Indeed, the full time path of our elasticity estimates contains information useful for disciplining international macro models, as demonstrated recently by Auclert et al. (2021).

Related literature Anderson and van Wincoop (2004) and Head and Mayer (2014) review existing trade elasticity estimates. One common approach is to use tariff variation to estimate this elasticity (e.g. Head and Ries, 2001; Hertel et al., 2007; Romalis, 2007; Caliendo and Parro, 2015; Imbs and Mejean, 2015, 2017; Fontagné, Guimbard, and Orefice, 2022). Other methods exploit differences in prices across locations (Eaton and Kortum, 2002; Simonovska and Waugh, 2014; Giri, Yi, and Yilmazkuday, 2021) or rely on variation in transport costs (Hummels, 2001; Shapiro, 2016; Adão, Costinot, and Donaldson, 2017). Existing estimates typically do not address the endogeneity of tariffs, and do not distinguish different time horizons.[3] An alternative is to estimate an elasticity of substitution structurally (e.g. Feenstra, 1994; Broda and Weinstein, 2006; Feenstra et al., 2018; Soderbery, 2015, 2018; Fajgelbaum et al., 2020). In some environments the elasticity of substitution (or demand elasticity) governs the trade elasticity, but in many others, such as the Melitz or Eaton-Kortum models, it does not. Our empirical strategy is not confined to environments in which the trade elasticity coincides with the elasticity of substitution.

An important recent strand of the literature uses customs data to estimate firm-level elasticities of exports to tariffs, and aggregates firm-level responses to recover macro elasticities (see, among others, Bas, Mayer, and Thoenig, 2017; Fitzgerald and Haller, 2018; Fontagné, Martin, and Orefice, 2018). Often, similar to our strategy, the exogenous identifying variation comes from comparisons of MFN and non-MFN destinations. Our approach complements these firm-level analyses. The customs data have the clear advantage of the forensic precision with which different dimensions of firm-level responses to tariffs can be pinned down. On the other hand, this approach normally uses data for a limited set of countries (most often 1) and years, making it challenging to control for multilateral resistance terms and/or exploit time series variation in tariffs for identification.

Bown and Crowley (2016) describe the empirical features of tariff policy in general, and the MFN system in particular. A property of MFN tariffs important for our purposes is that countries negotiate upper bounds on MFN tariffs, and are then free to set actual MFN tariffs anywhere below those bounds. In the data, a significant fraction of MFN tariffs is actually below the bounds, and thus countries can vary them without violating their WTO commitments. There is a voluminous theoretical and empirical literature on trade policy, both unilateral and within the framework of trade agreements, synthesized most recently in Bagwell and Staiger (2016). This literature emphasizes endogeneity of tariffs to a variety of factors, and thus calls for an effort to overcome that endogeneity in estimation.

The rest of the paper is organized as follows. Section 2 lays out the econometric framework and the identification strategy. Section 3 describes the data, and Section 4 the main results. Section 5 explores the empirical estimates in a number of dimensions, while Section 6 connects the estimates to theory. Section 7 concludes.

[3] A strand of the literature uses time series methods (most commonly Error Correction Models) to estimate time-varying trade elasticities with trade prices or trade cost changes as independent variables (e.g. Hooper, Johnson, and Marquez, 2000; Gallaway, McDaniel, and Rivera, 2003; Alessandria and Choi, 2019; Yilmazkuday, 2019; Khan and Khederlarian, 2021). Our work builds on this line of research by tackling tariff endogeneity, using flexible local projections, and expanding the scope of the analysis to many more importers, exporters, and products.

2 Estimation Framework

2.1 The horizon-h trade elasticity

As the objective of this paper is to estimate elasticities of trade flows to tariffs at different time horizons, we start with a definition of a horizon-specific trade elasticity. Let i and j index countries, p products, and t time. Let $X_{i,j,p,t}$ be the exports of p from j to i, and $\tau_{i,j,p,t}$ be the gross ad valorem tariff. Denote by Δ_h a time difference in a variable between periods $t-1$ and $t+h$: $\Delta_h x_t \equiv x_{t+h} - x_{t-1}$.

Definition. For $\Delta_h \ln \tau_{i,j,p,t} \neq 0$ the *horizon-h trade elasticity* ε^h is defined as

$$\varepsilon^h = \frac{\Delta_h \ln X_{i,j,p,t}}{\Delta_h \ln \tau_{i,j,p,t}}. \tag{2.1}$$

Both conceptually and for the purposes of estimation, it is important to take into account the fact that tariffs follow a stochastic process, and the h-horizon change $\Delta_h \ln \tau_{i,j,p,t}$ is a cumulation of a sequence of period-to-period changes that occur between t and $t+h$. A useful way to think about this horizon-h-specific trade elasticity is as follows. Suppose an unanticipated shock to tariffs occurs at time t. The denominator $\Delta_h \ln \tau_{i,j,p,t}$ captures the effect of this shock on tariffs h periods into the future relative to time $t-1$. It can thus be thought of as a horizon-h impulse response. Similarly, the numerator $\Delta_h \ln X_{i,j,p,t}$ captures the effect of the time-t shock to $\ln \tau_{i,j,p,t}$ *and of the subsequent changes in* $\ln \tau_{i,j,p,t}$ on trade flows h periods into the future.

This discussion makes clear that both the numerator $\Delta_h \ln X_{i,j,p,t}$ and the denominator $\Delta_h \ln \tau_{i,j,p,t}$ can be thought of as sequences following the initial shock. They jointly inform the time path of the response of trade flows to tariff changes in dynamic models.

Traditionally, models of international trade are static, representing a metaphor for the long run. Thus, parameterizing these models requires the long-run elasticity ε, defined as the limit:

$$\varepsilon = \lim_{h \to \infty} \varepsilon^h,$$

if it exists. This limit measures the permanent change in trade flows that accompanies a permanent change in tariffs.

2.2 Estimating equations

Consider a change in tariffs $\Delta_0 \ln \tau_{i,j,p,t}$ between $t-1$ and t. We estimate the following equation using local projections (Jordà, 2005):

$$\Delta_h \ln X_{i,j,p,t} = \beta_X^h \Delta_0 \ln \tau_{i,j,p,t} + \delta_{i,p,t}^{d,X,h} + \delta_{j,p,t}^{s,X,h} + \delta_{i,j,p}^{b,X,h} + u_{i,j,p,t}^{X,h}, \tag{2.2}$$

where the δs are fixed effects. As we will discuss throughout the paper, these fixed effects will help control for the effects of other determinants of trade flows that may be correlated with tariff changes. The coefficient β_X^h in (2.2) captures the change in trade flows h periods ahead that follows an initial one-period change in tariffs: $\frac{\Delta_h \ln X_{i,j,p,t}}{\Delta_0 \ln \tau_{i,j,p,t}}$. If tariff changes were always one-time permanent shocks, β_X^h would be an estimate of the horizon-h trade elasticity, a point we return to below.

This estimation approach affects the interpretation of the coefficients. Because the estimating equation (2.2) includes importer-product-time and exporter-product-time fixed effects $\delta_{i,p,t}^{d,X,h}$ and $\delta_{j,p,t}^{s,X,h}$, the version of (2.1) that we estimate in the data is a partial elasticity. The fixed effects control for determinants of trade flows that vary at the importer-product-time level (e.g. demand shifters such as the importer price index and aggregate consumption), and the exporter-product-time level (such as the marginal costs of production). In general equilibrium models a tariff change generally affects these demand and supply shifters, and hence the total response of trade flows to tariffs generally differs from the partial effect on trade flows estimated here. Section 6.2 illustrates this point in a dynamic general equilibrium model. It also shows that the total response of trade flows in general equilibrium depends strongly on a set of structural parameters that can be disciplined with our estimates.

Estimation of the partial elasticity is preferable for several reasons. In part, it is driven by necessity. Isolating exogenous variation in tariff changes without these fixed effects is substantially more challenging. We claim instrument validity only conditional on including importer-product-time and exporter-product-time fixed effects. An additional advantage of the partial elasticity is that its mapping to model parameters is substantially cleaner, as we demonstrate in Section 6.1. Lastly, estimation of a partial elasticity is in line with virtually all of the modern literature on this topic. For instance, in a large class of static trade models, the long-run partial elasticity is a critical determinant of the welfare gains from trade (Arkolakis, Costinot, and Rodríguez-Clare, 2012).

Autocorrelation in tariffs In equation (2.2), if $\Delta_0 \ln \tau_{i,j,p,t}$ was a one-time change in tariffs (that is, $\Delta_h \ln \tau_{i,j,p,t} = \Delta_0 \ln \tau_{i,j,p,t}$), $\hat{\beta}_X^h$ is indeed an estimator of ε^h for all h. We can, and do, estimate β_X^h, but it is often misleading as a measure of the trade elasticity if following the initial change $\Delta_0 \ln \tau_{i,j,p,t}$ tariffs themselves keep changing during the next h periods. For instance, if a tariff reduction in the initial year tends to be followed by further tariff reductions, we would attribute a large change in trade flows to a small initial tariff change not taking into account the impact of subsequent, dependent, tariff decreases. The opposite would happen if tariffs were mean-reverting, such that initial reductions tend to be followed by increases. The h-period change in trade flows thus conflates the impact of initial and subsequent tariff changes. Below we show that in the data, tariffs do continue to change following an initial impulse.

To account for this, we estimate a local projection of the h-period tariff change on the initial shock in tariffs:

$$\Delta_h \ln \tau_{i,j,p,t} = \beta_\tau^h \Delta_0 \ln \tau_{i,j,p,t} + \delta_{i,p,t}^{d,\tau,h} + \delta_{j,p,t}^{s,\tau,h} + \delta_{i,j,p}^{b,\tau,h} + u_{i,j,p,t}^{\tau,h}, \tag{2.3}$$

where the impact effect is $\beta_\tau^0 = 1$ by definition. The horizon-h trade elasticity can then be recovered as $\varepsilon^h = \frac{\beta_X^h}{\beta_\tau^h}$.

Further, we estimate the combined specification:

$$\Delta_h \ln X_{i,j,p,t} = \beta^h \Delta_h \ln \tau_{i,j,p,t} + \delta_{i,p,t}^{d,h} + \delta_{j,p,t}^{s,h} + \delta_{i,j,p}^{b,h} + u_{i,j,p,t}^{h}. \tag{2.4}$$

When $\Delta_0 \ln \tau_{i,j,p,t}$ is used as an instrument for $\Delta_h \ln \tau_{i,j,p,t}$, (2.4) is equivalent to (2.2)-(2.3), and directly identifies the trade elasticity at horizon h using the impulse at time t: $\widehat{\beta}^h$ is an estimator of ε^h. Estimating (2.4) has the advantage that standard errors for the elasticity estimates are easier to compute. To address the potential endogeneity of $\Delta_0 \ln \tau_{i,j,p,t}$, $\Delta_h \ln \tau_{i,j,p,t}$ can instead be instrumented with an exogenous subset of tariff changes, as we describe below.[4]

In practice, the period length is a year and this estimation is carried out at different horizons $h = 0, ..., 10$, to trace the full profile of ε^h over $h \leq 10$. If the estimates of β_X^h and β_τ^h stabilize within 10 years of the shock, we interpret it as convergence of both the numerator and the denominator in (2.1), rendering our estimates informative about the long-run trade elasticity. Section 6.1 provides a detailed discussion of the convergence to the long-run elasticity in the context of a conventional class of models. While the baseline analysis estimates a single elasticity across product categories, below we also implement these specifications for broad product groups to obtain a distribution of β_p^hs.

The estimating equations (2.2)-(2.4) are deliberately not tied to a particular theory. We posit a fairly general estimating equation that can be viewed as time-differenced gravity, and our objective is to obtain a set of estimates that can potentially serve as targets for multiple theories. Indeed, it is common in both macroeconomics and trade that multiple microfoundations lead to the same estimating equation. For instance, many business cycle models have a vector autoregressive (VAR)

[4] Equation (2.3) includes the same fixed effects as equations (2.2) and (2.4). This is because when estimating the trade elasticity, these same fixed effects will also be partialled out from the tariff change on the right-hand side of equation (2.4). The estimates from (2.3) therefore illustrate the tariff dynamics after a tariff shock using the same variation that is used to estimate the trade elasticity.

representation (Sims, 1980; Canova and Sala, 2009). In trade, the gravity relationship can be derived from Armington, Ricardian, and monopolistic competition models (Head and Mayer, 2014). We relate the econometric estimates to a tractable dynamic model in Section 6. This model delivers estimating equations (2.2) and (2.3), and illustrates that the fixed effects capture dynamic analogues of multilateral resistance terms. In particular, the importer-product-time and exporter-product time effects absorb weighted averages of past, present and expected future demand and supply shifters.

Conventional estimation A common approach to estimating the long-run elasticity ε starts from a static gravity equation: $\ln X_{i,j,p,t} = \beta \ln \tau_{i,j,p,t} + \delta^d_{i,p,t} + \delta^s_{j,p,t} + u_{i,j,p,t}$, and relies on either cross-sectional variation or a single-horizon difference of this equation. The coefficient β is interpreted as an estimate of the long-run elasticity ε.

Conventional approaches cannot speak to the horizon-h trade elasticity. This is immediate for estimates in log-levels, which mostly use cross-sectional variation for identification. However, it is also true for estimates in differences. A research design that estimates an elasticity based on, say, 5-year differences in both tariffs and trade ignores the timing of tariff shocks. A 5-year tariff change of a given magnitude could be due to shocks at the beginning or the end of the five year period. As a result, a 5-year difference specification will estimate a conflation of horizon-0 to horizon-5 trade elasticities. We formalize this argument based on our model in Section 6. Appendix Proposition C.1 shows that estimation in h-period differences does not generally identify the horizon-h trade elasticity. As an example, if tariffs follow a random walk, estimation in h-period differences instead identifies the simple average of horizon-0 to horizon-h trade elasticities, but the result is of course more general than the random walk case. This observation suggests the use of macroeconometric methods such as local projections to estimate the trade elasticity.

A corollary is that estimation in long differences will not necessarily identify the long-run trade elasticity since many tariff shocks could have occurred close to the end-point of the difference. We will additionally show below that estimation approaches based predominantly on cross-sectional variation – without differencing – likely suffer from omitted variable problems. Thus, we argue that our long-run estimates are preferable to the conventional alternatives even for researchers only interested in the long-run elasticity for calibrating a static trade model.

2.3 Identification

To achieve identification, we control for omitted variables by means of fixed effects and time differencing, and propose an instrument to address residual endogeneity.

Omitted variables The importer-product-year and exporter-product-year fixed effects capture the changes in multilateral resistance terms. These control not just for the textbook multilateral resistance forces, such as time-varying importer- or exporter-product-specific demand or supply shocks, but also broad tariff changes by a country across a number of products simultaneously, and any aggregate effects of tariffs, such as trade-induced technology upgrading.

It has been recognized that unobserved bilateral taste or trade cost shifters are important for the variation in trade flows. If these shifters are correlated with tariffs, not accounting for them in estimation leads to omitted variable bias. For instance, if consumers in a particular importing country have idiosyncratically high taste for products from a particular exporter, the policymaker might set lower tariffs on those imports. In their Handbook chapter Head and Mayer (2014, p. 162) recommend including bilateral fixed effects. Indeed, some papers in the literature control for bilateral unobservables via either bilateral fixed effects (see, among others, Lai and Trefler, 2002; Baier and Bergstrand, 2007; Shapiro, 2016; Donaldson, 2018), or time-differencing (e.g Feenstra, 1994; Head and Ries, 2001; Romalis, 2007; Imbs and Mejean, 2015). For this reason, our estimating equations are time-differenced, which removes all time-invariant importer-exporter-product-specific determinants of bilateral product-level trade flows. After presenting the main results, Section 5.2 provides a detailed treatment of this point, and shows that controlling for bilateral unobservables is the key reason for the comparatively low elasticity estimates we report.

In addition, our baseline specifications include source-destination-product fixed effects, that absorb trends in product-specific impacts of bilateral resistance forces like distance, as well as trends in bilateral taste shocks for a product, that could be correlated with tariffs applied on the product.

Residual endogeneity in changes Despite fixed effects and differencing, an identification problem can still arise from time-varying, bilateral, non-tariff barriers, or other time-varying, bilateral product-specific supply or demand shocks. In practice tariffs are set by governments which, in turn, are influenced by lobbyists, and subject to the WTO policy framework. There are three concerns with viewing applied tariff changes as exogenous. First, it is possible that a third factor in the importing country drives both tariff changes and changes in trade flows. A newly elected government, for instance, could change not only tariffs but also other policies that affect import demand. In a similar spirit, business cycle fluctuations could induce governments to change tariffs (Bown and Crowley, 2013; Lake and Linask, 2016). Again, imports would change in part because of the tariff change, and in part due to the changes in economic conditions. Further, a taste shock for a product from a specific source country could trigger both larger imports of the product and lower tariffs on that product due to lobbying. Second, there could be reverse causality, whereby the importer's government changes tariffs because of observed or anticipated changes in trade patterns (e.g. Trefler, 1993). Third, foreign governments could influence the importer's government to change tariffs, either through the WTO body, or through other channels (Gawande, Krishna, and Robbins, 2006; Antràs and Padró i Miquel, 2011).

Instrument An instrument for tariff changes is difficult to find, as changes in trade policy are unlikely to ever be orthogonal to economic activity in general and trade flows in particular. We turn to the WTO's MFN tariff system to construct a plausibly exogenous instrument. All WTO member countries are bound by treaty to apply tariffs uniformly to all other WTO countries. Thus, when a WTO country changes its MFN tariffs, those tariffs change for all of its partners that trade on MFN terms. Of course, when a country changes its MFN rate on a product, it might do so due to concerns about contemporaneous imports from an important partner country, or lobbying by an important partner country.[5] The baseline instrument uses the insight that third countries are also affected by this tariff change if they are MFN partners. From the point of view of these third countries, the tariff change is plausibly exogenous. The response of imports from these third countries can then identify the trade elasticity. As a control group we use countries to whom the MFN tariff change does not apply because they do not trade on MFN terms. These are countries in preferential trade agreements (PTAs).

Our baseline instrument is:

$$\begin{aligned}\Delta_0 \ln \tau_{i,j,p,t}^{instr} \quad = \quad & \mathbf{1}\left(\tau_{i,j,p,t} = \tau_{i,j,p,t}^{\text{applied MFN}}\right) \times \mathbf{1}\left(\tau_{i,j,p,t-1} = \tau_{i,j,p,t-1}^{\text{applied MFN}}\right) \\ & \times \left[\ln \tau_{i,j,p,t}^{\text{applied MFN}} - \ln \tau_{i,j,p,t-1}^{\text{applied MFN}}\right], \end{aligned} \tag{2.5}$$

together with the sample restriction that observations are dropped if both

$$\begin{aligned} & \mathbf{1}\left(\tau_{i,j,p,t} = \tau_{i,j,p,t}^{\text{applied MFN}}\right) \times \mathbf{1}\left(\tau_{i,j,p,t-1} = \tau_{i,j,p,t-1}^{\text{applied MFN}}\right) = 1 \\ & \text{and} \\ & \mathbf{1}\left(j \text{ is a major trading partner of } i \text{ in } t-1 \text{ in aggregate}\right) \\ & +\mathbf{1}\left(j \text{ is a major trading partner of } i \text{ in } t-1 \text{ in product } p\right) \\ & +\mathbf{1}\left(j \text{ is a major trading partner of } i \text{ in } t \text{ in aggregate}\right) \\ & +\mathbf{1}\left(j \text{ is a major trading partner of } i \text{ in } t \text{ in product } p\right) > 0. \end{aligned} \tag{2.6}$$

We estimate equations (2.2) and (2.3) with $\Delta_0 \ln \tau_{i,j,p,t}^{instr}$ as an instrument for $\Delta_0 \ln \tau_{i,j,p,t}$ and equation (2.4) using $\Delta_0 \ln \tau_{i,j,p,t}^{instr}$ as the instrument for the h-year endogenous tariff change $\Delta_h \ln \tau_{i,j,p,t}$. The two indicator functions on the first line of (2.5) simply say that the applied MFN tariff is binding for the countries and product in question both in the pre-period $t-1$ and the impact period t. The term $\ln \tau_{i,j,p,t}^{\text{applied MFN}} - \ln \tau_{i,j,p,t-1}^{\text{applied MFN}}$ is simply the log change in the tariff from $t-1$ to t.

In addition, we impose a sample restriction specified in (2.6). In words, we drop from the sample the

[5] Lagged imports are included as a pre-trend control in most of our specifications, so they do not pose a threat to identification.

MFN trade flows in which exporter j is a major trading partner of importer i, either in terms of j's total exports to i, or in terms of exports to i in product p, where p is an HS4 product group. In our baseline a partner is major when it is a top-10 exporter to market i. We presume that endogeneity concerns that persist after the fixed effects will mostly apply to the importer's major MFN trading partners. Thus, major MFN partners, either in terms of total trade flows or product-level trade flows, are dropped from the sample. We stress that the classification into major and minor trading partners is from the perspective of each individual importer and product. Section 5.1 shows that this filter does not produce a treated group composed of only small countries. This is because large countries are often minor trading partners from the perspective of individual importing countries.

Discussion To succinctly state the source of the identifying variation: we compare the changes in imports from countries hit by a plausibly exogenous tariff change to the changes in imports from countries to whom those tariff changes did not apply.[6] The "treatment" countries experienced tariff changes because they are part of the MFN system. The "control" countries did not experience the MFN tariff changes because they trade on different terms. Note that the IV strategy is more than simply a sample restriction to minor MFN partners. Importantly, it constrains the identifying variation to MFN tariff changes. By doing so, the instrument sets up a comparison between treated and control observations, and is thus an "instrumented difference-in-differences."

Our approach thus follows the long tradition in the literature of estimating the trade elasticity based on the comparison of trade flows across product-country pairs subjected to differential tariff changes. It is well-understood that this strategy is correct and internally consistent in an environment with sector-level isoelastic gravity (see, e.g., the Handbook chapter by Head and Mayer, 2014), which characterizes the large majority of both empirical and theoretical work in trade. This environment allows for the "non-treated" (non-MFN or control group) trade flows to change following a tariff change in the treated group. That is, if an importing country raises its MFN tariffs, imports from non-MFN source countries can increase, as would be predicted by any CES aggregator. Our gravity-based approach will still correctly identify the elasticity, as long as importer-product multilateral resistance terms are used in estimation. We include such multilateral resistance terms in all baseline specifications.

Section 5.3 contains further discussion of threats to identification, alternative instruments, as well as extensive robustness checks.

[6]Because our differenced specification includes importer-exporter-HS4 fixed effects, the statement above should be strictly speaking interpreted as referring to deviations from importer-exporter-HS4-specific trends. We show in Section 5.2 and Appendix Figure B4 that this aspect of our empirical strategy is not crucial to the results.

2.4 Institutional background

When countries join the WTO, their accession treaty sets maximum MFN tariff rates ("bounds") that they can impose on imports from WTO member countries. These MFN bounds are country- and product-specific, and vary from very low rates for developed countries and large economies to much higher rates for developing countries. For instance, the average bound rate is 3.5% in the US, 10.0% in China, and 48.6% in India. The number of products covered by the bounds is also negotiated and varies by country. In many countries, including the US and China, 100% of products are covered by the bounds. By contrast, 74% of products are subject to MFN bounds in India, and 50% in Turkey. The bounds themselves vary substantially across products. In the US in 2015, about 40% of products had a bound of 0, while about one-tenth of products had bounds above 10%.[7] Once these MFN bounds are set, they rarely change, except in subsequent rounds of WTO negotiations. As such, changes in MFN bounds do not provide sufficient variation for an instrument.

In practice, actual applied MFN tariffs are frequently far below the bounds. Thus, countries can and do legally vary their applied tariffs below the bounds. Some motives are business-cycle related. For instance Turkey raised a number of MFN tariffs temporarily around its financial crisis. The tariffs were lowered again post-crisis. Similar patterns were observed in Argentina. Sometimes the rationale for changing the MFN rates is less clear – India raises and lowers tariffs on varied products year-to-year. Such tariff changes are potentially endogenous, necessitating both the inclusion of a rich set of fixed effects (to remove business cycles and broad partner-specific variation), and an identification strategy to deal with residual endogeneity.

3 Data and Basic Patterns

Our trade dataset is the BACI version of UN-COMTRADE, covering years 1995-2018. The data contain information on the trade partners, years, and product codes at the HS 6-digit level of disaggregation, as well as the value and quantity traded. We link these data to information on tariffs from the TRAINS dataset, also covering 1995-2018. This database reports the applied and the MFN tariff rates. The applied tariffs can differ from MFN tariffs for country pairs that are part of a PTA. Unfortunately, for many countries comprehensive information on tariff rates is often not available before they join the WTO. The sample covers 183 economies and over 5,000 HS6 categories.

We drop observations for which trade is subject to non-ad valorem (specific or nonlinear/compound) tariffs. For these tariffs TRAINS reports ad-valorem equivalents. However, computation of these equivalents requires data on quantities, which are often noisy and could also endogenously respond to changes in tariffs. Since the large majority of MFN tariffs are ad valorem, the impact of dropping

[7]Further details can be found in Bown and Crowley (2016). We are grateful to Chad Bown for useful suggestions and examples.

these observations for our sample size is small.[8] Detailed documentation on the construction of our tariff data from the raw TRAINS data is available in Appendix A. For robustness exercises, we also use data containing information on standard gravity variables such as distance, common border, common language, etc., from CEPII.

The most detailed product classification available in the trade data is at the HS6 level. However, we face the constraint that the data are provided in several different revisions of HS codes. Further, even within the same year, countries sometimes report trade flows in different vintages of HS codes.[9] While some concordances of HS6 codes over time are available, we do not implement these fully as they necessitate splitting values of trade across product codes in different revisions or aggregating product codes. As we do not observe transaction-level trade, any such split will introduce composition effects into our tariff measures. For instance, we could have spurious tariff changes coming from averaging tariffs when product codes are combined over time. Instead, our definition of a product is an HS6 code of a specific revision, tracked over time. We link product codes across revisions only when there is a one-to-one mapping between the codes across revisions. This approach is conservative, but it does reduce the effective sample size – and hence widens the standard errors – for any very long run elasticity estimates, as over a longer horizon there will be fewer product codes that map uniquely across revisions. Hence, the maximum horizon over which we estimate the trade elasticity in the baseline analysis is 10 years, which typically corresponds to only two HS revision transitions. Appendix Table A1 provides the fraction of codes that map uniquely across revisions. In a single revision transition, on average 89% of product codes have a unique mapping.[10] In a small number of instances, the meanings of HS4 (and therefore HS6) codes change across revisions, which would imply that importer-exporter-product fixed effect categories combine substantively different products across time periods. We manually identified those instances and eliminated them.

While HS6 product lines are often the most detailed level at which applied tariffs vary, a few countries have tariffs that vary within HS6 product groups (for instance at the HS8 or HS9 level). We do not have trade flows at a more detailed level, so we assess the robustness of our results to excluding series where countries apply different MFN tariffs within an HS6 product group.

The values of trade flows reported in these data are not inclusive of tariffs. Thus, the elasticities estimated by our procedure are tariff-exclusive, and must be appropriately adjusted to obtain the elasticity relevant from the consumer's perspective.[11]

[8] Among the 148 WTO members in 2013, the median fraction of HS6 products covered by non-ad valorem tariffs is 0.01%, and the mean fraction is 1.76% (World Trade Organization, 2014).

[9] As far as we are aware, there is no double counting of trade flows reported under different HS revisions.

[10] Naturally, alternative specifications that include several lags of tariff changes require longer horizons than ten years, reducing the sample size and increasing the standard errors of the estimates.

[11] Section 6.1 contains the complete discussion. As an example, if the underlying model is Armington, our long-run estimates would correspond to the elasticity in the CES aggregator $-\sigma$, while the trade elasticity inclusive of tariffs would be $1 - \sigma$.

Patterns in tariff changes Figure A1 plots histograms of tariff changes. It shows that while tariff decreases are more frequent, still a substantial share of tariff changes in our data are increases. Further, the treatment and the control group both experience a range of tariff changes. Note that our identification strategy does not require the control group to experience no tariff changes. Since our specifications include importer-product-time fixed effects, we exploit differential changes in MFN and non-MFN tariffs for identification. Below we also check the robustness of our estimates by removing from the control group observations in which non-MFN tariffs change. Figure A2 plots the autocorrelation function of tariff changes in our data. It highlights a negative first-order autocorrelation. This pattern motivates the use of time-series methods that explicitly account for the fact that impact tariff changes are not fully permanent, but partially reversed in subsequent periods.

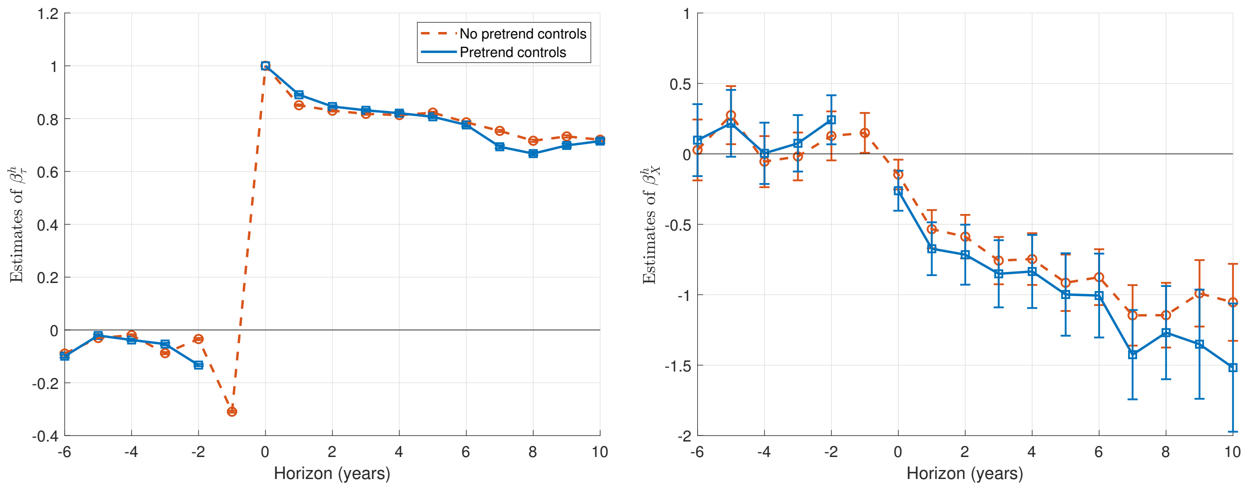
Appendix A presents additional summary statistics about our sample: (i) the average share of imports by destination (Figure A3) and by product (Figure A4); and (ii) the incidence of MFN and non-MFN trade (Figure A5) in the sample.

Examples of the treatment/control assignments Appendix Table A2 provides an illustration of how the instrument is implemented. As our instrument is defined at the product level, we illustrate it for a 4-digit HS code 6403, "Footwear; with outer soles of rubber, plastics, leather or composition leather and uppers of leather." For three large importers (the USA, Japan, and Germany) in 2006, we list partner countries that fall into each of the following three categories: treatment group, control group, and excluded group.

Columns 1-2 list the 10 largest MFN trading partners at $t-1$ and t. Trading on MFN terms is the first criterion for being assigned to the treatment group. (Of course, there are many more than 10 countries in this category). Columns 3-4 list the 10 major trade partners in terms of aggregate trade. These countries are disqualified from the treatment group. Columns 5-6 list the 10 major trading partners for the product code HS 6403. These are also disqualified from the treatment group. As expected, there is imperfect overlap between the set of major partners overall and in a specific HS4 code.

After these countries are dropped from the treatment group, columns 7-9 list the treatment, control, and excluded groups. As the table highlights, for the US NAFTA countries such as Canada and Mexico are important in the control group. The excluded group comprises large trading partners like Germany, China, and France, but also smaller economies such as Vietnam that are important exporters of footwear to the US. The treatment group includes smaller trading partners in footwear who trade at MFN rates, such as Portugal, Poland, Slovakia, and Hungary. While we do not incorporate explicit data on regional trade agreements, the instrument design appropriately assigns countries in customs unions or PTAs to the control group. For Germany, for instance, EU member countries do not appear in the treatment group, and are only part of the control group.

Figure 1: Local Projections: Tariffs and Trade



Tariffs　　　　Trade

Notes: This figure displays the results from estimating equations (2.2) and (2.3) – the local projection of h-period tariff growth (left panel) and h-period import growth (right panel) on the tariff change from $t-1$ to t, instrumented with our baseline instrument (2.5). For negative time horizons the dependent variable is the one-year log change in tariffs (left panel) and trade (right panel). All specifications include exporter-HS4-year, importer-HS4-year, and exporter-importer-HS4 fixed effects. The specification with pre-trend controls additionally includes log-changes in tariffs from $t-2$ to $t-1$, instrumented with our baseline instrument, and log-changes in trade from $t-2$ to $t-1$. The bars display 95% confidence intervals. Standard errors are clustered at the country-pair-product level.

4 Main Results

We begin by estimating the effects of a one-period tariff change on h-periods ahead trade flows and tariffs, as in equations (2.2)-(2.3), using our instrument as described above. For the baseline estimation, the product disaggregation for the fixed effects is at the HS4-level.[12] We also exclude trading partners based on a classification into major and minor at the importer-HS4-level. The left panel of Figure 1 reports the time path of tariff changes h periods after the initial one percent change. Thus, by construction the $h=0$ coefficient is 1. A partial mean reversion in tariff changes is evident: following the initial impulse, about 80% of the change remains after 5 years, and approximately 75% after 10 years. At the same time, the pattern shown in the figure is contrary to the hypothesis that our low elasticity estimates may come from using temporary/short-term tariff changes as the source of variation. Figure 1 makes clear that the large majority of the initial tariff change persists for (at least) a decade. These results illustrate the need for an estimation method that takes explicit account of the non-trivial time series behavior of tariffs.

[12] With many fixed effects, standard errors may be biased downward if there are many "singleton" observations that are perfectly absorbed by a fixed effect (Correia, 2015). The routine we use drops singleton observations from the sample prior to estimation, addressing this concern.

The figure suggests a presence of a pre-trend. A tariff increase of one percent is preceded by a reduction of approximately 0.3 percent in the pre-period, reflecting again the negative first order autocorrelation highlighted above. We thus include a lagged pre-trend control for both tariffs and trade in our baseline estimates throughout and instrument the lagged tariff change with a lag of our MFN tariff instrument. The blue lines in Figure 1 depict the estimates after including the pre-trend controls. They make little difference to the results. We include additional lags in robustness checks.

The right panel of Figure 1 displays the impact of an initial one percent tariff change on trade flows. Trade falls gradually and stabilizes between 1 and 1.5 percent after 7 to 10 years. Unlike for tariffs, there is no evident pre-trend in trade flows, regardless of whether we use pre-trend controls, ruling out an important role for anticipation effects. Including the pre-trend control modestly amplifies the point estimates of the effect of the tariff shock on trade values at longer horizons, though the difference is not significant. Columns 1 and 4 of Appendix Table B1 report the estimated impulse response coefficients and standard errors for tariffs and trade, respectively.

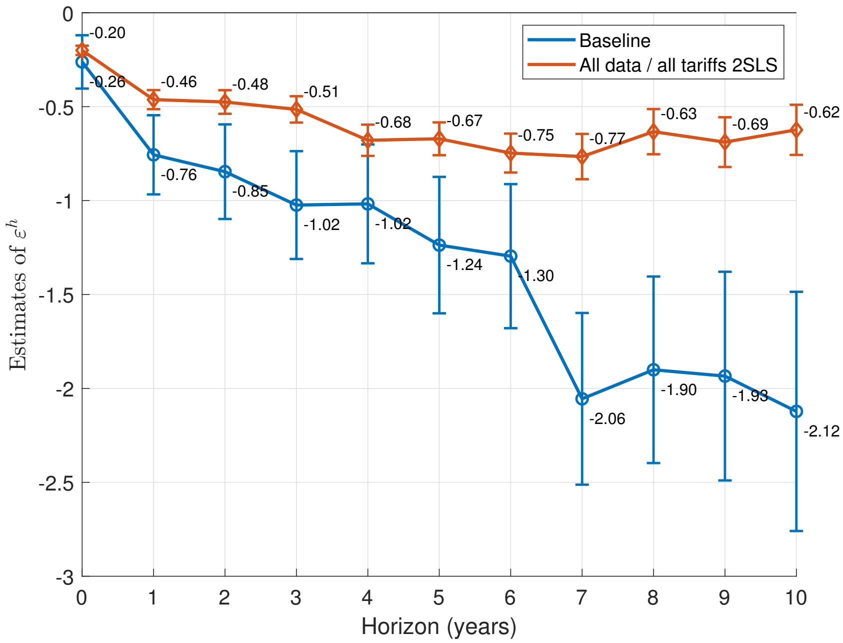
Figure 2 reports the baseline estimates of the trade elasticity ε^h across horizons. The impact ($h = 0$) elasticity is -0.26. Our data are annual, and it is unlikely that all tariff changes go into effect on January 1. Thus, we do not focus attention on the impact elasticity as it can be low due to partial-year effects. The point estimate in the year following the tariff change is probably a better indicator of the short-run elasticity. At $h = 1$, the elasticity estimate is -0.76. The 10-year estimate is -2.12. Over the first 7 years, the elasticity converges smoothly to the long-run value, and then is stable for years 7-10. Appendix Table B2 reports the first stage F statistics, which indicate that the instrument is very strong. The point estimates of the horizon-specific elasticities are displayed in the figure.

Our short-run elasticities are similar to the low elasticities of trade flows to exchange rates typically found in the literature (e.g. Hooper, Johnson, and Marquez, 2000; Fitzgerald and Haller, 2018; Fontagné, Martin, and Orefice, 2018), and lend some support to the assumption often adopted in international business cycle literature that the Armington elasticity is below 1 (e.g. Heathcote and Perri, 2002).

The red line in Figure 2 reports the "all data/all tariffs 2SLS" estimates. This specification implements (2.4) on all the available data (i.e. without dropping major partners) and instrumenting the horizon-h tariff change $\Delta_h \ln \tau_{i,j,p,t}$ with the initial tariff change $\Delta_0 \ln \tau_{i,j,p,t}$. As discussed in Section 2, using only the initial tariff change variation allows us to estimate the horizon-h trade elasticity. In contrast, estimation in long differences conflates trade elasticities of different horizons (see Appendix Proposition C.1).[13] At horizon 0, this approach amounts to a standard OLS estimation in differences.

[13] Additionally, relying on higher frequency variation typically reduces confounding.

Figure 2: Trade Elasticity: Baseline and All Data/All Tariffs 2SLS



Notes: This figure displays estimates of the trade elasticity based on specification (2.4), and including one lag of the changes in tariffs and trade as pre-trend controls. 2SLS estimates with the baseline instrument (2.5) are in blue, and all data/all tariffs 2SLS estimates are in red. All specifications include exporter-HS4-year, importer-HS4-year, and exporter-importer-HS4 fixed effects. The bars display 95% confidence intervals. Standard errors are clustered at the country-pair-product level.

Note that because this strategy uses all tariff changes rather than the exogenous subset, it is subject to the concern that tariff changes are endogenous. Thus, the economic interpretation of these 2SLS horizon-h estimates should be in the spirit of OLS.

All data/all tariffs 2SLS actually produces a significantly smaller trade elasticity than our baseline IV at all horizons, a finding we revisit in Section 5.2. A substantive explanation for our baseline IV estimates being larger in absolute value than the all data/all tariffs 2SLS is that – conditional on all the fixed effects – tariffs are endogenously higher when imports are also high. One possible rationalization of this pattern is that greater import competition leads to more intense lobbying for protection. Trefler (1993) formalizes this argument, and shows that accounting for this type of endogeneity in US non-tariff barriers increases coefficient estimates of their impact of trade substantially.

Our estimates of β_X^h, β_τ^h, and ε^h should be interpreted as averages in the following sense. For a given size shock to tariffs, the subsequent evolution of tariff changes likely differs across shocks in our sample. Further, the responses of tariffs and trade could depend on the initial state of the world, they could vary by country pair, and/or depend on the product p for which the tariff changes.

The estimation approach above will effectively average tariff and trade responses over all shocks, all evolutions of tariffs, all initial states of the world, and all country-pairs and products. We now relax this assumption somewhat and report elasticities for broad product groups.

4.1 Sectoral heterogeneity

HS codes are organized into 21 sections that are consistent across countries. These sections describe broad categories of goods, such as "Live Animals, Animal Products" (Section 1). In practice, there is insufficient tariff variation in some of these sections to obtain precise estimates of the elasticity at all horizons. Thus, we combine a few of the sections together, leaving us with 11 sections. Appendix Table A3 describes the sections and lists the sections that are aggregated.

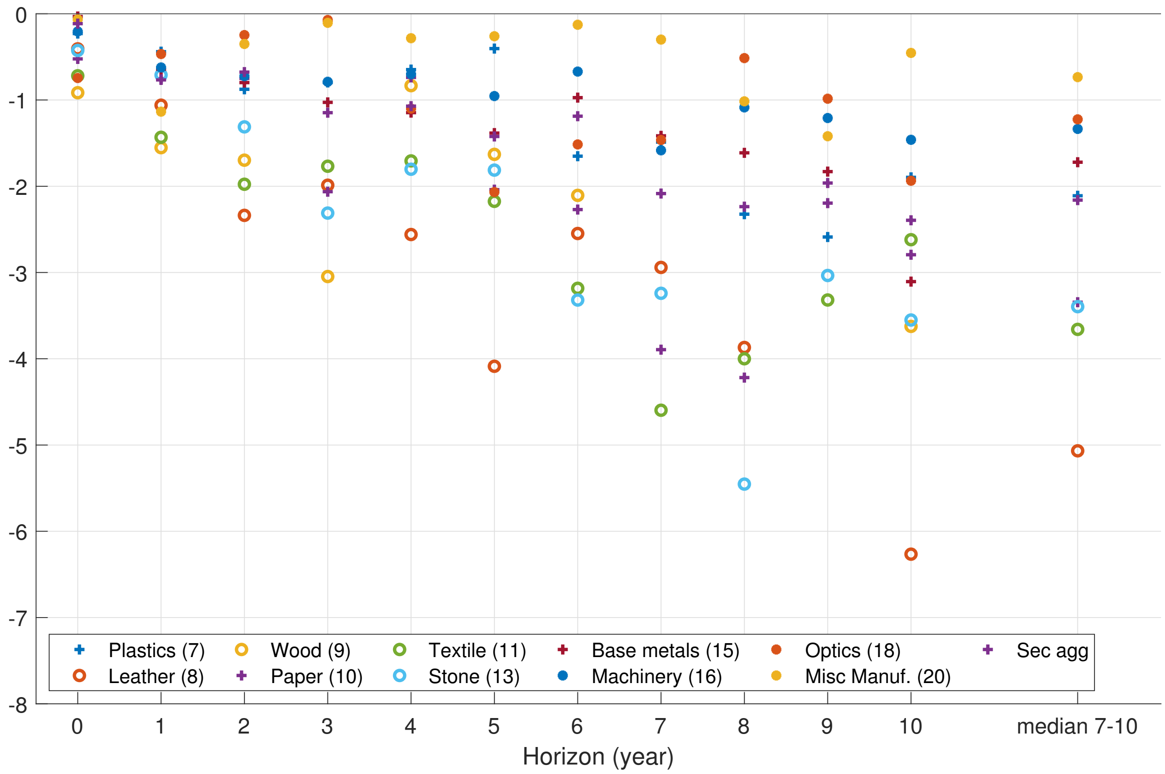
Figure 3 plots the point estimates of the trade elasticities over h for the 11 HS product groups. To contain the role of estimation error, we also report the median of the estimates across horizons 7 to 10 for each product group in the figure. The long-run elasticities range from -0.75 to approximately -5 even in this coarse sectoral breakdown. The highest elasticities are in HS sections 8 (leather articles), 11 (textiles and apparel), whereas the least elastic sections are 18 (optical and precision instruments) and 20 (miscellaneous manufacturing). In addition, the elasticities fan out over time. The range at $h = 1$ is from -0.5 to about -1.5, much narrower than the long-run range.

One might be concerned that the headline elasticity values in the baseline analysis are unrepresentative of world trade, if product groups with higher or lower elasticities predominate in the data. Appendix Figure B1 plots the baseline horizon-specific elasticities from Figure 2, together with the world-trade-weighted mean and median of the sector-specific elasticities reported in Figure 3. The trade-weighted mean elasticities essentially coincide with the pooled baseline estimates, allaying compositional concerns. The trade-weighted median elasticities exhibit a similar time path but are, if anything, closer to zero.

5 Additional Results and Robustness

We have now presented the main estimation results of the paper. This section explores our findings in greater detail. In particular, it (i) shows that our estimates are identified from broad variation representative of countries and sectors; (ii) discusses the relationship between our estimates and the conventional wisdom values in the literature, uncovering the source of the differences; (iii) reports a large battery of robustness checks. Together, these exercises demonstrate that our estimates are both quite stable and are not an artefact of non-representative data or non-standard estimation strategies.

Figure 3: Trade Elasticity: Sectoral Heterogeneity



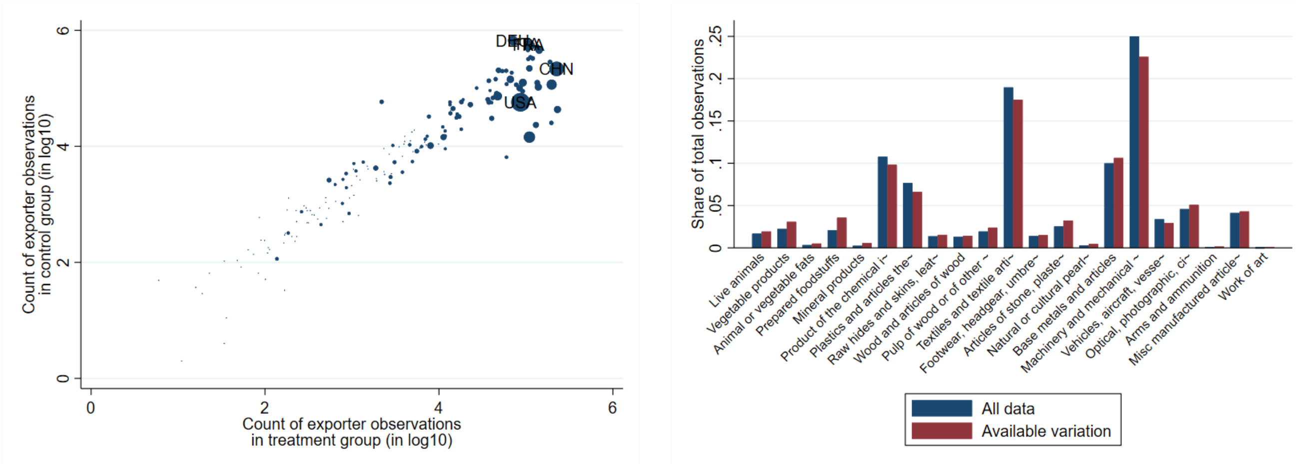
Notes: This figure displays the trade elasticity point estimates by HS Section based on specification (2.4) and using the baseline instrument (2.5). All specifications include exporter-HS4-year, importer-HS4-year, and exporter-importer-HS4 fixed effects as well as one lag of the log change in tariffs and trade. Some HS Sections are grouped into a single aggregate section "Sec agg" as described in the text.

5.1 Identifying variation

One might be concerned that the coefficient estimates are identified from special and/or non-representative segments of world trade. One possibility might be, for instance, that dropping major trading partners leaves a treated group composed of only small developing countries. Another possibility is that tariff changes might occur predominantly in products that account for relatively little of world trade. These potential concerns would be exacerbated by the large number of fixed effects, that further sweep out "singleton"-like observations, for instance, in cases in which the entirety of an importer-product trade is carried out on MFN basis.

To better understand the identifying variation in the data, we regress the one year (Δ_0) change in log trade flows and tariffs on the full set of fixed effects, and discard observations that are perfectly explained by the fixed effects. In this step we also impose the sample restriction that drops major trading partners. The resulting sample reflects the variation in trade flows and tariffs that is poten-

Figure 4: Country and Product Variation



Countries HS Sections

Notes: The left panel displays the scatterplot of (base 10) log counts an exporter appears in the control group on the vertical axis against the log count the same country appears in the treatment group on the horizontal axis. The size of the circle is proportional to relative country size as measured by GDP. The plot is based on a residualized sample from which importer-HS4-year, exporter-HS4-year, and importer-exporter-HS4 fixed effects have been taken out, and the sample restrictions have been imposed. The right panel displays the sectoral distribution of all trade data in our sample (blue bars), and the residualized sample after fixed effects have been taken out and the sample restrictions have been imposed (red bars).

tially available to identify the coefficients of interest. The observed patterns are reassuring on several fronts. The left panel of Figure 4 plots the (log) counts of instances countries appear as treatment or controls in the residualized data. The relative size of the circle reflects country GDP. It is apparent that the same countries appear in both treatment and control groups, and indeed economies large in absolute size are frequently in the treatment group. The figure rules out the possibility that identifying variation comes from very small or esoteric countries. It also allays the concern that the control group countries are dramatically different from the treatment group. Appendix Figure B2 displays the frequency of country appearance in treatment or control group against per-capita income. It is evident that a broad range of income levels is represented in both treatment and control groups.

The right panel of Figure 4 plots the distribution across HS sections. The blue bars plot the shares of observations of all trade data. The red bars display the shares of observations remaining in the residualized data after the fixed effects are taken out and sample restrictions imposed. The available variation is spread across all broad product groups, and is representative of the unconditional sectoral distribution of trade. The figure thus suggests that we are not identifying our elasticity coefficients from sectorally un-representative trade flows. Appendix Figure B3 plots the frequency of different product groups in our residualized data at a finer level of sectoral disaggregation (HS2).

5.2 Relationship to other estimates

Our preferred IV estimates of the trade elasticity are -0.76 in the short run, falling to about -2 in the long run. These are substantially smaller in absolute value than the conventional wisdom of -5 to -10 (see for instance the review in Anderson and van Wincoop, 2004). To get a sense of the range of existing values, Appendix Table B3 summarizes the data, methods, and elasticity estimates of the set of papers closest to ours. These are the studies that use tariff variation in a gravity framework. Closest to our approach in terms of level of aggregation and spirit of the exercise are Hummels (2001), Hertel et al. (2007) and Fontagné, Guimbard, and Orefice (2022) (disaggregate data, log-levels specification, some bilateral gravity controls) and Romalis (2007) (diff-in-diff in the cross section, HS6 data). Also closely related are the papers that use firm-level data and rely on variation in MFN vs. non-MFN tariffs (Bas, Mayer, and Thoenig, 2017; Fitzgerald and Haller, 2018). All in all, the range is quite wide and encompasses our estimates. Our values are at the low end of the range in Romalis (2007), and broadly consistent with the horizon-specific aggregated elasticities in Fitzgerald and Haller (2018). There are a number of potential reasons we would not expect the estimates to line up exactly, including our substantially larger country sample, longer and non-overlapping time period, use of local projections to estimate the entire time path while accounting for the timing of shocks, and use of an instrument.

Table 1 investigates the sources of these differences formally. Columns 1-2 of the table estimate the elasticity using a log-levels OLS specification, assuming all tariff variation is exogenous, similar to papers such as Head and Ries (2001). This specification, both without fixed effects and with the most commonly used multilateral resistance fixed effects (importer-product-time and exporter-product-time, as in e.g. Hummels, 2001), yields values between -3.7 and -7.0, similar to previous estimates.

However, as argued above, failing to control for bilateral unobservables can bias the OLS estimates if these bilateral unobservables are correlated with tariffs. Columns 3-4 include country-pair-product fixed effects and time-difference the data by 5 years, respectively. Such fixed-horizon differencing is similar to the approach used by Feenstra (1994), for instance. In both cases, the elasticity estimates fall sharply to around -1. Thus, as recognized in several important contributions in the literature, controlling for unobserved bilateral determinants of trade either with fixed effects or by differencing is important for obtaining reliable estimates.

As discussed in Section 2.2, while long-differencing tackles the concern about bilateral unobservables, it ignores the timing of tariff shocks. Accounting for the timing of the shock might be important for estimating longer-run elasticities. Column 5 instruments the 5-year change with the initial tariff change ("all-data/all-tariffs" estimation) to account for the timing of tariff changes. For closer com-

Table 1: Elasticity Estimates: Alternative Approaches

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Log Levels			5-year Log Differences					10-year
	No FE	Multilateral FE	Multilateral + Bilateral FE	OLS	2SLS	Baseline IV			
$\ln \tau_{i,j,p,t}$	-3.70***	-6.96***	-1.04***	-0.66***	-0.47***	-1.17***	-1.11***	-1.24***	-2.12***
	(0.02)	(0.05)	(0.02)	(0.02)	(0.03)	(0.11)	(0.12)	(0.19)	(0.33)
R^2	0.01	0.38	0.57	0.18					
Obs	107.1	106.2	104.9	38.1	38.1	21.4	21.1	16.7	8.31
First stage F					554972	39917	36815	13428	4957
Fixed effects									
Imp×HS4×year, Exp×HS4×year		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Imp×Exp×HS4			Yes				Yes	Yes	Yes
Pre-trend controls								Yes	Yes

Notes: This table compares alternative approaches of estimating trade elasticities. The dependent variables are log levels of trade values (columns 1-3) and log-differences of trade flows (columns 4-9), and the independent variable of interest is the log of tariffs (columns 1-3), 5-year log-differences of tariffs (columns 4-8), and the 10-year log-difference of tariffs (column 9). Column 1 reports the results with no fixed effects. Column 2 adds importer-HS4-year and exporter-HS4-year fixed effects. Column 3 further adds importer-exporter-HS4 fixed effects. Column 4 estimates the coefficient by OLS. Column 5 reports the all data/all tariffs 2SLS as explained in the text. Columns 6-9 present the results using our baseline IV. The specifications with pre-trend controls additionally include log-changes in tariffs from $t-2$ to $t-1$, instrumented with our lagged baseline instrument, and log-changes in trade from $t-2$ to $t-1$. The reported R^2s include the explanatory power of the fixed effects. Standard errors clustered by country-pair-product are in parentheses. *** denotes significance at the 99% level. Numbers of observations are reported in millions.

parison to Column 4, we do not include pre-trend controls. The estimates are similar to the 5-year differencing. While quantitatively this adjustment does not change the estimates much, we caution that accounting for the timing of the shock may matter in other instances. As discussed in Section 2.2 and Appendix Proposition C.1, estimation in simple h-period differences does not generally identify the horizon-h trade elasticity.

Columns 6, 7 and 8 report IV estimates using our baseline instrument, varying the importer-exporter-HS4 effects and pre-trend controls. The elasticity estimates have a tight range between -1.11 and -1.24 at the five year horizon, demonstrating that the importer-exporter-HS4 fixed effects and pre-trend controls do not play an important role in the differenced specifications (more on this below). Relative to the OLS estimates in column 4, and consistent with the main results above, instrumental variables push the estimates away from 0. Finally, column 9 presents the 10-year baseline estimates. The coefficient increases substantially in absolute value from -1.24 to -2.12.

To summarize, there are 4 lessons from this exercise. First, controlling for bilateral unobservables drastically lowers the estimated elasticity, by a factor of about 3 to 7. Second, accounting for residual endogeneity by means of the instrument increases the estimated absolute value of the elasticity substantially, also evident in Figure 2. Using our baseline IV more than doubles the 10-year elasticity estimate. Third, the results in Figure 2 and Table 1 caution against using fixed-window differencing over a small number of years and interpreting the result as the long-run elasticity. In our estimates, the elasticity at 10 years is 71.5% greater than at 5 years, indicating that the adjustment to the trade cost shock is not completed after 5 years. Estimation in levels does not solve this issue. As evident in column 3 of Table 1, a levels specification with bilateral fixed effects still produces an elasticity that is much too low when interpreted as a long-run elasticity. And fourth, simple differencing does not take into account the time path of tariffs, and therefore can produce incorrect elasticities depending on the timing of the shocks. While our local projections approach takes this explicitly into account, this adjustment does not make an economically significant difference in the case of the 5-year horizon illustrated in Table 1.

Sample composition The relatively low headline elasticity values we report are not due to any potential lack of representativeness of our baseline sample. The log-levels specifications in columns 1-3 of Table 1 have quite similar sample sizes, as all three are estimated essentially on all of the world's trade. Thus, the large drop in the elasticity in column 3 is not due to changes in sample composition. The log-differenced specification in column 4 has fewer observations, as it requires non-zero trade flows in both beginning and end periods. The IV estimates reported in columns 5 and 6 have even fewer observations, as the sample is constrained to minor exporters. The patterns in the coefficients are nonetheless not driven by changes in the sample. Appendix Table B4 replicates Table 1 on a sample that is constant across columns. If anything, the difference between the cross-sectional estimates in columns 1-2 and the fixed effects/differenced specifications in columns 3-4 is even starker, as the cross-sectional variation implies even larger elasticity estimates in this subsample (as high as $8-11$). Section 5.3 addresses in detail a related phenomenon, namely the extensive margin of trade.

Fixed effects and omitted variables bias Another concern might be that "overcontrolling" for bilateral product-level determinants of trade by means of either high-dimensional fixed effects or differencing may remove "too much" of the variation available for the purposes of elasticity estimation. Table 2 explores whether the estimated coefficients fall because the fixed effects are absorbing an excessive amount of variation in the data. Column 1 reproduces the traditional gravity specification in log-levels without any bilateral fixed effects from Table 1. Columns 2 adds the traditional gravity controls (distance, common border, common language, and colonial relationship). Columns 3-6 add bilateral fixed effects in increasing order of resolution, starting from the coarsest possible (country-pair, as suggested by Head and Mayer, 2014), up through the country-pair-HS4 fixed effects.

The takeaway from the table is that compared to the specification with no bilateral variables, the

Table 2: Log-Level Elasticity Estimates Varying the Fineness of the Importer-Exporter Effects

	(1) No Bilateral	(2) Gravity variables	(3) Country-pair	(4) Country-pair ×HS2	(5 Country-pair ×HS3	(6)) Country-pair ×HS4
$\ln \tau_{i,j,p,t}$	-6.96***	-2.10***	-1.39***	-1.21***	-1.17***	-1.04***
	(0.05)	(0.02)	(0.02)	(0.03)	(0.02)	(0.02)
R^2	0.38	0.45	0.48	0.50	0.52	0.57
Obs	106.2	104.9	106.2	106.1	105.9	104.9
Fixed effects and Controls						
Imp×HS4×year, Exp×HS4×year	Yes	Yes	Yes	Yes	Yes	Yes
Bilateral gravity controls		Yes				
Imp×Exp			Yes			
Imp×Exp×HS2				Yes		
Imp×Exp×HS3					Yes	
Imp×Exp×HS4						Yes

Notes: This table presents the results of estimating the trade elasticity in log levels in a traditional gravity specification. The dependent variable is the log of trade values, and the independent variable of interest is the log of tariffs. Column 1 reports the results with importer-HS4-year and exporter-HS4-year fixed effects. Column 2 additionally includes common gravity variables as controls (distance, contiguity, common language, and colonial relationship). Columns 3-6 replace the observable bilateral gravity variables with progressively finer bilateral fixed effects, from importer-exporter to importer-exporter-HS4. The reported R^2s include the explanatory power of the fixed effects. Standard errors clustered by country-pair-product are in parentheses. *** denotes significance at the 99% level. Numbers of observations are reported in millions.

majority of the fall in the estimated elasticity comes from adding either the usual gravity controls, or the very coarsest bilateral fixed effect at the country-pair level (column 1 versus column 3). There are comparatively few of these (around 30 thousand relative to a sample of 106 million). Thus the concern about oversaturating the data with too many fixed effects is the least applicable for these fixed effects. And yet, it is these country-pair effects that lower the elasticity estimates the most. While by no means a formal proof, Table 2 suggests that controlling for omitted variables via either fixed effects or differencing is very much worthwhile in spite of overcontrolling concerns.[14,15]

Finally, our baseline estimation also includes country-pair-HS4 fixed effects, that in a differenced specification absorb *trends* in these bilateral shifters, rather than levels. We favor including these because we found that the results were slightly more stable across specifications under this approach. These fixed effects are not the reason for the low elasticity estimates. Appendix Figure B4 plots the time path of trade elasticity estimates under different versions of bilateral fixed effects includ-

[14]While traditional gravity controls also lead to a large drop in the estimated elasticity, the bilateral fixed effects have the advantage of additionally absorbing unobserved gravity variables and bilateral preferences, which might be only imperfectly correlated with observed gravity variables.

[15]Appendix Table B5 replicates Table 2 with multilateral resistance terms at the HS6 rather than the HS4 level. The results are virtually identical.

ing without any bilateral fixed effects. There are at most modest, and not statistically significant differences across these specifications. Omitting bilateral fixed effects actually produces a somewhat lower trade elasticity.

Measurement error A related concern is that differencing may exacerbate measurement error on the right-hand side, biasing OLS coefficients towards zero. While differencing removes a country-pair-HS6 fixed effect, amplification of residual measurement error due to differencing is not the reason behind the low elasticity estimates. As Table 2 makes clear, the coarse country-pair effects in a levels specification is sufficient to sharply lower the coefficient estimates.

More broadly, we argue that right-hand side measurement error should not be an overriding concern here for three reasons. First, our right-hand side variable is tariffs, which are statutory policy instruments less likely to be measured with error. Second, we have done extensive checks on the tariff data, and eliminated known issues such as specific or compound tariffs and product reclassifications. A few countries set tariffs at the HS8 or HS9 level, rather than the HS6 level of our data. By constraining the sample to instances of zero standard deviation in tariffs within an importer-HS6-year, we can eliminate cases in which tariffs are set at the 8-digit or 9-digit level. Doing so barely changes the estimates (see Table 4 below). Third, the solution to measurement error on the right hand side is to use an instrument, which we employ in our baseline approach. This will help if any measurement error in the instrument is not correlated with any residual measurement error in the tariff data overall. The one-year initial MFN tariff changes that form the basis of the instrument are broad, published, changes affecting the applied tariffs to several countries, and are least likely to be measured with error. Finally, even if measurement error remains an important worry, it must still be traded off against an equally important and well-recognized concern about omitted variables, as discussed in detail above.

Multilateral resistance Finally, we explore the impact of controlling for multilateral resistance terms on our estimates. This part of the empirical model is the least controversial, as it has been universally recognized since Anderson and van Wincoop (2003) that multilateral resistance terms are essential in gravity specifications. Nonetheless, it is still informative to know how estimates change if we depart from the conventional approach. Figure B5 displays the time paths of the elasticity estimates for the baseline, no multilateral resistance terms, and the multilateral resistance terms at intermediate levels of product disaggregation (im/exporter-year, im/exporter-year-HS2 and im/exporter-year-HS3). What emerges is that it is important to control for some multilateral resistance terms. Including no multilateral resistance terms at all leads to larger elasticity estimates, as large as -4 at the 8-9 year horizon. Including any multilateral resistance fixed effects sharply lowers the elasticity estimates in absolute value. In fact, coarser fixed effects lead to even lower elasticities than the baseline.

5.3 Robustness

Pre-trends and anticipation effects Tariff decreases often follow tariff increases (tariff changes are negatively autocorrelated), as shown above. Indeed, the left panel of Figure 1 reveals some evidence of a pre-trend in tariffs. We account for differential pre-trends in tariffs using the standard approach of controlling for lagged tariff and trade changes. Our baseline estimates use a single lag of both as pre-trend controls. Columns 2-3 of Table 3 report results with no lags and 5 lags, respectively, to compare the results to the baseline in column 1. The substantive conclusions change little when adding or subtracting lags, although with more lags the sample size drops substantially and the standard errors increase. Columns 1-3 and 4-6 of Table B1 reports the results of local projections of tariffs and trade flows directly on the initial tariff change, as in (2.2)-(2.3), while allowing for 1, 0 and 5 lags. Once again, the point estimates change little when adding lags.

A distinct concern is anticipation effects. Even if pre-treatment tariffs are constant, countries might begin to adjust their exports in response to an expected future MFN tariff change by the importer. We check for the presence of such anticipation effects by examining pre-trends in trade flows. Figure 1 shows no evidence of pre-trends in trade flows even without controlling for lagged changes in tariffs and trade.

Alternative samples and standard errors Column 4 of Table 3 restricts the sample so that each fixed effect is estimated from at least 50 observations. Column 5 two-way clusters the standard errors by importer-exporter-HS4 and year. In both cases the estimates and their precision change little. Column 6 reports estimates on a constant sample. While the point estimates are slightly lower in absolute value, the standard errors widen substantially. Overall, the difference from the other specifications is typically not statistically significant. This is reassuring as the constant sample conditions on positive trade flows for all time horizons. This sample likely has different characteristics than the full sample, but the stability of the estimates suggests that sample selection is not a big concern. Column 7 reports the results from an estimation where we drop observations from the control group that experience tariff changes. The estimates are slightly lower than the baseline, but not significantly so at most horizons.

Our estimated tariff impulse responses stabilize fast and are very persistent, with about 75% of the initial shock surviving 10 years.[16] This alleviates concerns that our estimates are driven by very short-run temporary MFN tariff changes. To further explore the impact of potentially more

[16]Consistent with our estimates, Bown and Crowley (2014) document that most MFN tariff changes below bounds are permanent or very persistent.

TABLE 3: Trade Elasticity, Robustness: Pre-Trends, Alternative Clustering, Alternative Samples

	Baseline (1)	No Lags (2)	Five Lags (3)	FE50 (4)	Two-way Clustering (5)	Constant Sample (6)	Alternative Control Group (7)	Extensive Case 1 (8)	Extensive Case 2 (9)
t	-0.26***	-0.15***	0.17	-0.23**	-0.26***	-0.59**	-0.19**	0.02	-0.08
	(0.07)	(0.05)	(0.14)	(0.09)	(0.10)	(0.29)	(0.08)	(0.04)	(0.06)
Obs	31.7	41.5	14.6	17.6	31.7	5.0	27.3	131.0	56.4
$t+1$	-0.76***	-0.63***	-0.13	-0.60***	-0.76***	-0.10	-0.49***	-0.48***	-0.81***
	(0.11)	(0.08)	(0.21)	(0.13)	(0.14)	(0.38)	(0.12)	(0.06)	(0.09)
Obs	26.2	32.8	12.5	15.2	26.2	5.0	22.6	108.1	49.1
$t+3$	-1.02***	-0.93***	-0.63**	-0.86***	-1.02***	-0.89*	-0.74***	-0.59***	-0.95***
	(0.15)	(0.10)	(0.31)	(0.17)	(0.20)	(0.47)	(0.16)	(0.08)	(0.11)
Obs	20.8	26.2	9.8	12.5	20.8	5.0	17.9	87.2	41.5
$t+5$	-1.24***	-1.11***	-1.15***	-1.01***	-1.24***	-0.92**	-0.79***	-0.73***	-1.18***
	(0.19)	(0.12)	(0.43)	(0.22)	(0.25)	(0.44)	(0.20)	(0.10)	(0.12)
Obs	16.7	21.1	7.3	10.2	16.7	5.0	14.3	69.7	34.6
$t+7$	-2.06***	-1.52***	-2.33***	-1.85***	-2.06***	-0.99**	-1.38***	-0.90***	-1.50***
	(0.23)	(0.15)	(0.59)	(0.27)	(0.36)	(0.49)	(0.25)	(0.11)	(0.14)
Obs	13.2	17.0	5.2	8.2	13.2	5.0	11.1	55.2	28.4
$t+10$	-2.12***	-1.46***	-2.55**	-1.76***	-2.12***	-1.82***	-1.60***	-0.94***	-1.64***
	(0.32)	(0.19)	(1.02)	(0.37)	(0.33)	(0.54)	(0.38)	(0.15)	(0.18)
Obs	8.3	11.3	3.2	5.2	8.3	5.0	6.8	35.1	19.2

Notes: This table presents robustness exercises for the results from estimating equation (2.4). All specifications include importer-HS4-year, exporter-HS4-year, and importer-exporter-HS4 fixed effects, and the baseline pre-trend controls (one lag of each the log change in tariffs and trade) unless otherwise specified. Columns 2 and 3 vary the pre-trend controls (including alternatively zero lags or five lags of import growth and tariff changes). Column 4 reports the results when the sample is restricted to fixed-effects clusters with a minimum of 50 observations per cluster. Column 6 restricts the sample to a constant sample across horizons. Column 7 reports results where the control group only contains observations with zero tariff changes. Column 8 presents results including the extensive margin using the inverse hyperbolic sine transformation for trade flows, and all zero trade observations for importer-exporter-section pair with ever positive trade. Column 9 presents results including the extensive margin using the inverse hyperbolic sine transformation for trade flows, and only zero trade observations when trade switches from zero to positive, or vice versa. Standard errors are clustered at the importer-exporter-HS4 level, except in Column 5 where they are additionally clustered by year. ***, **, and * indicate significance at the 99, 95, and 90 percent level respectively. Observations are reported in millions.

permanent tariff changes, we estimate elasticities using only the tariff changes of the Uruguay Round GATT/WTO negotiations. It is likely that firms viewed these as persistent or permanent—at least until the next successful multilateral negotiation. In practice, we constrain the sample to only MFN tariff changes during 1995-1997, which corresponds to the staggered phasing in of the Uruguay round MFN bounds. Reassuringly, we find all data/all tariffs 2SLS estimates that are not significantly different from our baseline IV coefficients (Appendix Table B8). This may suggest that the Uruguay Round tariff changes were more "exogenous" than typical tariff changes, since they resulted from protracted multilateral negotiations. Estimates using our baseline IV on the 1995-1997 sample are imprecise and not informative, as the sample size is drastically reduced.

Extensive margin Our baseline specifications are in log differences and our data are at the country-pair product level. Thus, our sample consists of instances where country-pair product flows are positive in both the initial and end periods. Many trade models emphasize exit and entry of firms into export markets (see, e.g. Melitz, 2003; Ruhl, 2008; Alessandria and Choi, 2014; Alessandria, Choi, and Ruhl, 2021; Ruhl and Willis, 2017). The firm-level entry and exit in country-pair-product markets with positive trade is already reflected in our baseline elasticity estimates.[17]

Our baseline estimation abstracts from the possibility that tariff changes lead to (dis)appearance of trade flows at the country-pair-product level. As a benchmark for how important the product-level extensive margin can be, Kehoe and Ruhl (2013) report that it contributed only 10% of the overall growth in North-American trade following NAFTA implementation. While instances of rapid economic growth and structural change – such as South Korea – can be associated with a contribution of the product-level extensive margin as high as 25%, the extensive margin plays a negligible role in trade growth under more conventional circumstances (such as US-UK trade).

To implement specifications with the product-level extensive margin, we use the differenced inverse hyperbolic sine transformation instead of log differences as suggested by Burbidge, Magee, and Robb (1988). This transformation allows us to include zero or missing trade flows, while approximating logs for larger values of the data.[18]

We stress that including zero trade observations in the sample need not increase the trade elasticity point estimates. How the point estimates change relative to the baseline depends on the relative importance of observations where trade switches from, say, zero to positive, compared to observations where trade goes from zero to zero. If a tariff falls and many zero trade observations turn positive, the elasticity will be pushed up. However, if following a tariff reduction many zero observations stay at zero, the elasticity estimate will be pushed down, since, on average, trade changes become less responsive to tariff changes.

As a result, elasticity estimates that incorporate the extensive margin are sensitive to *which* zeros are added to the sample. We report two sets of estimates. In the first, we include all available zero trade observations for exporter-HS section to any importer in instances where some exports

[17] While we cannot examine the firm-level extensive margin using our data, available empirical evidence often suggests that it is not large quantitatively. For example, Buono and Lalanne (2012) analyze the response of French firm-level exports to the Uruguay round tariff reductions, and conclude that extensive margin responses did not materially contribute to the overall changes in trade. Fitzgerald and Haller (2018) estimate that in Ireland, the contribution of the firm-level extensive margin to the long-run elasticity of trade to tariffs is less than 10%.

[18] Tariff data are typically not missing and we can always construct $\ln \tau_{i,j,p,t}$, so we do not need the inverse hyperbolic transformation for tariffs. Bellemare and Wichman (2020) highlight that caution must be used in interpreting the estimated coefficient as an elasticity, but in our case the estimated β^h can be interpreted as an elasticity. The estimated coefficient converges to an elasticity as the underlying variable being transformed (trade values in our case) takes on large enough values on average. This is the case in the trade data.

are ever observed.[19] In the second, we only include observations where trade goes from zero to positive, or from positive to zero. This approach gives the extensive margin maximum chance to increase the absolute values of elasticity estimates, in the sense that it only admits observations for which extensive margin changes actually occur. This sample restriction corresponds more closely to quantitative models and firm-level analyses where the extensive margin is active. However, it should interpreted as an upper bound on the sensitivity of trade flows to tariffs as it effectively selects the sample based on outcomes. All extensive margin estimates do not include pre-trend controls. Therefore the results in this exercise must be compared to the baseline estimates without pre-trend controls (Column 2 of Table 3).[20]

The resulting estimates in columns 8 and 9 of Table 3 can be interpreted as the elasticity inclusive of both the intensive and product-level extensive margins. When including more zeros (column 8), the point estimates are similar to the baseline initially, and smaller in the long run. We conjecture that this is because the estimation sample now includes many instances of trade being zero at both $t-1$ and $t+h$. Since these appear as zero changes in the sample, they drive down the point estimate. Column 9 reports the extensive margin response when we only include zeros in instances where trade goes from zero to positive, or from positive to zero. As expected, the 10 year elasticity including the extensive margin is slightly higher (-1.64) than the corresponding intensive margin instrumented specification without pre-trend controls (-1.46).

Alternative instruments, outcome variables, and samples The baseline instrument excludes the top 10 largest trading partners from the treatment group. Column 2 of Table 4 reports the results when we include all trading partners but restrict the variation to MFN tariff changes ("All data/MFN tariffs"). As in the baseline, the instrument is the change in the MFN tariff rate for all countries subject to the MFN tariff rate. The point estimates fall to about -0.9 for the long-run elasticity. Column 3 implements a different cutoff for major partner, by only classifying the top 5 importers as major. The resulting long-run elasticity estimate of -1.5 is between the baseline and the version

[19] That is, if country A ever exports any product in HS 1-digit section Z to importer B in any year, all the zero exports of products belonging to section Z from A to B in every year are added to the sample. This leaves out of the estimation sample export flows between pairs of countries in broad sectors that never occurred, and thus are unlikely to respond to tariff changes. A more extreme approach is to just include all the possible zeros. Predictably, this leads to even lower elasticity point estimates, as it increases the fraction of the sample in which trade flows go from zero to zero. Note that fixed effects will automatically absorb instances in which there is never any trade within a fixed effect category, and those observations will not contribute to elasticity estimates.

[20] Including pre-trend controls leads to elasticity estimates much lower in absolute value, and below the baseline (intensive margin) estimates. This appears to be due to the fact that adding zero observations adds to the sample many instances of occasional exporting, where entry is followed by exit and vice versa. As a result, the pre-trend control for lagged log change in trade has a negative sign and is a very powerful predictor of the subsequent change in trade (t-statistic of about 2000). If this part of the sample is dominated by idiosyncratic shocks that manifest themselves in occasional exporting behavior, there would be less for tariff changes to explain. Reporting extensive margin estimates without pre-trend controls thus gives the extensive margin maximum chance to produce larger elasticities relative to the baseline.

Table 4: Trade Elasticity, Robustness: Alternative Instruments, Outcomes, and Samples

	Baseline	All data/ MFN tariffs	Top-5 Maj. Partners	Quantities	Unit Values	Weighted	SD1	PTA	TTB
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
t	-0.26***	-0.28***	-0.24***	-0.18*	-0.05	-0.24***	-0.31***	-0.24***	-0.26***
	(0.07)	(0.03)	(0.05)	(0.09)	(0.06)	(0.08)	(0.10)	(0.07)	(0.07)
Obs	31.7	57.1	39.0	31.7	31.7	31.6	28.7	31.8	31.7
$t+1$	-0.76***	-0.62***	-0.67***	-0.66***	-0.03	-0.82***	-0.89***	-0.73***	-0.76***
	(0.11)	(0.05)	(0.08)	(0.14)	(0.08)	(0.12)	(0.14)	(0.11)	(0.11)
Obs	26.2	47.2	32.1	26.2	26.2	26.2	23.8	26.3	26.2
$t+3$	-1.02***	-0.65***	-0.86***	-0.81***	-0.13	-1.05***	-1.23***	-0.97***	-1.02***
	(0.15)	(0.06)	(0.10)	(0.18)	(0.10)	(0.16)	(0.20)	(0.15)	(0.15)
Obs	20.8	38.2	25.6	20.8	20.8	20.8	18.9	20.9	20.8
$t+5$	-1.24***	-0.72***	-1.08***	-1.42***	0.29**	-1.21***	-1.18***	-1.12***	-1.24***
	(0.19)	(0.07)	(0.12)	(0.23)	(0.13)	(0.21)	(0.25)	(0.19)	(0.19)
Obs	16.7	30.9	20.6	16.7	16.7	16.7	15.1	16.8	16.7
$t+7$	-2.06***	-0.94***	-1.53***	-2.17***	0.16	-2.14***	-1.99***	-1.97***	-2.06***
	(0.23)	(0.09)	(0.16)	(0.29)	(0.16)	(0.26)	(0.32)	(0.23)	(0.23)
Obs	13.2	24.6	16.3	13.2	13.2	13.2	12.0	13.3	13.2
$t+10$	-2.12***	-0.87***	-1.48***	-1.76***	-0.08	-2.37***	-2.36***	-2.08***	-2.12***
	(0.32)	(0.12)	(0.22)	(0.41)	(0.22)	(0.37)	(0.44)	(0.33)	(0.32)
Obs	8.3	15.9	10.3	8.3	8.3	8.3	7.5	8.4	8.3

Notes: This table presents alternative estimates for the results from estimating equation (2.4), varying the instrument, outcome variable, or sample. All specifications include importer-HS4-year, exporter-HS4-year, and importer-exporter-HS4 fixed effects, and the baseline pre-trend controls (one lag of each the log change in tariffs and trade). Column 2 uses an alternative sample where all trade partners subject to the MFN regime are included. Column 3 presents results where the sample excludes only the top-5 major MFN trade partners. Column 4 reports results for quantities, and column 5 the results for unit values. Column 6 presents results for a weighted specification where $t-1$ log trade values are used as weights. Column 7 reports the results based on a sample where tariffs do not vary within an importer-exporter-HS6-year observation. Column 8 presents results where we assign observations covered by a PTA listed in the WTO PTA Database to the control group. Column 9 reports the results after dropping country-pair-product-year observations where imports were subject to temporary trade barriers. Standard errors are clustered at the importer-exporter-HS4 level. ***, **, and * indicate significance at the 99, 95, and 90 percent level respectively. Observations are reported in millions.

in which none of the major partners are dropped (column 2), which is intuitive. Columns 4 and 5 report results for quantities and unit values, respectively. It turns out that the impact in the long run is mostly on quantities. The response of unit values is noisy and in general insignificant. For interpreting the unit values coefficients, it is important to keep in mind that these are unit values exclusive of tariffs. Thus, a zero estimated coefficient on unit values indicates complete pass-through of tariff changes to the buyers in the importing country. Column 6 implements a weighted regression, with weights given by the initial log imports. The estimates are very similar to the baseline.

Column 7 of Table 4 estimates the elasticity on a sample where tariffs do not vary within an importer-HS6. This specification drops importer-product instances where tariffs are set at finer levels of disaggregation, such as HS8 or HS10. Again, the results are very similar to the baseline at all horizons. In the baseline analysis, we place a country in the control group if its applied tariff is below the MFN tariff in either period $t-1$ or period t. If an applied tariff is equal to the MFN tariff in period $t-1$ and period t, we assume it trades on MFN terms. This observation is then either in the treated group, or in the excluded (dropped) group if it is one of the top-10 trading partners. Thus, we do not use outside information on PTA membership to place countries in the treated/excluded or control groups. There is a possibility, then, that a country-pair-product is technically in a PTA, but the PTA tariff coincides with the MFN tariff in both $t-1$ and t. This is a gray area, in the sense that these observations trade on *de facto* MFN terms. Without knowledge of the political process that led these PTA tariffs to coincide with MFN tariffs, we cannot be sure whether to assign them to the control group or if these more closely resemble the treated/excluded groups. The baseline analysis assigns these observations to the treated (if minor) or excluded (if major partner) groups. A reasonable alternative is to assign them to the control group on account of the fact that they are legally PTA observations. The best available information on product-specific PTA tariffs comes from the WTO Tariff Download Facility. We merged these data with ours, and used it to reclassify those instances into the control group. Column 8 presents the results. The elasticity estimates are quite similar to the baseline.[21] Finally, column 9 drops the instances in which a trade flow is subject to a temporary trade barrier (TTB), such as antidumping, countervailing, or safeguard duties. The data on TTBs come from Bown (2011), updated to 2019 by the World Bank.[22] Dropping observations covered by the TTBs leaves the results virtually unchanged.[23]

Additional results, diagnostics, and robustness Appendix B presents further robustness and diagnostics. Tables B1, B6, and B7 report the results for all the specifications at every horizon. Table B2 reports the first stage F-statistics for the baseline specification for every horizon. In all cases, the first stage F-statistics are much higher than 10. Columns 3-4 of Appendix Table B8 report results for the elasticity estimated with the multilateral resistance terms at the HS6 level. The estimates are somewhat smaller than the baseline, though the sample shrinks and the standard errors widen.[24] Column 5 of Table B8 estimates a distributed-lag model as an alternative to the local projection specification. This approach has two disadvantages relative to the baseline: (i) it requires a panel of non-missing log growth rates for trade, tariffs, and the instrument for every lag,

[21] The WTO Tariff Download Facility is accessible at http://tariffdata.wto.org/ReportersAndProducts.aspx. We do not adopt this approach as the baseline in part because the WTO product-specific PTA tariff data are self-reported and turn out to be highly incomplete.

[22] Available at https://www.worldbank.org/en/data/interactive/2021/03/02/temporary-trade-barriers-database.

[23] We also checked whether the trade response depends on the size of the tariff shock. To do so, we estimated separate elasticities depending on whether the absolute value of the initial (nonzero) tariff change is below or above the median nonzero absolute value tariff change. The estimated elasticities for both size categories are very similar and we do not report them here.

[24] Note that in our baseline estimation, time differencing already eliminates importer-exporter-HS6 fixed effect in levels.

reducing the estimation sample greatly; and (ii) it imposes linearity on the estimates. Caveats aside, the distributed lag specification with 10 lags yields a long-run trade elasticity of 3.17 with a standard error of 1.25, while the number of observations falls to just around 6.08 million. This point estimate is statistically indistinguishable from our baseline estimates.[25]

6 Theory and Applications

We stress that equations (2.2), (2.3), and (2.4) are not tied to a particular theory, and under our identification assumptions will produce estimates of ε^h by definition. The mapping between these estimates and parameters in theoretical models then depends on model structure. This section provides a mapping to dynamic and static trade models.

We first develop a simple partial equilibrium dynamic model of sluggish adjustment to trade cost shocks. Partial equilibrium is a natural starting point. Since our econometric estimates identify a partial elasticity this framework fits tightly with the empirics. The recent literature on trade dynamics is rich in both substantive mechanisms and quantification (see, among many others, Costantini and Melitz, 2007; Ruhl, 2008; Drozd and Nosal, 2012; Burstein and Melitz, 2013; Alessandria and Choi, 2014; Alessandria, Choi, and Ruhl, 2021; Ruhl and Willis, 2017; Blaum, 2019; Fitzgerald, Haller, and Yedid-Levi, 2016; Leibovici and Waugh, 2019; Alessandria, Arkolakis, and Ruhl, 2021; Steinberg, 2022). The goal of this section is not to revisit all of the proposed mechanisms for gradual adjustment of trade. Rather, we focus on the minimal common structure that characterizes these models. Appendix C lays out the model details and proves the propositions in this section.

An attractive feature of our model is that it delivers analytical expressions for trade elasticities at all horizons that clarify the determinants of the adjustment dynamics. In this setting, we state the short- and long-run model-implied elasticities and the properties of their time path. We also show that this framework delivers the estimating equations used above up to a first order approximation.

We then develop a dynamic multi-country multi-sector general-equilibrium (GE) model, that embeds a special case of this simple partial equilibrium (PE) framework. We use this GE model to illustrate that our estimated partial elasticities are key for disciplining the total (GE) responses of trade flows to shocks. Finally, turning to the mapping from our estimates to the parameter relevant for static trade models, we explore the quantitative implications of our estimates for the long run gains from

[25]Formally, we estimate the equation $\Delta_0 \ln X_{i,j,p,t} = \sum_{k=0}^{10} \gamma^k \Delta_0 \ln \tau_{i,j,p,t-k} + \delta^d_{i,p,t} + \delta^s_{j,p,t} + \delta^b_{i,j,p} + u_{i,j,p,t}$ instrumenting $\Delta_0 \ln \tau_{i,j,p,t-k}$ with $\Delta_0 \ln \tau^{instr}_{i,j,p,t-k}$, for all k. The trade elasticity at horizon h reported in Table B8 is then the estimate of $\sum_{k=0}^{h} \gamma^k$. As this estimation requires 11 instruments for 11 endogenous variables, we report the Sanderson-Windmeijer F-statistic for weak instruments in Appendix Table B2. Conceptually, there is a subtle difference between the object estimated by local projections and the distributed lag approach. Whereas the local projections take into account the time series behavior of the tariff variable, the distributed lag coefficients cumulated up to horizon h are estimates of the response of trade to a permanent once-and-for-all change in tariffs that happened at horizon 0. This distinction does not matter for the long-run limit, but is relevant for finite h.

trade.

6.1 Dynamics of trade elasticities

Setup The minimalist model that can capture differing trade elasticities in the short vs. the long run has to feature a variable that determines trade flows but cannot instantaneously and fully adjust upon a change in trade costs. In addition, a long and smooth path of increasing trade elasticities requires some curvature in the costs of adjustments, such that the long run is not reached in the first period after the shock. Following a long tradition in the literature, we assume that foreign markets are served by monopolistically-competitive firms that face CES demand. We focus on the PE decisions of firms from one market selling to another, and thus suppress importer, exporter, and product subscripts. Consistent with the gravity tradition, GE objects such as domestic unit costs or foreign demand shifts are absorbed by country-product-time fixed effects, and thus we ignore GE forces in most of this subsection. Throughout, we assume that marginal costs are constant at the firm level and thus exporting decisions are separable across locations. The setup below nests versions of the Krugman (1980), Melitz (2003), and Arkolakis (2010) models, as well as extensions with pricing to market (e.g. Burstein, Neves, and Rebelo, 2003; Atkeson and Burstein, 2008).

Trade between the two countries can be expressed as

$$X_t = p_t^x q_t n_t,$$

where n_t is a generic mass, p_t^x is the exporters' price exclusive of tariffs, and q_t is the quantity exported per unit mass. Crucially for the short vs. long-run distinction, we assume that p_t^x and q_t adjust instantaneously to tariff changes, whereas n_t is pre-determined by one period, and can only change from the next period onwards. Quantity and price are functions of tariffs, and quantity must be consistent with market clearing at the price: $p_t^x = p^x(\tau_t)$ and $q_t = q(p_t^x, \tau_t)$. Exporting generates flow profits $\pi(\tau_t)$ per unit mass n_t. Define the following elasticities:

$$\eta_{q,p} := \frac{\partial \ln q}{\partial \ln p^x}, \quad \eta_{q,\tau} := \frac{\partial \ln q}{\partial \ln \tau}, \quad \eta_{p,\tau} := \frac{\partial \ln p^x}{\partial \ln \tau}, \quad \eta_{\pi,\tau} := \frac{\partial \ln \pi}{\partial \ln \tau}, \tag{6.1}$$

where we assume that $\eta_{q,p} < 0$, $\eta_{q,\tau} < 0$, and $\eta_{\pi,\tau} < 0$.

The measure n_t comes from profit-maximizing agents serving the export market. Let r denote the real interest rate at which firms discount future profits, and G a positive and increasing function.

Dynamics in this model are governed by two equations:

$$v_t = \frac{1}{1+r}\mathbb{E}_t\left[\pi_{t+1} + (1-\delta)\, v_{t+1}\right], \tag{6.2}$$

$$n_t = n_{t-1}\,(1-\delta) + G\,(v_{t-1})\,, \tag{6.3}$$

subject to the transversality condition $\lim_{t\to\infty}\left(\frac{1-\delta}{1+r}\right)^t v_t = 0$. The forward-looking equation (6.2) states that the value of exporting v_t is the expected present value of future flow profits from exporting. The backward-looking equation (6.3) describes how the mass n_t evolves. The increment to the mass n_t today $G\,(v_{t-1})$ is a function of the value of exporting last period, when the entry or investment decision was made. Parameter δ is a rate of depreciation or an exogenous exit rate.

The model's tractability stems from the fact that equations (6.2) and (6.3) can be solved sequentially. For any stochastic process for tariffs $\{\tau_t\}_{t=0}^{\infty}$, equation (6.2) can be solved forward to obtain

$$v_t = \frac{1}{1+r}\mathbb{E}_t\left[\sum_{k=0}^{\infty}\left(\frac{1-\delta}{1+r}\right)^k \pi\,(\tau_{t+k+1})\right]. \tag{6.4}$$

Importantly the value v_t does not depend on the evolution of n_t. The resulting sequence $\{v_t\}_{t=0}^{\infty}$, can then be used to obtain n_t after solving equation (6.3) backwards,

$$n_t = \sum_{\ell=0}^{t-1}(1-\delta)^{\ell}\, G\,(v_{t-1-\ell}) + (1-\delta)^t\, n_0. \tag{6.5}$$

For a given initial value of n_0 and a stochastic process for tariffs $\{\tau_t\}_{t=0}^{\infty}$, equations (6.4)-(6.5) and elasticities (6.1) characterize the path of the mass of exporters n_t. The evolution of n_t together with the static price and quantity decisions then fully determines exports $X_t = p_t^x q_t n_t$. We treat the elasticities (6.1) as constant throughout, which amounts to solving the model to first order.

Examples In the Krugman (1980) model or the Arkolakis (2010) model with a representative firm, $\eta_{p,\tau} = 0$ (recall this is the tariff-exclusive price elasticity), and $\eta_{q,p} = \eta_{q,\tau} = \eta_{\pi,\tau} = -\sigma$, where σ is the demand elasticity. In the Melitz (2003) model, if the exporting cutoff can change instantaneously conditional on the constant mass of firms n_t, $\eta_{p,\tau} = -\partial \ln \widetilde{\varphi}/\partial \ln \tau$, where $\widetilde{\varphi}$ is an aggregate productivity measure of firms serving the export market, and $\eta_{q,p} = \eta_{q,\tau} = -\sigma$. In the Krugman (1980) and Melitz (2003) models, n_t is the mass of exporting firms and $G(\cdot)$ is the cumulative distribution function of the sunk costs of entry into exporting. To ensure smooth adjustment of the mass of firms following a change in trade costs, we assume that this distribution is nontrivial. In the Arkolakis (2010) model with a representative firm, n_t is the fraction of the foreign market penetrated by the firm, and the function G is a transformation of the convex cost of acquiring new customers. Appendix

C.2 provides a detailed discussion of the specific microfoundations of this model.

The short-run trade elasticity Let t_0 denote the date of the tariff change. The short run trade elasticity is:

$$\varepsilon^0 := \frac{d\ln X_{t_0}}{d\ln \tau_{t_0}} = (1+\eta_{q,p})\,\eta_{p,\tau} + \eta_{q,\tau}. \tag{6.6}$$

Recall that the mass n_t is predetermined within the period, and hence the derivative of n_{t_0} with respect to τ_{t_0} is zero. The short-run trade elasticity is determined by the exporters' price response ($\eta_{p,\tau}$), the quantity response to tariff changes ($\eta_{q,\tau}$), and the quantity response to price changes ($\eta_{q,p}$). Because p_t^x and q_t are static decisions, they are fully determined by period-t tariffs. Thus, the short-run elasticity is not a function of future tariffs. As an example, in the Krugman (1980) model the short-run trade elasticity is $\varepsilon^0 = -\sigma$.

The long-run trade elasticity The long-run trade elasticity is the steady state change in trade following a steady state change in tariffs. The long-run trade elasticity differs from the short-run elasticity because n_t adjusts. If tariffs are constant ($\tau_t = \tau\ \forall t$) equation (6.4) becomes $v = \frac{\pi(\tau)}{\delta+r}$. Equation (6.5) then implies that n_t monotonically converges to $n = \frac{G(v)}{\delta}$.[26] It follows that $\frac{d\ln n}{d\ln\tau} = \chi\eta_{\pi,\tau}$, where $\chi := \frac{g(v)v}{G(v)}$. These two expressions characterize the non-stochastic steady state of the model. Hence, the long-run trade elasticity is

$$\varepsilon := \frac{d\ln X}{d\ln\tau} = \varepsilon^0 + \frac{d\ln n}{d\ln\tau} = \varepsilon^0 + \chi\eta_{\pi,\tau}. \tag{6.7}$$

In the long run, the response of trade to tariff changes depends on $\chi > 0$ and $\eta_{\pi,\tau} < 0$, the elasticity of flow profits with respect to tariffs. Consistent with intuition, the more sensitive are profits to tariffs, the greater the absolute value of the long-run trade elasticity.

The long-run trade elasticity increases (in absolute value) in the elasticity χ of mass n with respect to value v. The precise meaning of χ depends on the underlying microfoundation. In the dynamic Krugman (1980) model, χ captures the mass of firms at the margin of entry. The greater the mass of firms at the margin, the more n changes in response to a change in per-firm profits and hence value v. In the dynamic Arkolakis (2010) model, firms face a convex cost function $f(a)$ of adding a mass of a new customers. In that case, $\chi = \left(\frac{f''(a)a}{f'(a)}\right)^{-1}$. Greater curvature of this cost function leads to a lower value of χ, implying a smaller trade response to tariff shocks.

Transitional dynamics and horizon-h elasticities To derive a horizon-specific elasticity, we must specify further details of the time path of tariffs. This is because unlike in the short run or the steady state calculations, the entire path of (expected) tariffs matters for the entry decision in

[26] The convergence of n_t to its steady state value is geometric and monotone. The rate of convergence is δ. We provide details in Appendix C.3.

each period. To make progress, we consider an unexpected change to tariffs at time t_0. This shock is followed by a subsequent evolution of tariffs (an impulse response), denoted by $\left\{\frac{d\ln\tau_{t_0+h}}{d\ln\tau_{t_0}}\right\}_{h=0}^{\infty}$. This sequence is the model counterpart of our estimated impulse response function of tariff changes as depicted in the left panel of Figure 1. Since the tariff shock at time t_0 may be followed by further shocks thereafter, agents cannot perfectly predict future tariffs or profits and therefore form expectations as in equation (6.4).

The horizon-h impulse response function of trade to the tariff shock at t_0 is:

$$\frac{d\ln X_{t_0+h}}{d\ln\tau_{t_0}} = \varepsilon^0 \frac{d\ln\tau_{t_0+h}}{d\ln\tau_{t_0}} + \frac{d\ln n_{t_0+h}}{d\ln\tau_{t_0}}. \tag{6.8}$$

The horizon-h trade elasticity is then computed as the ratio of the two impulse response functions:

$$\varepsilon^h := \frac{\frac{d\ln X_{t_0+h}}{d\ln\tau_{t_0}}}{\frac{d\ln\tau_{t_0+h}}{d\ln\tau_{t_0}}} = \varepsilon^0 + \frac{\frac{d\ln n_{t_0+h}}{d\ln\tau_{t_0}}}{\frac{d\ln\tau_{t_0+h}}{d\ln\tau_{t_0}}}, \tag{6.9}$$

as long as this object is finite (i.e. $\frac{d\ln\tau_{t_0+h}}{d\ln\tau_{t_0}} \neq 0$). Note that this definition of the horizon-h trade elasticity coincides with equation (2.1) for a tariff change of one marginal unit, when we replace the infinitesimal difference with the difference operator Δ.

To fully characterize the horizon-h trade elasticity, we must characterize the last term in (6.9), the adjustment of n_t to the tariff shock.

Proposition 1. *Consider an arbitrary evolution of tariffs $\left\{\frac{d\ln\tau_{t_0+\ell}}{d\ln\tau_{t_0}}\right\}_{\ell=1}^{\infty}$ after the shock at t_0. The impulse response function of $\ln n_t$ at horizon $h = 0, 1, 2, \ldots$ is*

$$\frac{d\ln n_{t_0+h}}{d\ln\tau_{t_0}} = \chi\eta_{\pi,\tau}\frac{\delta+r}{1+r}\delta\sum_{k=0}^{h-1}(1-\delta)^{h-1-k}\,\mathbb{E}_{t_0+k}\left[\sum_{\ell=0}^{\infty}\left(\frac{1-\delta}{1+r}\right)^{\ell}\frac{d\ln\tau_{t_0+k+\ell+1}}{d\ln\tau_{t_0}}\right]. \tag{6.10}$$

Proof. See Appendix C.4. □

Plugging (6.10) into (6.9) delivers the horizon-h trade elasticity. As is clear from equations (6.8) and (6.9), the sluggish adjustment of trade to tariff shocks is entirely driven by the sluggish adjustment of n_t. While this adjustment is somewhat complicated (equation 6.10), it delivers a useful insight: in general, all tariff changes from time t_0 into the infinite future affect the trade response to tariff shocks. Proposition 1 captures these tariff changes as the elasticities of time $t_0 + \ell$ tariffs with respect to the tariff shock at time t_0, for $\ell = 1, 2, \ldots$. For a given time horizon h, elasticities for $0 \leq \ell < h$ reflect changes to past tariffs, the elasticity for $\ell = h$ reflects a change to current tariffs, and elasticities for $\ell > h$ reflect expected changes to future tariffs.

As the following proposition shows, ε^h converges to the long-run trade elasticity, unless the tariff change induced by the shock in period t_0 returns to zero in the limit.

Proposition 2. *If* $\lim_{h\to\infty} \frac{d\ln\tau_{t_0+h}}{d\ln\tau_{t_0}} \neq 0$ *and is finite, then* $\lim_{h\to\infty}\varepsilon^h = \varepsilon$.

Proof. See Appendix C.4. □

Although not surprising, this result is important because it validates our interpretation of horizon-h trade elasticities for large h as estimates of the long-run elasticity.

For concreteness, we next consider two simple examples.

Example 1: tariff constant after 1 period Let there be a surprise change in the tariff sequence of the form $\left\{\frac{d\ln\tau_{t_0+h}}{d\ln\tau_{t_0}}\right\}_{h=0}^{\infty} = \{1, \Delta\ln\tau_{>t_0}, \Delta\ln\tau_{>t_0}, \Delta\ln\tau_{>t_0}, ...\}$. That is, the tariff change takes the value one in the impact period, and is subsequently constant at $\Delta\ln\tau_{>t_0}$. Note that this example nests a one-time permanent change in tariffs (if $\Delta\ln\tau_{>t_0} = 1$), and is a good approximation of our estimated impulse response function in Figure 1.

At horizon $h \geq 1$ the trade elasticity is

$$\varepsilon^h = \varepsilon^0 + \chi\eta_{\pi,\tau}\left(1 - (1-\delta)^h\right), \tag{6.11}$$

with ε^0 given by (6.6). The trade elasticity converges geometrically to the long-run trade elasticity at the rate δ. Convergence occurs in one period if $\delta = 1$.

Example 2: AR(1) Second, let the tariffs follow a first order autoregressive process following an initial shock, so that $\Delta\ln\tau_{t+1} = \rho\cdot\Delta\ln\tau_t$ for $t > t_0$ and $0 < \rho < 1$. Since this process is mean-reverting, the tariff change approaches zero as h tends to infinity. It follows that the premise of Proposition 2 does not hold and that the long-run trade elasticity is not defined in this case. However, we can still compute the elasticity at a finite horizon.

First, consider the case $1-\delta < \rho$. Intuitively, this condition requires that the rate of depreciation is higher than the rate of mean reversion of tariffs. In this case the horizon-h trade elasticity is

$$\varepsilon^h = \varepsilon^0 + \chi\eta_{\pi,\tau}\frac{(\delta + r)\,\delta}{[1 + r - (1-\delta)\,\rho]\left(1 - \frac{1-\delta}{\rho}\right)}\left(1 - \left(\frac{1-\delta}{\rho}\right)^h\right). \tag{6.12}$$

As in Example 1, the trade elasticity increases with time horizon h in absolute value. Further, with $1-\delta < \rho$ the horizon-h trade elasticity does converge, although not generally to the long-run trade elasticity. While convergence is still geometric, the rate of convergence now depends on the persistence of the tariff process. Convergence is faster for more persistent tariff processes, i.e. greater values of ρ. If tariffs mean-revert sufficiently quickly, $\rho \leq 1-\delta$, the horizon-h trade elasticity does not converge.

Notice that as ρ approaches 1, the horizon-h trade elasticity in the AR(1) case (6.12) converges pointwise to the horizon-h trade elasticity under a permanent tariff change (6.11). This property is important for our empirical application. Although tariff changes in our sample retain 75% of their initial impulse 10 years later, in short samples it is not possible to statistically distinguish between tariff processes featuring truly permanent or highly persistent tariff changes (Hamilton, 1994, p. 445). Since Proposition 2 does not apply under mean-reverting tariffs ($\rho < 1$), one may be concerned that the horizon-h trade elasticity is not informative about the long-run trade elasticity. This property alleviates this concern. For ρ sufficiently close to one, the horizon-h trade elasticity essentially converges to the long-run trade elasticity, even though tariffs mean-revert in the very long run.

Estimating equations While we led off the paper with an atheoretical estimating equation, we now show that this estimating equation can be microfounded by means of the model above.

Proposition 3. *The model delivers estimating equation* (2.2)*, where*

$$\beta_X^h = \chi\eta_{\pi,\tau}\frac{r+\delta}{1+r}\delta\sum_{k=0}^{h-1}(1-\delta)^{h-1-k}\sum_{\ell=0}^{\infty}\left(\frac{1-\delta}{1+r}\right)^{\ell}\beta_\tau^{k+\ell+1}+\varepsilon^0\beta_\tau^h,$$

and β_τ^h *is defined as the regression coefficient of* $\Delta_h \ln \tau_{i,j,p,t}$ *on* $\Delta_0 \ln \tau_{i,j,p,t}$ *in the population, and can be estimated from equation* (2.3)*.*

The fixed effects $\delta_{j,p,t}^{s,X,h}$ *and* $\delta_{i,p,t}^{d,X,h}$ *capture a weighted sum of past, present, and expected future changes in interest rates, demand, the cost of production, the cost of entry, and non-tariff trade barriers that vary at the exporter-product-time* (j,p,t) *and importer-product-time* (i,p,t) *level, respectively, in model extensions in which these vary over time. The error term includes past, present, and expected future time-varying importer-exporter-product-specific demand shocks and non-tariff trade barriers, as well as the initial state.*

Proof. See Appendix C.4. □

We stress that this proposition extends to GE settings. The changes in supply and demand absorbed by the multilateral resistance terms include both exogenous (shocks), and endogenous GE changes in prices and aggregate consumption. As a result, the econometric estimates identify a partial elasticity of trade with respect to trade costs holding these terms constant. The intuition for this result is similar to conventional static microfounded gravity equations. Appendix D.4 presents a fully articulated special case of this proposition in the context of our GE model and clarifies the economic interpretation of the objects absorbed by the exporter-product-time and importer-product-time fixed effects.

Trade elasticities to tariffs and non-tariff barriers Before moving to the quantification, we note a distinction that will matter for connecting the model to the data. Our estimates are of trade elasticities with respect to tariffs, and in our data trade flows do not include tariff payments. Theoretical models usually also include non-tariff iceberg trade barriers such as transport costs. The elasticity of tariff-exclusive trade flows with respect to non-tariff trade barriers is in general related to but distinct from the tariff elasticity. This is because non-tariff iceberg trade costs shift prices received by the exporter, whereas tariffs do not. Letting κ_t denote the non-tariff iceberg trade cost and c_t denote the domestic marginal cost, in the CES model the price received by the exporter is $p_t^x = \frac{\sigma}{\sigma-1}\kappa_t c_t$, and the quantity produced is $q_t = (\tau_t p_t^x)^{-\sigma} D_t$, where D_t is the demand shifter. As a result, the elasticity of tariff-exclusive trade flow per unit mass of firms $p_t^x q_t$ is $-\sigma$ with respect to tariffs, and $1-\sigma$ with respect to non-tariff trade costs. By the same token, those two elasticities would coincide for trade flows inclusive of tariff payments.

Thus, in many static models the mapping between our estimates and the elasticity of trade to non-tariff trade barriers is particularly simple: we should simply add 1 to our estimates. This will be relevant when we apply our estimates to the Arkolakis, Costinot, and Rodríguez-Clare (2012) gains from trade exercise in Section 6.3. The mapping between the two elasticities is more complex in dynamic models, and Appendix C.6 provides details for the class of models considered in this section. With CES demand, the short-run (resp. long-run) elasticity to tariffs is $-\sigma$ (resp. $-\sigma(1+\chi)$) while the elasticity to non-tariff trade barriers is $1-\sigma$ (resp. $(1-\sigma)(1+\chi)$). Importantly, our estimates of the elasticity of trade flows to tariffs can be used to infer the non-tariff trade elasticity in many static and dynamic models.[27]

Quantification Next, we explore the time path of tariff elasticities. To do this, we calibrate the dynamic model and subject it to the two tariff shocks in the examples above.

We choose a demand elasticity σ of 1.1. This parameter immediately determines the short-run elasticity, since in the CES-monopolistic competition model $\varepsilon^0 = -\sigma$. Based on equation (6.7), and using the fact that $\eta_{\pi,\tau} = -\sigma$ in the CES-monopolistic competition model, we set $\chi = 0.82$ to match our estimated long-run elasticity of $\varepsilon = -2$. We further set the depreciation rate to $\delta = 0.25$ to roughly match the rate of convergence to the long run. Calibration of these parameters is sufficient

[27] Our estimates are informative about trade elasticities to tariffs and non-tariff trade barriers when trade costs take the iceberg form. Mappings to models with non-iceberg trade costs would have to be considered on a case-by-case basis.

to compute the transition path of exports in Example 1. For Example 2, we also need the interest rate and the AR(1) coefficient. We set these to $r = 0.03$ and $\rho = 0.955$. The latter parameter is chosen to roughly match the impulse response function of tariffs.

The left panel of Figure 5 plots the paths of tariffs. The red line depicts the tariff response of Example 1, where tariffs increase by one unit in the impact period, and then stay constant at 0.75 starting in period 1 onwards. The blue line is the AR(1) path of tariffs following an impulse of unit size (Example 2). The green line plots the impulse response of tariffs estimated in the data, which is quite similar to the two model experiments.

The right panel of Figure 5 displays the trade elasticities. The green line depicts the econometric estimates. Because the data are annual, and it is unlikely that all tariff changes went into effect on January 1, the year-zero trade elasticity is most likely subject to partial-year effects. Thus, for the purposes of comparing to the model, we consider the $h = 1$ empirical estimate to be the impact elasticity ε^0. The red and blue lines depict the model trade elasticity in the two experiments. They are nearly indistinguishable from one another.

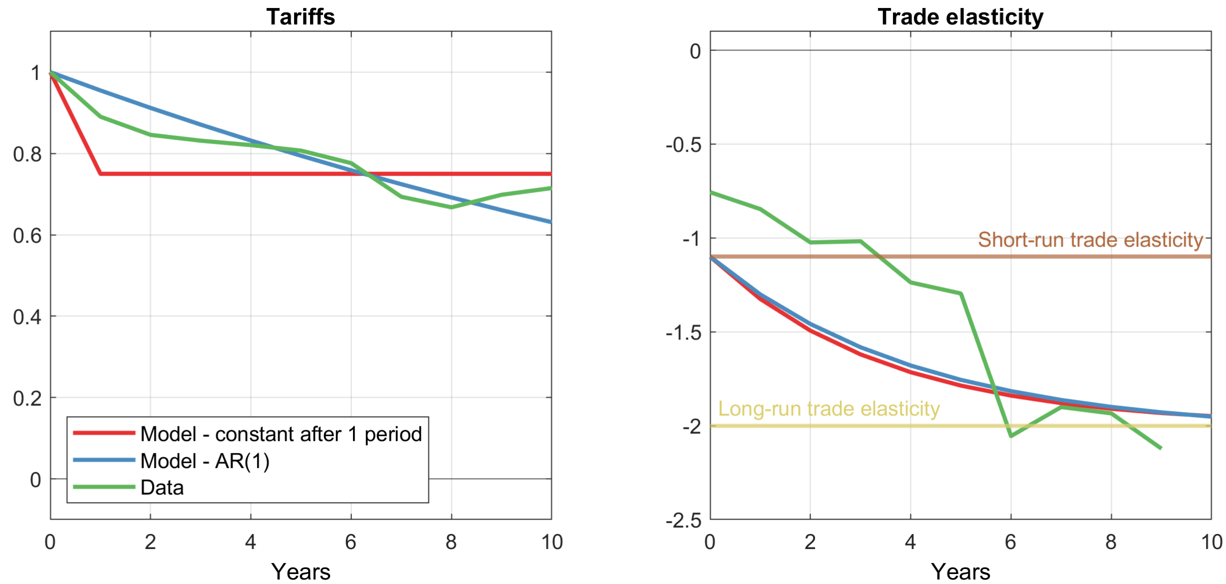
The model succeeds in delivering a smooth path of adjustment that takes approximately a decade. The key parameter for the speed of adjustment is the depreciation rate δ. The slow adjustment observed in the data implies that δ is substantially below 1. The main shortcoming of the model is that it cannot match our short-run elasticity point estimate of -0.76, since the CES-monopolistic competition assumption requires that $\sigma > 1$.[28]

6.2 General equilibrium

The above setup is in PE, which allows for a precise mapping to the empirical estimation and unified analytical results in a number of environments. It is well-understood that the GE response of trade will not coincide with the PE response, and thus the partial elasticities that we estimate do not capture the total change in trade following a trade cost shock. However, these estimates are a crucial input for disciplining the parameters of GE models. While this is well understood in static trade

[28] A natural conjecture is that flexible markups may help push the short-run trade elasticity below 1. We experimented with versions of the model with local distribution costs à la Burstein, Neves, and Rebelo (2003). With local distribution costs, the net-of-tariff price received by the exporter p_t^x falls when a tariff increases, helping push down the trade elasticity all else equal. However, the flip side of a fall in p_t^x is a *ceteris paribus* increase in the quantity imported. It turns out there is no combination of $\sigma > 1$ and local distribution cost share between 0 and 1 that delivers a less than unitary trade elasticity as we measure it (of $p_t^x q_t$ with respect to τ_t). In addition, Table 4 shows a virtually nil response of p_t^x to tariffs, a finding consistent with recent estimates using the US-China trade war (Fajgelbaum et al., 2020; Cavallo et al., 2021). Both of these points suggest that imperfect pass-through into net-of-tariff prices is unlikely to produce a short-run elasticity below 1. Developing a framework that can successfully reproduce a short-run elasticity below 1 remains a fruitful avenue for future research. One possibility is variable distribution margins. Indeed, Cavallo et al. (2021) document a fall in retail margins for US imports affected by the trade war.

Figure 5: Time Path of Elasticities in the Dynamic Model



Notes: This figure illustrates the trade elasticities as implied by the model in Examples 1 and 2, and compares them to the baseline estimates. The parameters are set as follows: $\sigma = 1.1$, $\chi = 0.82$, $\delta = 0.25$, $r = 0.03$, and $\rho = 0.955$.

models, it is an open question to what extent the partial elasticity estimated in the data matters for the GE trade response in dynamic models.

To show that our estimates are important for disciplining GE models, we take one of the PE models laid out above – the dynamic Krugman model – and embed it in GE. Appendix D lays out the details of the model and the calibration. In the quantitative implementation we limit the size of the economy to 6 countries with 5 sectors for computational reasons. The model is calibrated to standard data on import and expenditure shares from KLEMS and the World Input-Output database. The calibration is summarized in Appendix Table D1.

Figure 6 displays the impulse responses of US imports for sets of unexpected and permanent tariff shocks. The panels differ in how broad-based the tariff shock is, starting from the most localized in Panel A to the most pervasive in Panel D. Panel A reports the responses of trade flows to a 1% tariff shock on one product from one importer, while Panel D displays the results for an across-the-board 1% tariff shock on all US imports from all source countries.

The solid blue lines and the dashed red lines display the PE responses under different trade elasticities. The blue line is calibrated to our estimates, setting $\sigma = 1.1$ and targeting a long-run elasticity of 2. Thus, it matches the impulse response reported in Figure 5. The dashed red line is instead calibrated to match the long-run partial elasticity of 6, more common in the trade literature, and assumes a short-run elasticity of $\sigma = 3$.[29] By construction, since these are partial elasticities, the blue and dashed red lines are the same in every panel.

The blue (resp. red) shaded areas are the ranges, across source countries and sectors, of the GE trade responses to the same tariff shocks under the two alternative calibrations. The main finding is that the GE trade responses are very different across elasticities. That is, the parameter values required to match a particular partial elasticity matter a great deal for the GE responses of trade. Not surprisingly, higher partial elasticities translate to higher GE elasticities. This main conclusion is not sensitive to whether we consider isolated or pervasive tariff shocks. Thus, our estimates are informative and quantitatively important in GE settings. Appendix Figure B6 reports analogous results for Canada, a smaller economy than the US. The results are very similar.

6.3 The long-run welfare gains from trade

As is well known from Arkolakis, Costinot, and Rodríguez-Clare (2012, henceforth ACR), the gains from trade relative to autarky in many static quantitative trade models can be expressed as a function of the trade elasticity and the domestic absorption share: $1 - \lambda_{jj}^{1/\theta}$, with λ_{jj} the share of spending on domestically-produced goods in total spending. The models in which this formula applies are metaphors for the long run, and the gains from trade should be interpreted as steady state comparisons between autarky and trade. Thus, we use the longest horizon elasticity estimated above, $h = 10$, as the long-run value. ACR formulas normally apply the tariff-inclusive elasticity, or alternatively, the elasticity of trade with respect to non-tariff iceberg costs. To translate our tariff-exclusive estimates to the welfare-relevant elasticity θ we must add 1, as discussed in Section 6.1. Thus, our estimates imply that the welfare-relevant elasticity θ is around -1.

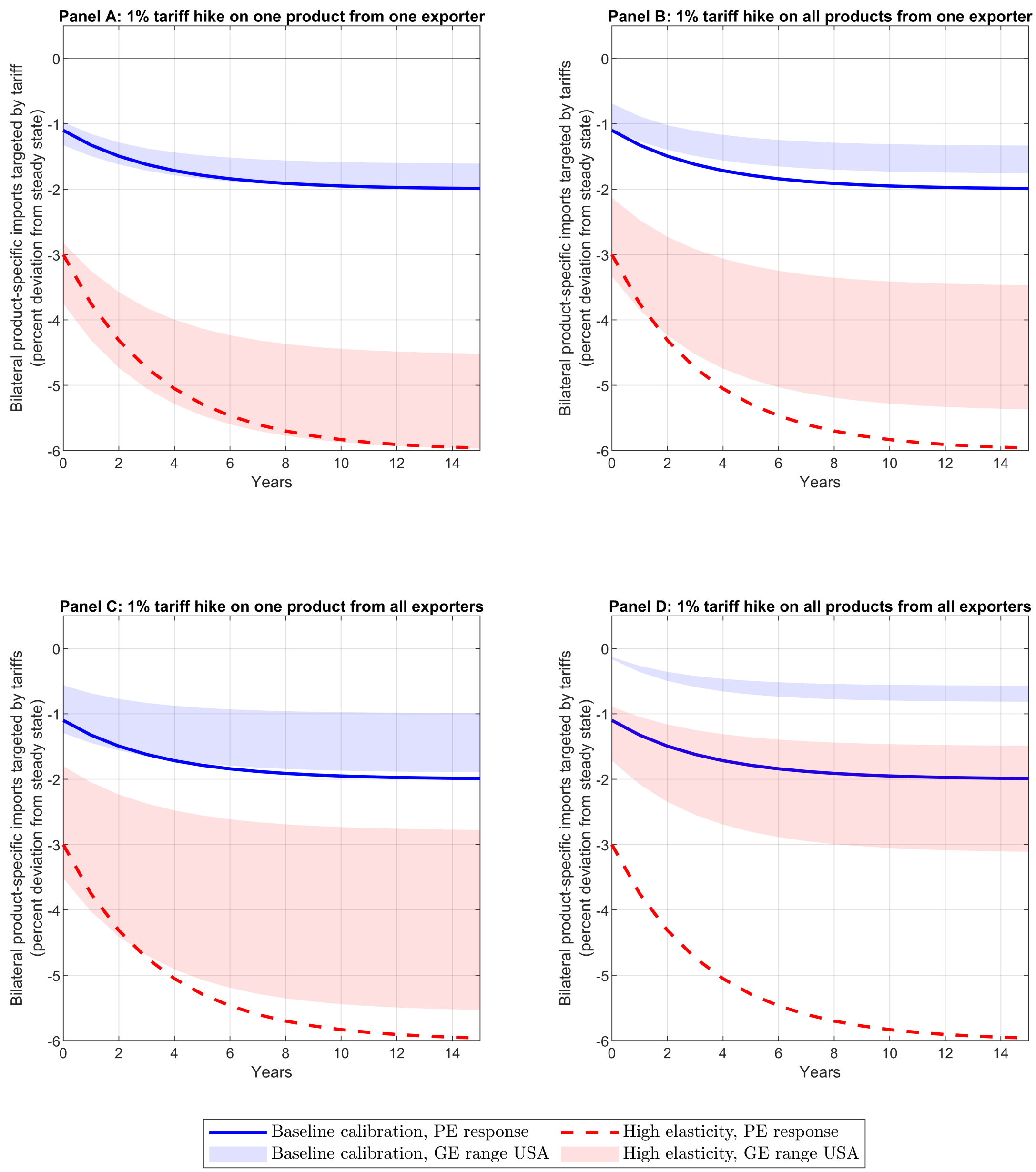
Figure 7 displays the gains from trade as a function of λ_{jj}, under our value of θ and under a tariff-inclusive elasticity of -5 considered by ACR.[30] As expected, the gains from trade are substantially larger with our elasticity. For the US, gains from trade are 5.27% for $\theta = -1$, compared to 1.0% for $\theta = -5$. The median welfare gain is 22.9% in a sample of 64 countries, compared to 4.2% implied by $\theta = -5$. Table B9 reports the gains from trade under $\theta = -1$, -5, and -10 for selected countries in the sample.

The blue bars in Appendix Figure B7 report the gains from trade using the multi-sector ACR formula

[29] A long-run tariff-exclusive elasticity of -6 as in Figure 6 implies that the long-run non-tariff iceberg trade cost elasticity of -5 – common in the trade literature (e.g. Costinot and Rodríguez-Clare, 2014). See also the discussion in Section 6.1.

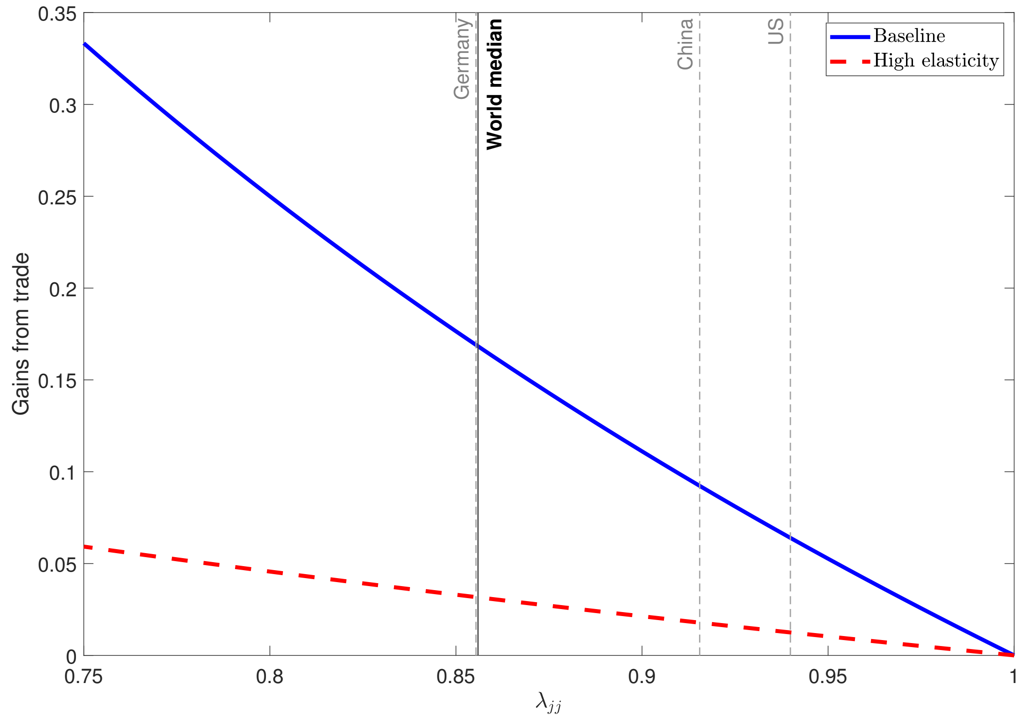
[30] We use data from the 2006 World Input-Output Database (WIOD).

Figure 6: General Equilibrium Trade Responses: US Imports



Notes: This table reports the impulse responses of US imports to unexpected and permanent 1% tariff hikes in partial equilibrium (solid blue lines and dashed red lines) and in general equilibrium (shaded areas). The shaded areas represent the ranges of impulse response functions in GE taken over exporters and sectors. In the baseline calibration $\sigma = 1.1$ and $\chi = 0.82$, so that the long-run elasticity $\varepsilon = 2$. In the high elasticity calibration, $\sigma = 3$ and $\chi = 1$, so that $\varepsilon = 6$. See Appendix Table D1 for details on the calibration.

Figure 7: Gains from Trade



Notes: This figure displays the gains from trade as a function of the domestic absorption share λ_{jj} under our baseline welfare-relevant elasticity of -1 (solid blue line) and a comparison elasticity of -5 (red dashed line). "World Median" denotes the median domestic absorption share from the 2006 World Input-Output Database (WIOD) over 43 countries.

and our sector-specific elasticity values (Section 4.1). We benchmark these to the sector-specific trade elasticity estimates from Ossa (2015), who explores the properties of multi-sector ACR formulas. To do this, we concord the sectoral elasticity estimates in that paper to the 11 HS sections for which we estimate elasticities. Once again, the gains from trade implied by our estimates are considerably larger than previously suggested in the literature. Our estimates applied to the ACR multi-sector formula imply average gains from trade of 26.7%, compared to 12.8% using the elasticities in Ossa (2015).

We caveat these results in two respects. First, we acknowledge that ACR formulas are not known to apply in explicitly dynamic models (for some results bridging ACR with dynamics, see Arkolakis, Eaton, and Kortum, 2011; Alessandria, Choi, and Ruhl, 2021). This is a general critique of all applications of the ACR formulas in static environments. Nonetheless, the widespread use of ACR formulas makes them a natural setting for benchmarking the implications of our elasticity estimates relative to the conventional values. The notion that the value of the partial trade elasticity matters for the size of the gains from trade of course applies to dynamic settings, even if there are no known analytical formulas. To illustrate this, Appendix Figure B8 displays the gains from trade in the dynamic GE model used in Section 6.2 and detailed in Appendix D. Because of the transition path, there is no unique way of calculating the gains from trade, as the total welfare change depends on the time path of trade costs. We start from the autarky equilibrium and implement a one-time unexpected permanent change in trade costs large enough to deliver a new steady state that matches the current level of trade. We then record the change in welfare between autarky and trade, taking into account the transition path to the new steady state. As in the ACR formula application in Figure 7, in the dynamic model the trade elasticity matters a great deal for the magnitude of the gains from trade, with a lower elasticity producing larger gains.[31]

Second, care must be taken when going from the micro elasticity estimated in our empirical work to the macro elasticity that enters the ACR formula. The calculations above make the implicit assumption that the two coincide. While there are many models in which this is not true, some of this concern can be allayed by using the multi-sector variant of the formula, that aligns more closely the levels of disaggregation at which the coefficients are estimated and the theory. Using our micro elasticity values in place of the macro elasticity is conservative in the sense that we would expect the elasticities of substitution to be higher at finer levels of product disaggregation.

7 Conclusion

We develop a novel method to estimate the trade elasticity, a key parameter in virtually all models in international economics. Our main contributions are to (i) tackle the endogeneity problem that tariffs and trade flows are jointly determined, and (ii) estimate the full time path of trade elasticities at different horizons. Our main findings are that the trade elasticity falls from about -0.76 in the short run to about -2 in the long run. It takes 7-10 years for the point estimate to stabilize at the long-run value. While our estimation approach is not specific to a particular theoretical framework, we relate our empirical strategy and results to several theoretical applications. Our finding that the trade elasticity differs by horizon and converges to the "long-run" after about 7-10 years implies substantial adjustment costs to changing trade flows. The long-run estimates imply that the welfare-relevant trade elasticity is significantly smaller than conventional wisdom in the literature, suggesting the welfare gains from trade are larger than previously thought.

[31] The dynamic gains in Appendix Figure B8 are larger than the ACR gains in Figure 7. This is in part due to the different interpretation of a long-run elasticity of 2 in the two settings. In static models, since there is no time dimension, a long-run elasticity of 2 is rationalized by setting $\sigma = 2$ in an Armington/Krugman setting. In the dynamic model, σ governs the short-run response of trade flows to tariffs, and in the long run the trade elasticity keeps increasing because of the adjustments to the mass of firms over the transition. Setting $\sigma = 1.1$ in the dynamic model appears to generate even larger gains from trade.

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ONLINE APPENDIX

(NOT FOR PUBLICATION)

Appendix A Data

A.1 Data sources and documentation

This appendix documents our data sources.

Tariff data Tariff data come from UN TRAINS, and are downloaded for each year between 1995-2018 from https://wits.worldbank.org. The raw data are at the importer-exporter-HS6 level, and include information on the year of the tariffs, MFN tariff rates, preferential tariff rates (if applicable), MFN bound rates, whether or not specific duties are applied, and the standard deviation of tariffs within the importer-exporter-HS6-year observation. Reported tariff rates are generally available as simple averages and trade-weighted averages.

When cleaning the data, we drop any observations where either the reporting country or partner country is not identified. We further drop observations where any specific tariffs are reported. When the simple average applied tariff is missing and the corresponding MFN rate is 0, we assume the missing applied tariff is 0, as it is unlikely a country which can export at an MFN rate of 0 actually trades at a higher applied tariff. In other instances, we do not replace missing tariff rates with MFN tariff rates even if MFN rates are available. Rather, we drop observations where the relevant tariff rates are missing, and so these are not used in our estimation.

Figure A1 reports the frequency distribution of tariff changes in our final dataset (where the cleaned tariff data is matched to trade flows). The left panels plot the changes including zero changes, highlighting that in most periods tariffs do not change. The right panels plot the distribution of tariff changes excluding zero changes, and illustrate that there is significant variation in our tariff data. Figure A2 reports the unconditional autocorrelation of tariff changes in our data. Tariff changes display a strong negative first order autocorrelation.

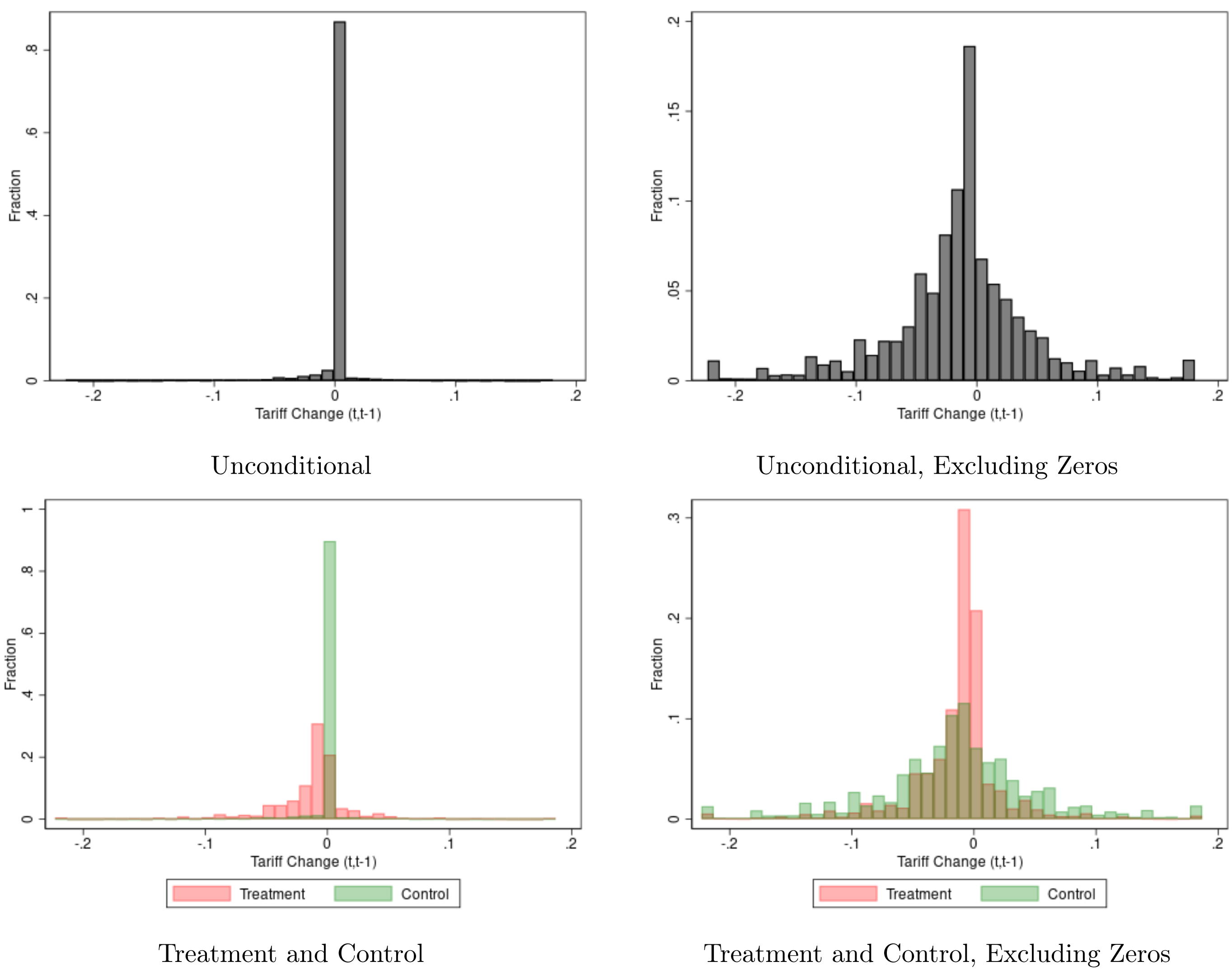
Trade data Trade data are obtained from the BACI version of UN Comtrade. This dataset is produced by the CEPII, and combines importer and exporter reports for more exhaustive and precise coverage of world trade flows. It can be downloaded by registering at the CEPII site `http://www.cepii.fr/CEPII/en/bdd_modele/presentation.asp?id=37`. The most detailed level of disaggregation available is HS6, which is the level of our analysis.

The trade data and tariff data come in several different HS vintages. As discussed in Section 3, we do not want to concord HS codes across vintages unless the concordance is one-to-one, to avoid spurious changes in trade flows or tariffs from splitting HS codes or aggregating HS codes across vintages. We therefore only link HS codes across vintages if their mapping is one-to-one. Codes that do not map one-to-one across vintages are kept in the sample, but their time series dimension will be short. Appendix table A1 documents the share of unique HS code mappings across vintages. Figures A3, A4 and A5 document patterns in the trade data. We find that a large share of trade is on an MFN basis, and there is substantial heterogeneity across HS sections (broad groupings of HS codes) in their shares of total trade.

Other data sources While information on ad-valorem tariffs and trade flows at the importer-exporter-HS6-year level are sufficient for the bulk of our analysis, in robustness exercises we use some alternative data sources. Data on temporary trade barriers such as antidumping duties and countervailing duties comes from the database constructed by Chad Bown and maintained by the WTO https://www.chadpbown.com/temporary-trade-barriers-database/. Standard variables for gravity controls come from the CEPII.

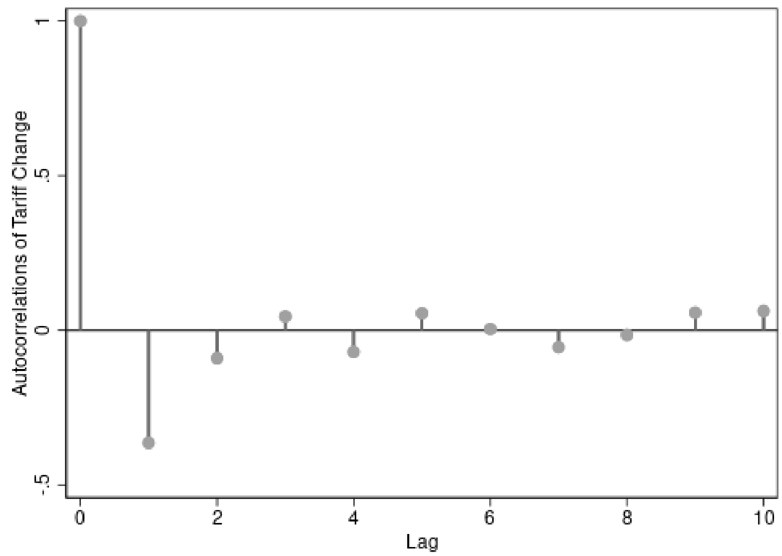
Our dynamic model in Section 6.1 requires some additional data for calibration. Data on countries' GDP are obtained from the Penn World Tables 9.1. Import shares and consumption shares by sector are obtained from the WIOD and World KLEMS data (2017 vintage).

Figure A1: Patterns of Tariff Changes: Frequency Distributions



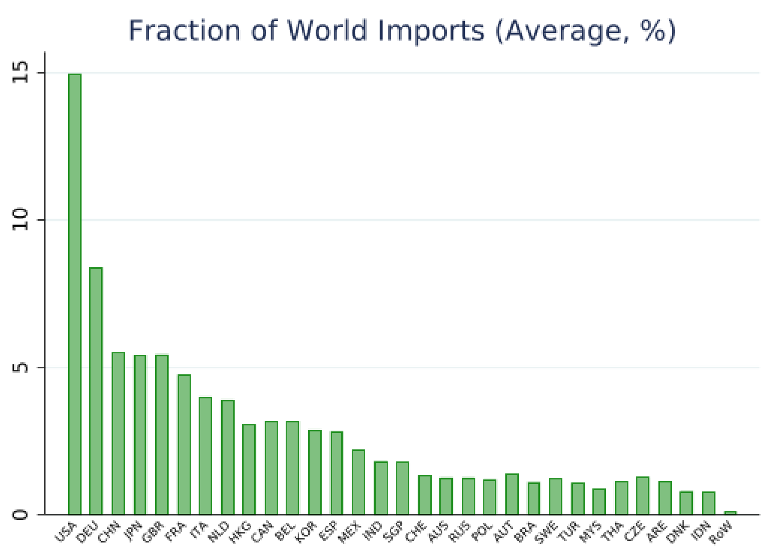
Notes: These figures display the frequency distribution of tariff changes in our data. The top two panels display the unconditional frequency of all tariff changes (top left) and the frequency excluding zeros (top right). The bottom panels displays the frequency distributions of changes in the treatment and control groups, including zero changes (left panel), and removing zero changes (right panel).

Figure A2: Patterns of Tariff Changes: Autocorrelation



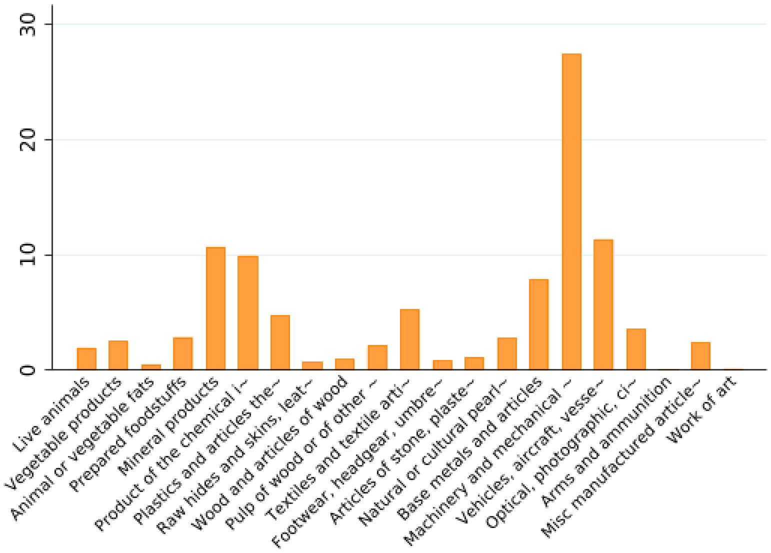
Notes: This figure displays the unconditional autocorrelation of tariff changes in the sample.

Figure A3: Share of World Imports by Country (Average, %)



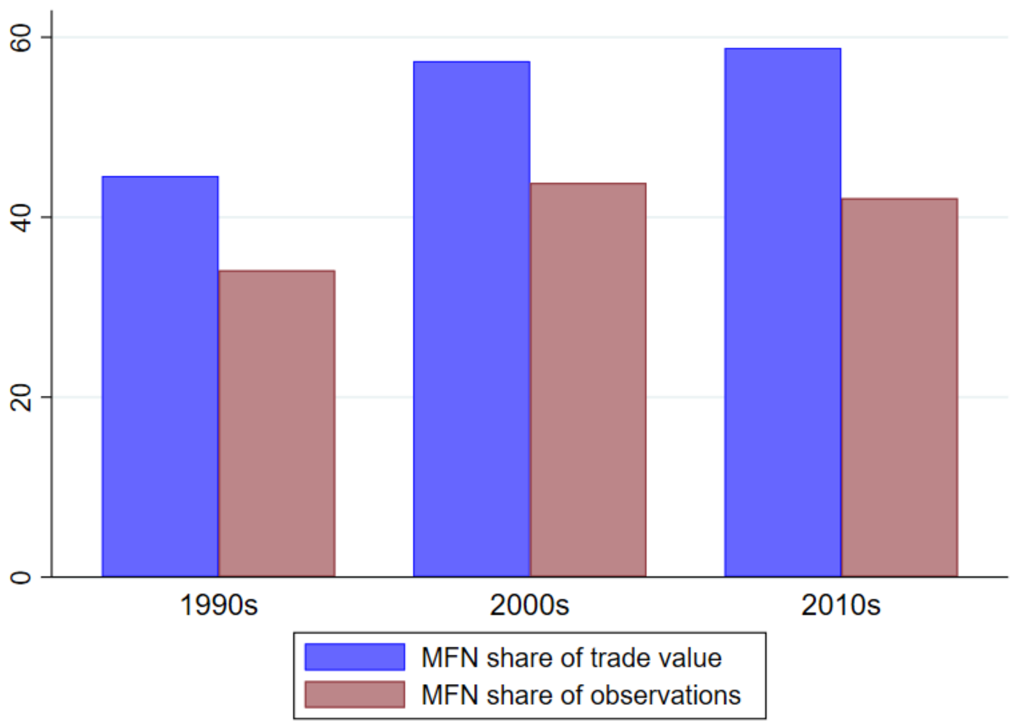
Notes: This figure shows the average share of world trade flows by importer in our sample. “ROW” is the mean share of world trade among countries outside of the top 20 importers.

Figure A4: Share of World Imports by HS Section (Average, %)



Notes: This figure shows the average share of trade that is in each HS Section in our sample.

Figure A5: Share of World Imports on MFN basis (%)



Notes: This figure shows the average share of the value of world trade that is subject to MFN tariffs by decade in our sample and the average share of exporter-importer-HS6-year observations that are trading on MFN terms by decade in our sample. For consistency with our estimation, an observation is treated as MFN only if it is currently trading on MFN terms and was also trading on MFN terms in the previous period.

Table A1: Share of one-to-one Mappings Across HS Revisions (percent)

		Mapped to:				
		HS-92	HS-96	HS-02	HS-07	HS-12
Mapped from:	HS-96	89.38				
	HS-02	81.55	90.81			
	HS-07	73.34	80.74	88.48		
	HS-12	68.17	74.91	81.81	91.93	
	HS-17	61.85	67.92	73.62	81.99	88.05

Notes: This table presents the share of HS codes that can be mapped uniquely from one HS revision (in the "Mapped from" row) to another HS revision (in a "Mapped to" column). All numbers are in percent.

Table A2: Examples of Treatment and Control Assignments

Importer	MFN Trade Partners		Major Trade Partners Aggregate		Major Trade Partners HS 6403		Treatment	Control	Excluded
	2005	2006	2005	2006	2005	2006			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Panel A: Germany									
	USA	USA	FRA	FRA	ITA	ITA	HKG	ITA	CHN
	CHN	CHN	BEL	BEL	CHN	CHN	KOR	PRT	IND
	JPN	JPN	NLD	NLD	PRT	PRT	SGP	AUT	USA
	KOR	KOR	ITA	ITA	AUT	AUT	NZL	VNM	
	IND	IND	GBR	GBR	VNM	VNM	CAN	NLD	
	HKG	HKG	CHN	CHN	NLD	NLD	AUS	ESP	
	CAN	CAN	USA	USA	ESP	ESP	JPN	SVK	
	SGP	RUS	AUT	AUT	IND	IND	PRK	FRA	
	BRA	SGP	CZE	CZE	SVK	SVK		IDN	
	RUS	BRA	CHE	CHE	FRA			GBR	
Panel B: Japan									
	CHN	CHN	CHN	CHN	KHM	CHN	BGR	KHM	CHN
	USA	USA	USA	USA	CHN	ITA	GBR	MMR	IDN
	KOR	KOR	AUS	SAU	MMR	KHM	HRV	BGD	VNM
	AUS	AUS	IDN	ARE	BGD	VNM	PRT	MEX	THA
	DEU	DEU	KOR	AUS	IDN	FRA	BIH	LAO	ITA
	ITA	ITA	DEU	IDN	VNM	IDN		NPL	USA
	FRA	FRA	THA	KOR	ITA	MMR		LBN	KOR
	VNM	VNM	MYS	DEU	FRA	ESP			FRA
	GBR	GBR	ARE	THA	ESP	BGD			ESP
	THA	THA	SAU	MYS	DEU	DEU			DEU
Panel C: USA									
	CHN	CHN	CAN	CAN	CHN	CHN	HKG	MEX	CHN
	JPN	JPN	MEX	MEX	ITA	ITA	PRT	CAN	ITA
	DEU	DEU	CHN	CHN	BRA	BRA	DNK	DOM	BRA
	KOR	KOR	JPN	JPN	VNM	VNM	SVK	ISR	VNM
	GBR	GBR	DEU	DEU	MEX	MEX	HUN	COL	THA
	ITA	ITA	GBR	GBR	THA	THA	CHE	SLV	IDN
	FRA	FRA	KOR	KOR	IDN	IDN	AUT	MAR	ESP
	IND	HKG	FRA	VEN	ESP	ESP	ALB	ZAF	IND
	HKG	SWE	ITA	FRA	IND	IND	POL	AUS	FRA
	SWE	IND	MYS	MYS	CAN	CAN	NLD	GTM	DEU

Notes: This table illustrates how partner countries are assigned to treatment group, control group, or excluded from the analysis, using as an example product code 6403 “Footwear; with outer soles of rubber, plastics, leather or composition leather and uppers of leather” in 2006. Columns 1-2 list the top exporters to three importing countries – USA, Germany and Japan – exporting under the MFN regime in periods $t = 2006$ and $t - 1 = 2005$. Columns 3-4 list the importing countries’ major aggregate trading partners in these periods. Columns 5-6 list the major trading partners in product 6403. Columns 7-9 then list the main countries in the treatment, control and excluded group for imports of product 6403 to the three importing countries.

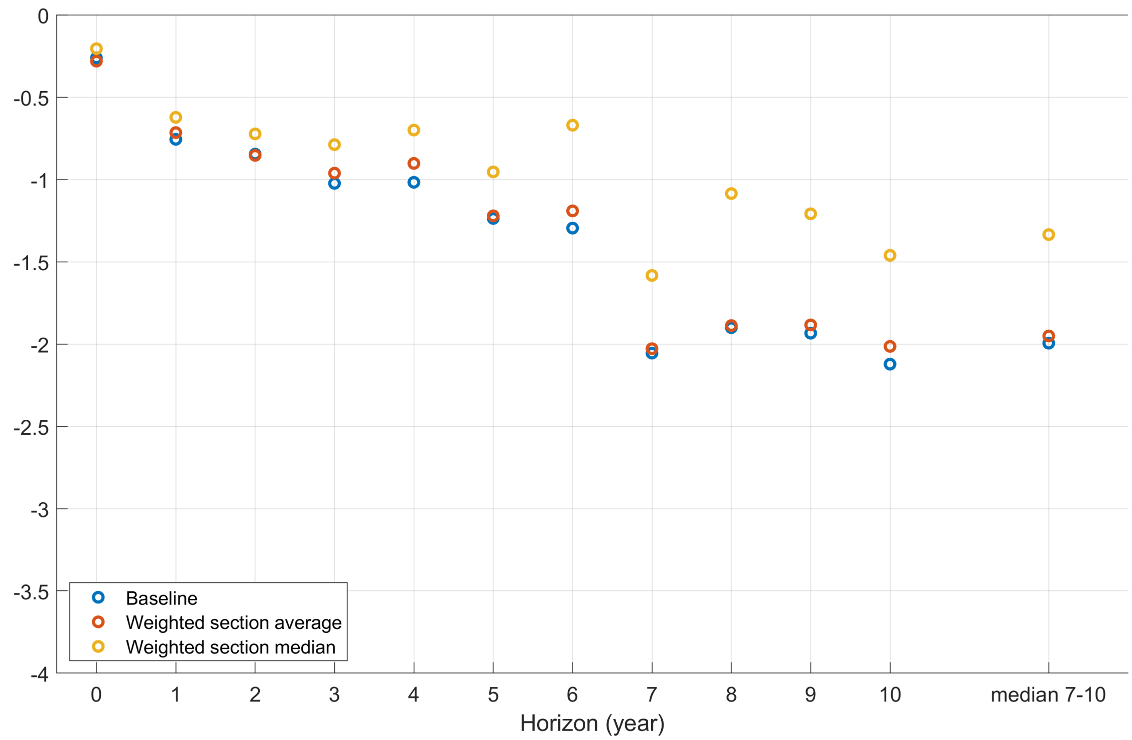
Table A3: HS Sections

Code	Name
7	PLASTICS AND ARTICLES THEREOF; RUBBER AND ARTICLES THEREOF
8	RAW HIDES AND SKINS, LEATHER, FURSKINS AND ARTICLES THEREOF;
	SADDLERY AND HARNESS; TRAVEL GOODS
9	WOOD AND ARTICLES OF WOOD; WOOD CHARCOAL;
	CORK AND ARTICLES OF CORK; MANUFACTURES OF STRAW,
	OF ESPARTO OR OF OTHER PLAITING MATERIALS;
	BASKETWARE AND WICKERWORK
10	PULP OF WOOD OR OF OTHER FIBROUS CELLULOSIC MATERIAL;
	RECOVERED (WASTE AND SCRAP) PAPER OR PAPERBOARD;
	PAPER AND PAPERBOARD AND ARTICLES THEREOF
11	TEXTILES AND TEXTILE ARTICLES
13	ARTICLES OF STONE, PLASTER, CEMENT, ASBESTOS, MICA OR SIMILAR MATERIALS
15	BASE METALS AND ARTICLES OF BASE METAL
	CERAMIC PRODUCTS; GLASS AND GLASSWARE
16	MACHINERY AND MECHANICAL APPLIANCES;
	ELECTRICAL EQUIPMENT; PARTS THEREOF; SOUND RECORDERS AND REPRODUCERS,
	TELEVISION IMAGE AND SOUND RECORDERS AND
	REPRODUCERS, AND PARTS AND ACCESSORIES OF SUCH ARTICLES
	ARTIFICIAL FLOWERS; ARTICLES OF HUMAN HAIR
18	OPTICAL, PHOTOGRAPHIC, CINEMATOGRAPHIC, MEASURING,
	CHECKING, PRECISION, MEDICAL OR SURGICAL INSTRUMENTS AND APPARATUS;
	CLOCKS AND WATCHES; MUSICAL INSTRUMENTS; PARTS AND ACCESSORIES THEREOF
20	MISCELLANEOUS MANUFACTURED ARTICLES
	Aggregated
1	LIVE ANIMALS; ANIMAL PRODUCTS
2	VEGETABLE PRODUCTS
3	ANIMAL OR VEGETABLE FATS AND OILS AND THEIR CLEAVAGE PRODUCTS
	HANDBAGS AND SIMILAR CONTAINERS; ARTICLES OF ANIMAL GUT (OTHER THAN SILK-WORM GUT)
4	PREPARED EDIBLE FATS;ANIMAL OR VEGETABLE WAXES
	PREPARED FOODSTUFFS;
	BEVERAGES, SPIRITS AND VINEGAR; TOBACCO AND MANUFACTURED TOBACCO SUBSTITUTES
5	MINERAL PRODUCTS
6	PRODUCTS OF THE CHEMICAL OR ALLIED INDUSTRIES
12	FOOTWEAR, HEADGEAR, UMBRELLAS, SUN UMBRELLAS,
	WALKING-STICKS, SEAT-STICKS, WHIPS, RIDING-CROPS AND PARTS THEREOF;
	PREPARED FEATHERS AND ARTICLES MADE THEREWITH;
14	NATURAL OR CULTURED PEARLS, PRECIOUS OR SEMI-PRECIOUS
	STONES, PRECIOUS METALS, METALS CLAD WITH PRECIOUS METAL
	AND ARTICLES THEREOF; IMITATION JEWELLERY; COIN
17	VEHICLES, AIRCRAFT, VESSELS AND ASSOCIATED TRANSPORT EQUIPMENT
19	ARMS AND AMMUNITION; PARTS AND ACCESSORIES THEREOF
21	WORKS OF ART, COLLECTORS' PIECES AND ANTIQUES

Notes: This table describes the 21 internationally compatible HS "Sections", which are groupings of HS product codes. We also list the 9 HS Sections that we aggregate in the main text into a Section 'aggregate', as there is insufficient variation in tariffs in these sections to estimate the elasticity. Figures 3 reports the elasticity estimates by section, and Figure B1 reports trade-weighted means and medians of section-specific elasticities.

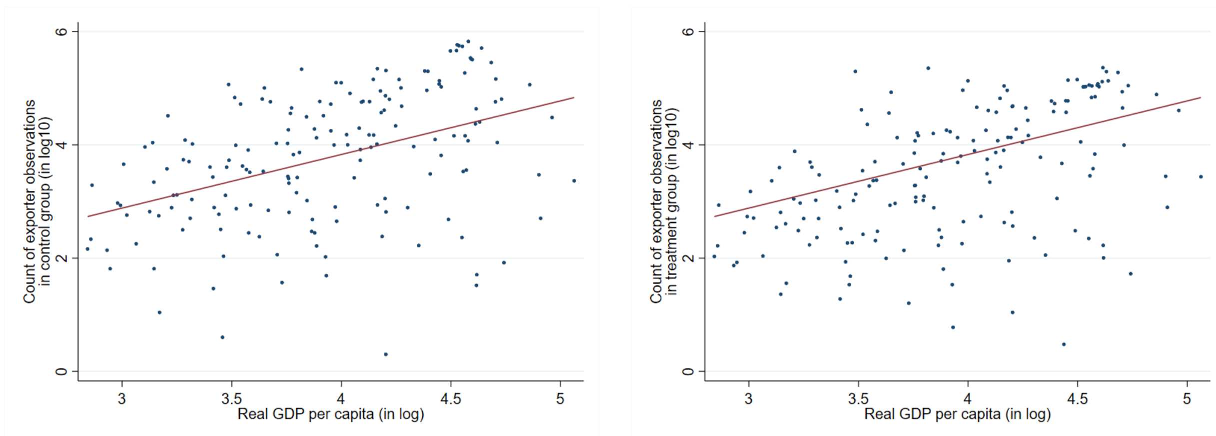
Appendix B Robustness

Figure B1: Trade elasticities: Full Sample Pooled vs. Trade-Weighted Sectoral Averages



Notes: The blue circles reproduce the baseline elasticity point estimates depicted in Figure 2. The red circles display world trade-weighted means of the HS section-specific elasticities reported in Figure 3. The yellow circles display world trade-weighted medians of the HS section-specific elasticities reported in Figure 3. Weighting uses the 2006 shares of world trade, and excludes the estimates of the combined HS aggregate section as described in the text.

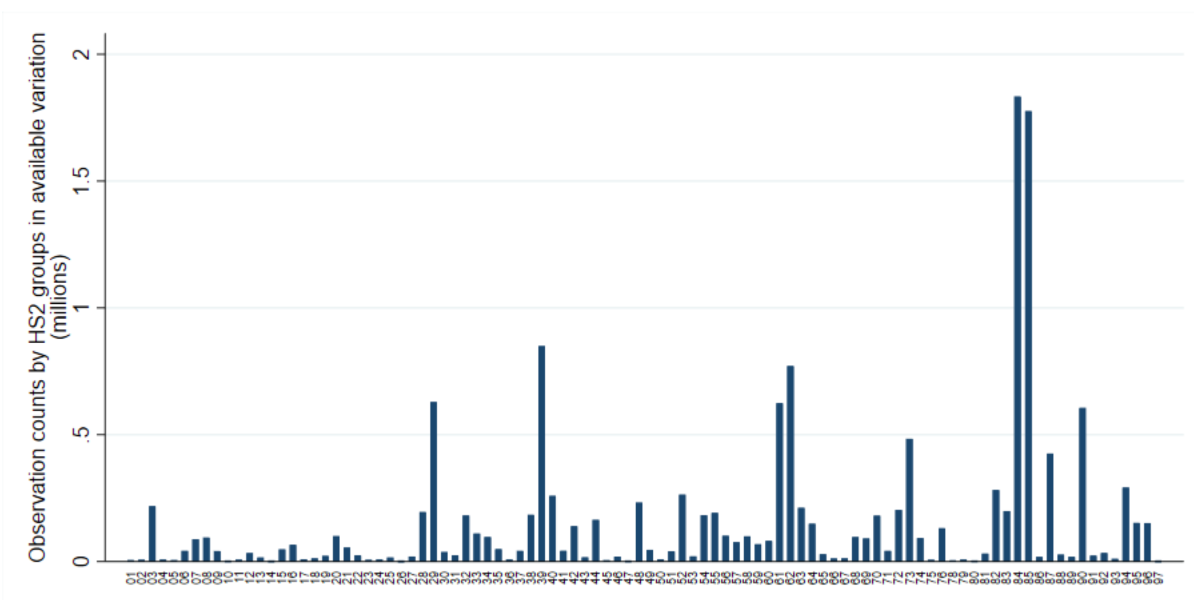
Figure B2: Country Variation



Control Treatment

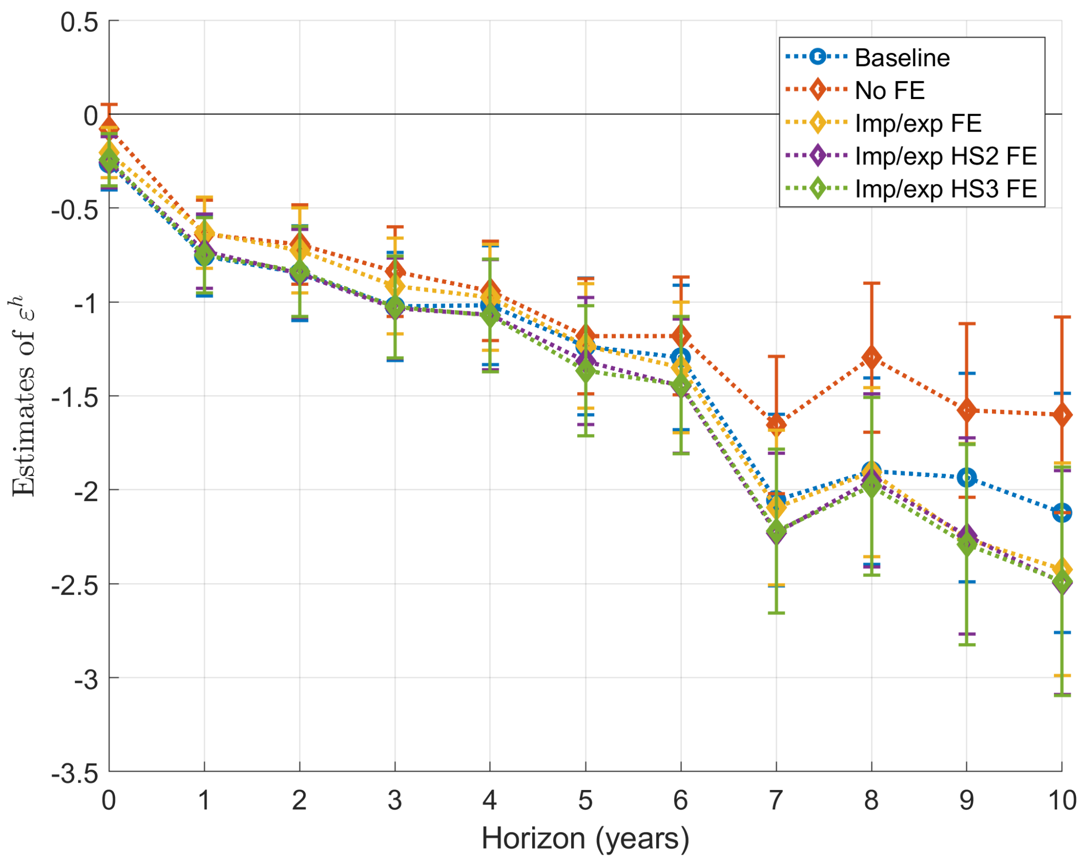
Notes: This figure plots the (log) counts a country appears in the control group (left panel) and in the treatment group (right panel) against log real PPP-adjusted per capita income from the Penn World Tables, after taking out the variation absorbed by the fixed effects and imposing the sample restrictions. The line depicts the OLS fit.

Figure B3: Product Variation



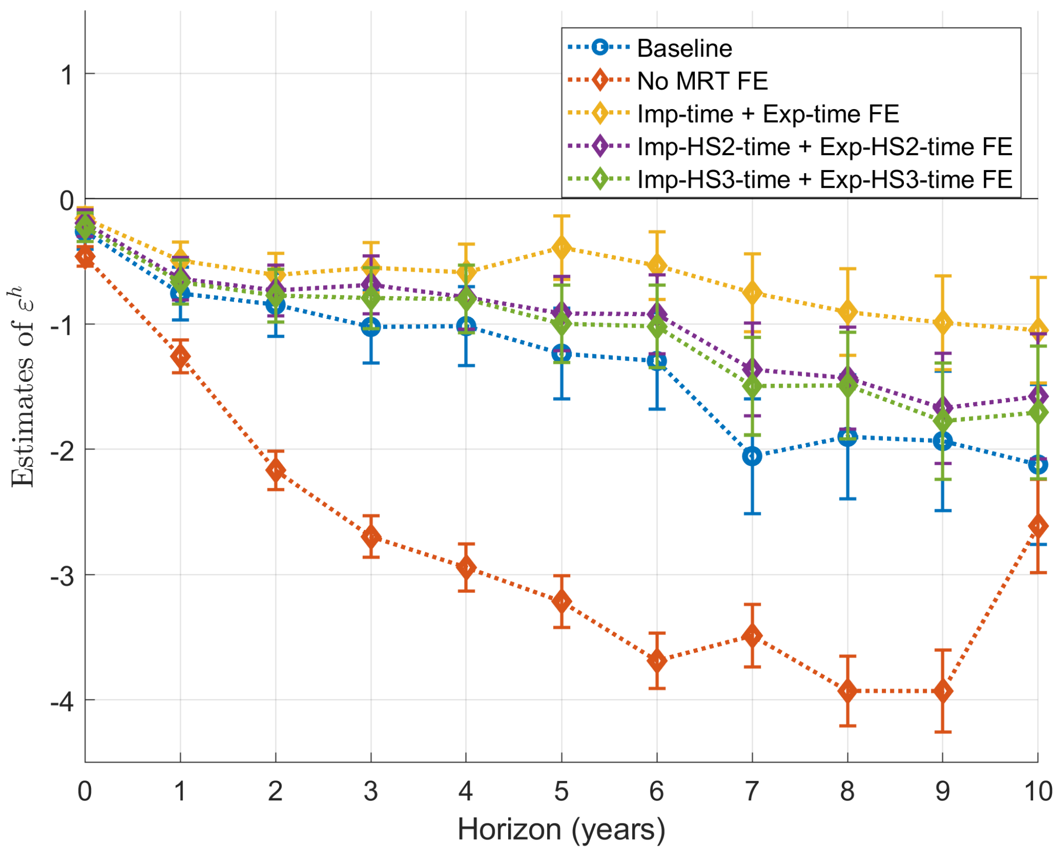
Notes: This figure plots the frequency of observations belonging to each HS-2 category, after taking out the variation absorbed by the fixed effects and imposing the sample restrictions.

Figure B4: Robustness: The Role of Bilateral Fixed Effects



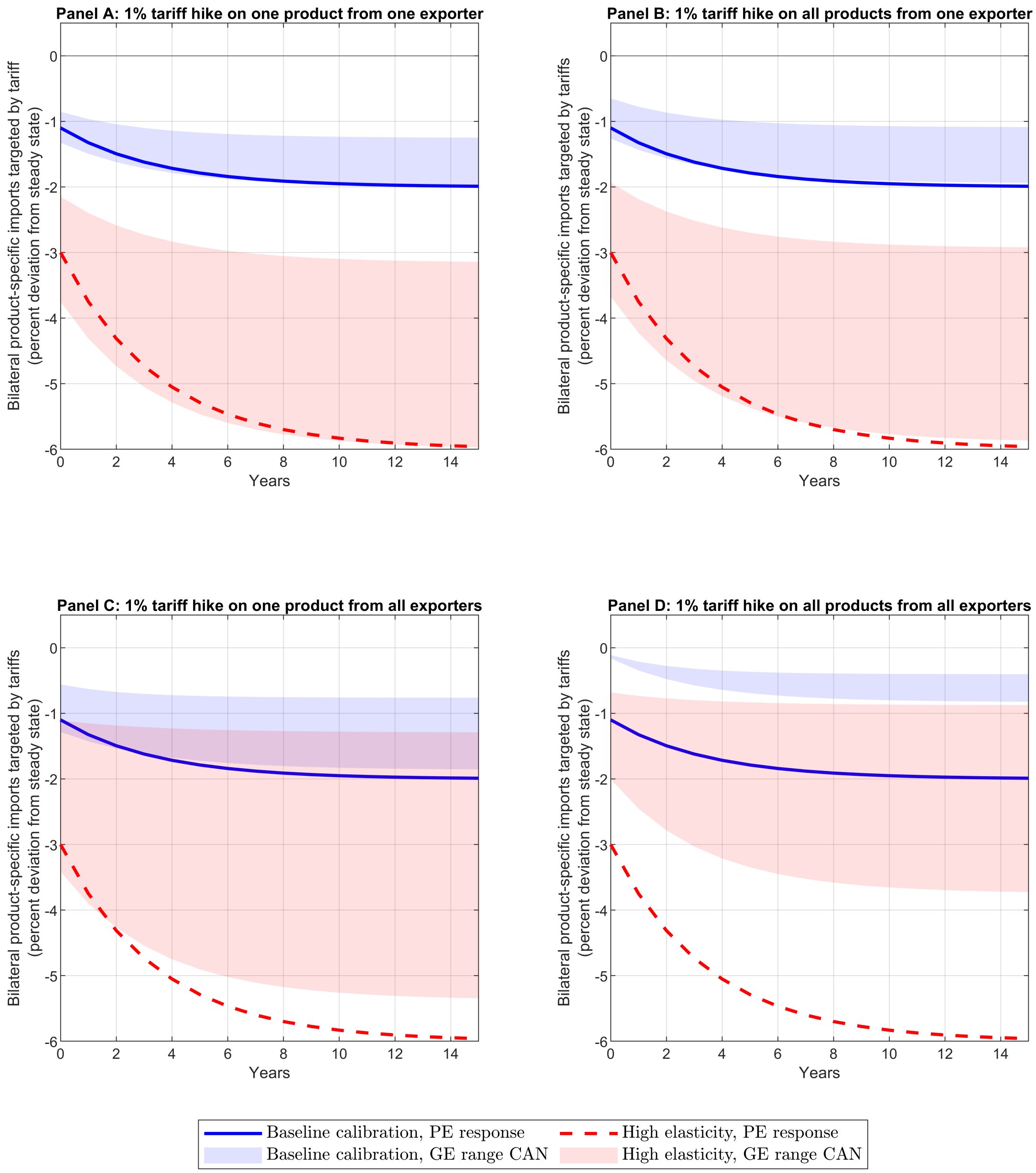
Notes: This figure displays estimates of the trade elasticity based on specification (2.4), with the baseline instrument (2.5), and including one lag of the changes in tariffs and trade as pre-trend controls. All specifications include exporter-HS4-year and importer-HS4-year fixed effects. The bilateral fixed effects are either importer-exporter-HS4 (the baseline), importer-exporter-HS3, importer-exporter-HS2, importer-exporter, or no bilateral fixed effects. The bars display 95% confidence intervals. Standard errors are clustered at the bilateral country-pair-product level.

Figure B5: Robustness: The Role of Multilateral Resistance Terms



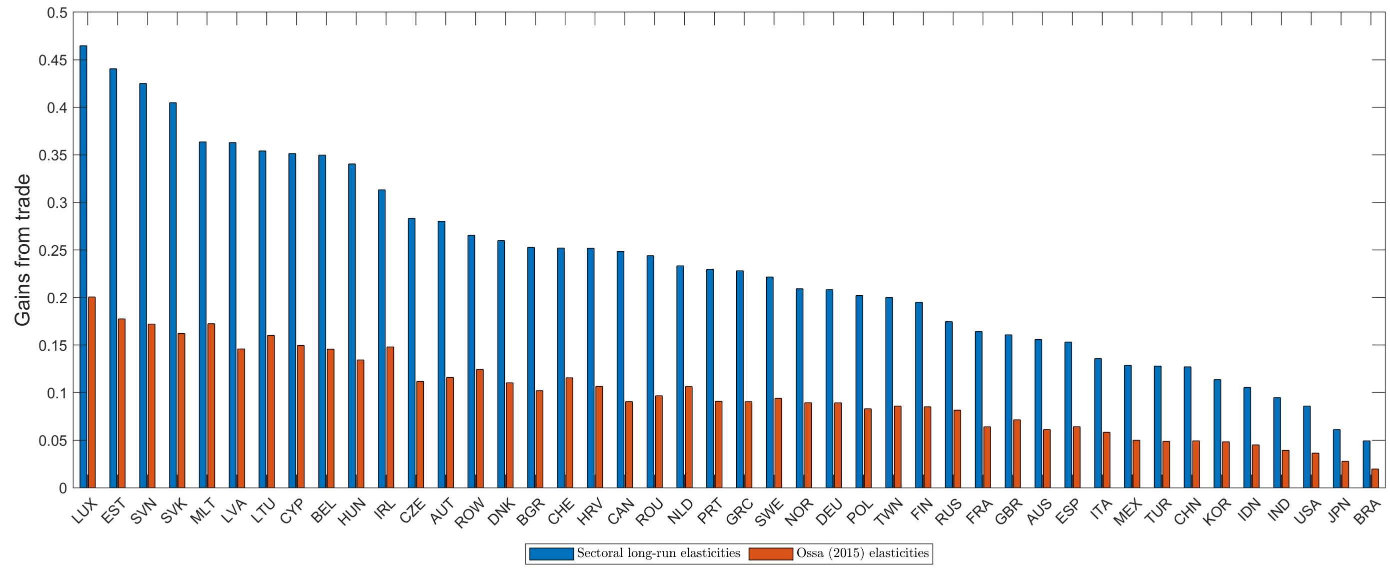
Notes: This figure displays estimates of the trade elasticity based on specification (2.4), with the baseline instrument (2.5) and including one lag of the changes in tariffs and trade as pre-trend controls. All specifications include importer-exporter-HS4 fixed effects. The multilateral resistance term (MRT) fixed effects are either importer- and exporter-year-HS4 (the baseline); importer- and exporter-year-HS3; importer- and exporter-HS2; importer- and exporter-year; or no multilateral fixed effects. The bars display 95% confidence intervals. Standard errors are clustered at the bilateral country-pair-product level.

Figure B6: General Equilibrium Trade Responses: Canadian Imports



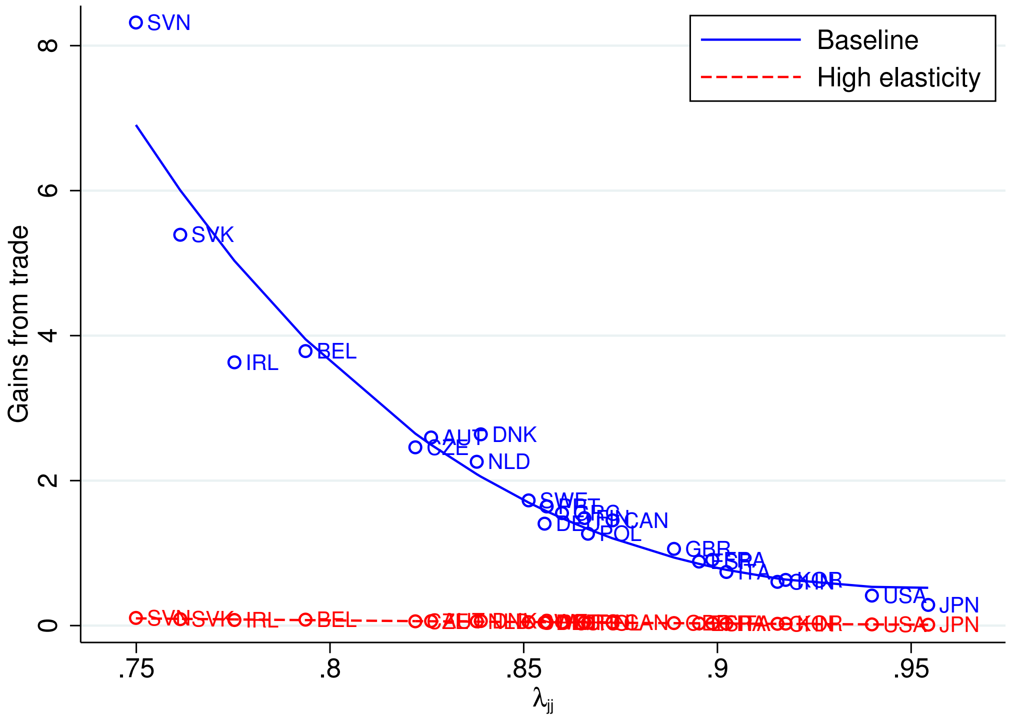
Notes: This table reports the impulse responses of Canadian imports to unexpected and permanent 1% tariff hikes in partial equilibrium (solid blue lines and dashed red lines) and in general equilibrium (shaded areas). The shaded areas represent the ranges of impulse response functions in GE taken over exporters and sectors. In the baseline calibration $\sigma = 1.1$ and $\chi = 0.82$, so that the long-run elasticity $\varepsilon = 2$. In the high elasticity calibration, $\sigma = 3$ and $\chi = 1$, so that $\varepsilon = 6$. See Appendix Table D1 for details on the calibration.

Figure B7: Gains From Trade: Multiple Sectors



Notes: Gains from trade relative to autarky are computed using the formula $1 - \sum_s \lambda_{jj,s}^{-\beta_{j,s}/\theta_s}$, where $\beta_{j,s}$ is the share of sector s in country j's total absorption and $\lambda_{jj,s}$ is 1 minus the import share in sector s. "Sectoral long-run elasticities" refer to the HS-section level elasticities estimated in Section 4.1. We use the median estimate between years 7-10 for each section as the long-run value. For a comparison, the red bars use elasticities obtained from Ossa (2015). Data come from the 2006 World Input-Output Database (WIOD). The input-output table is converted to HS classification using an OECD concordance between ISIC and HS. The GTAP sector estimates from Ossa (2015) are converted to the HS classification using GTAP's concordance table between GTAP sectors and HS classifications. The number of HS-6 categories in each GTAP-HS section pair is used as a weight.

Figure B8: Gains From Trade: Dynamic Krugman Model



Notes: This figure reports the gains from trade relative to autarky in the dynamic Krugman model as described in Appendix D. λ_{jj} denotes the domestic absorption share.

TABLE B1: Local Projections of Tariffs and Trade: Coefficients for Every Horizon

	Panel A: Tariffs			Panel B: Trade		
	Baseline	Zero Lag	Five Lags	Baseline	Zero Lag	Five Lags
	(1)	(2)	(3)	(4)	(5)	(6)
$t-6$	-0.10***	-0.09***	-0.10***	0.10	0.03	0.31*
	(0.01)	(0.00)	(0.01)	(0.13)	(0.11)	(0.16)
$t-5$	-0.02***	-0.03***	.	0.22*	0.27***	.
	(0.00)	(0.00)	.	(0.12)	(0.11)	.
$t-4$	-0.04***	-0.02***	.	0.00	-0.06	.
	(0.00)	(0.00)	.	(0.11)	(0.09)	.
$t-3$	-0.05***	-0.09***	.	0.07	-0.02	.
	(0.00)	(0.00)	.	(0.10)	(0.09)	.
$t-2$	-0.13***	-0.03***	.	0.24***	0.13	.
	(0.00)	(0.00)	.	(0.09)	(0.09)	.
$t-1$	.	-0.31***	.	.	0.15**	.
	.	(0.00)	.	.	(0.07)	.
t	.	.	.	-0.26***	-0.15***	0.17
	.	.	.	(0.07)	(0.05)	(0.14)
$t+1$	0.89***	0.85***	0.84***	-0.67***	-0.53***	-0.11
	(0.00)	(0.00)	(0.01)	(0.10)	(0.07)	(0.18)
$t+2$	0.85***	0.83***	0.79***	-0.72***	-0.59***	-0.13
	(0.00)	(0.00)	(0.01)	(0.11)	(0.08)	(0.21)
$t+3$	0.83***	0.82***	0.77***	-0.85***	-0.76***	-0.48**
	(0.01)	(0.00)	(0.01)	(0.12)	(0.09)	(0.24)
$t+4$	0.82***	0.81***	0.75***	-0.83***	-0.75***	-0.21
	(0.01)	(0.00)	(0.01)	(0.13)	(0.09)	(0.27)
$t+5$	0.81***	0.82***	0.72***	-1.00***	-0.92***	-0.82***
	(0.01)	(0.00)	(0.01)	(0.15)	(0.10)	(0.31)
$t+6$	0.78***	0.79***	0.66***	-1.01***	-0.88***	-0.50
	(0.01)	(0.00)	(0.01)	(0.15)	(0.10)	(0.32)
$t+7$	0.69***	0.75***	0.59***	-1.43***	-1.15***	-1.38***
	(0.01)	(0.00)	(0.01)	(0.16)	(0.11)	(0.35)
$t+8$	0.67***	0.72***	0.55***	-1.27***	-1.15***	-0.93**
	(0.01)	(0.00)	(0.01)	(0.17)	(0.12)	(0.39)
$t+9$	0.70***	0.73***	0.63***	-1.35***	-0.99***	-1.37***
	(0.01)	(0.00)	(0.02)	(0.20)	(0.12)	(0.51)
$t+10$	0.71***	0.72***	0.64***	-1.52***	-1.05***	-1.64**
	(0.01)	(0.01)	(0.02)	(0.23)	(0.14)	(0.65)

Notes: This table presents the results from estimating the local projections equations (2.3) (Panel A) and (2.2) (Panel B). The dependent variable for negative time horizons is the one-period change in the variable of interest. For instance, the dependent variable in column (2) for horizon $t-1$ is $\ln \tau_{i,j,p,t-1} - \ln \tau_{i,j,p,t-2}$. The first column in each panel presents the baseline local projects results, while the second and third columns in each panel present results with 2 and 5 lags of tariffs and trade as pre-trend controls respectively. Standard errors clustered by country-pair-product are in parentheses. ***, ** and * denote significance at the 99, 95 and 90% levels.

Table B2: Trade Elasticity: Estimates and First Stage F-Statistics

	Baseline IV	F-stat	Distributed Lag	SW F-stat
t	-0.26***	91422	-0.41	20536
	(0.07)		(0.34)	
$t+1$	-0.76***	42231	-0.52	18831
	(0.11)		(0.47)	
$t+2$	-0.85***	36469	-0.92	22499
	(0.13)		(0.59)	
$t+3$	-1.02***	28537	-1.58**	22570
	(0.15)		(0.68)	
$t+4$	-1.02***	23771	-1.60**	16227
	(0.16)		(0.77)	
$t+5$	-1.24***	22697	-2.10**	12463
	(0.19)		(0.86)	
$t+6$	-1.30***	19439	-2.18**	14722
	(0.20)		(0.93)	
$t+7$	-2.06***	15481	-2.71***	13473
	(0.23)		(1.02)	
$t+8$	-1.90***	13933	-2.80**	13475
	(0.25)		(1.11)	
$t+9$	-1.93***	10201	-3.08***	14278
	(0.28)		(1.18)	
$t+10$	-2.12***	8252	-3.17**	10962
	(0.32)		(1.25)	

Notes: This table presents the first-stage F-statistics for the main estimates. For the Distributed Lag model we report the Sanderson-Windmeijer F-statistic to test for weak instruments as we have 11 instruments and 11 endogenous variables.

Table B3: Trade Elasticity: Comparison to Existing Estimates of Responses to Tariffs

Papers	Method	Estimate(s)	Time Period	Country Sample
Country-Level				
Baier and Bergstrand (2001)	Single long difference, no MRT FEs	-4.49	1958-60 to 1986-1988	16 OECD countries
Anderson and Marcouiller (2002)	Ratios, US Base country	-4.8	1996	58 countries
Estevadeordal, Frantz, and Taylor (2003)	Log-levels panel, gravity controls	-0.8 to -1.6	1913, 1928, 1938	28 countries
2-digit sectors				
Nahuis (2004)	Log-levels cross section, gravity controls	-38 to $+46.5$	1998	27 countries
Tharakan, Beveren, and Ourti (2005)	Log-levels panel	insignificant	-	India
Fink, Mattoo, and Neagu Constantinescu (2005)	Log-levels cross-section, MRT, gravity controls	-0.5 to -3.5	1999	
Francois and Woerz (2009)	Log-levels panel, gravity controls	-2 to -5.5	1996-2005	EU, US, 20-46 partners
Dutt and Traca (2010)	Panel, gravity variables, Country FE + Country-level controls	-2.1 to -2.6	1980-2004	28 sectors
Caliendo and Parro (2015)	Cross-sectional double differencing	-0.37 to -51.08	1993	27 countries
3-digit sectors				
Head and Ries (2001)	Log-levels Panel	-7.9 to -11.4	1990-1995	US, Canada
5 digit SITC/HS6				
Hummels (2001)	Log-levels cross-section, MRT + gravity variables	-3 to -8	1992	6 FTAA countries + New Zealand
Hertel et al. (2007)	Log-levels cross-section, MRT, gravity variables	-1.8 to -34.4	1992	6 FTAA countries + New Zealand
Romalis (2007)	Log-levels diff-in-diff	-0.56 to -10.9	1990-1999	US, Mexico, Canada, EU and Rest-of-World
Fontagné, Guimbard, and Orefice (2022)	Log-levels panel MRT + gravity controls	-0.38 to -122.97	2001,'04,'07, '10,'13,'16	150+ importers
Our paper	Local Projections IV diff-in-diff	-0.75 to -2.25	1995-2018	180+ countries
HS8-HS10 (Firm-level)				
Bas, Mayer, and Thoenig (2017)	Log-levels cross-section with FEs, tetrads, Tobit	-2.5 to -5.5	2000	China, France and all export destinations
Fitzgerald and Haller (2018)	Firm-product-destination panel	-1.6 to -3.55		Ireland and top import destinations

Notes: This table summarizes the elasticity estimates of the papers closest to ours in methodology. MRT abbreviates multilateral resistance terms fixed effects.

Table B4: Elasticity Estimates: Alternative Approaches – Constant Sample

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Log Levels			5-year Log Differences					10-year
	No FE	Multilateral FE	Multilateral + Bilateral FE	OLS	2SLS	Baseline IV			
$\ln \tau_{i,j,p,t}$	-8.01***	-10.95***	-0.75***	-1.15***	-0.87***	-1.34***	-1.14***	-1.61***	-1.93***
	(0.07)	(0.15)	(0.09)	(0.07)	(0.08)	(0.22)	(0.26)	(0.30)	(0.36)
R^2	0.02	0.44	0.62	0.22					
Obs	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6
First stage F					71700	11505	9331	4801	4171
Fixed effects									
Imp×HS4×year, Exp×HS4×year		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Imp×Exp×HS4			Yes				Yes	Yes	Yes
pre-trend controls								Yes	Yes

Notes: This table compares alternative approaches of estimating trade elasticities on a constant sample. The dependent variables are log levels of trade values (columns 1-3) and log-differences of trade flows (columns 4-9), and the independent variable of interest is the log of tariffs (columns 1-3), 5-year log-differences of tariffs (columns 4-8), and the 10-year log-difference of tariffs (column 9). Column 1 reports the results with no fixed effects. Column 2 adds importer-HS4-year and exporter-HS4-year fixed effects. Column 3 further adds importer-exporter-HS4 fixed effects. Column 4 estimates the coefficient by OLS. Column 5 reports the all data/all tariffs 2SLS as explained in the text. Columns 6-9 present the results using our baseline IV. The specifications with pre-trend controls additionally include log-changes in tariffs from $t-2$ to $t-1$, instrumented with our lagged baseline instrument, and log-changes in trade from $t-2$ to $t-1$. The reported R^2s include the explanatory power of the fixed effects. Standard errors clustered by country-pair-product are in parentheses. *** denotes significance at the 99% level. Numbers of observations are reported in millions.

Table B5: "Traditional Gravity" Elasticity Estimates in Log-Levels, HS6 Multilateral Resistance Terms

	No Bilateral (1)	Country-pair (2)	Country-pair×HS2 (3)	Country-pair×HS3 (4)	Country-pair×HS4 (5)
$\ln \tau_{i,j,p,t}$	-12.62***	-1.70***	-1.36***	-1.28***	-1.04***
	(0.08)	(0.03)	(0.02)	(0.02)	(0.02)
R^2	0.55	0.67	0.70	0.71	0.76
Obs	103.1	103.1	102.9	102.7	101.7
Bilateral Fixed Effects					
	None	Imp×Exp	Imp×Exp×HS2	Imp×Exp×HS3	Imp×Exp×HS4

Notes: This table presents the results from estimating the trade elasticity in log-levels where the multilateral resistance terms are at the HS6 level. The dependent variable is the log of trade value. All specifications include importer-HS6-year and exporter-HS6-year fixed effects. Column 1 reports the results with no bilateral fixed effects. Column 2 adds country-pair fixed effects, Column 3 includes country-pair-HS2 fixed effects, column 4 includes country-pair-HS3 fixed effects, and Column 4 uses country-pair-HS4 fixed effects. The reported R^2s include the explanatory power of the fixed effects. Standard errors, clustered at the importer-exporter-HS4 level, are in parentheses. ***, ** and * denote significance at the 99, 95, and 90% levels. Number of observations are reported in millions.

Table B6: Trade Elasticity, Every Horizon, Robustness: Pre-Trends, Alternative Clustering, Alternative Samples

	Baseline	No Lags	Five Lags	FE50	Two-way Clustering	Constant Sample	Alternative Control Group	Extensive Case 1	Extensive Case 2
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
t	-0.26***	-0.15***	0.17	-0.23**	-0.26***	-0.59**	-0.19**	0.02	-0.08
	(0.07)	(0.05)	(0.14)	(0.09)	(0.10)	(0.29)	(0.08)	(0.04)	(0.06)
Obs	31.7	41.5	14.6	17.6	31.7	5.0	27.3	131.0	56.4
$t+1$	-0.76***	-0.63***	-0.13	-0.60***	-0.76***	-0.10	-0.49***	-0.48***	-0.81***
	(0.11)	(0.08)	(0.21)	(0.13)	(0.14)	(0.38)	(0.12)	(0.06)	(0.09)
Obs	26.2	32.8	12.5	15.2	26.2	5.0	22.6	108.1	49.1
$t+2$	-0.85***	-0.71***	-0.16	-0.72***	-0.85***	-0.76*	-0.45***	-0.43***	-0.73***
	(0.13)	(0.09)	(0.26)	(0.16)	(0.19)	(0.44)	(0.14)	(0.07)	(0.10)
Obs	23.3	29.2	11.1	13.8	23.3	5.0	20.1	97.0	45.2
$t+3$	-1.02***	-0.93***	-0.63**	-0.86***	-1.02***	-0.89*	-0.74***	-0.59***	-0.95***
	(0.15)	(0.10)	(0.31)	(0.17)	(0.20)	(0.47)	(0.16)	(0.08)	(0.11)
Obs	20.8	26.2	9.8	12.5	20.8	5.0	17.9	87.2	41.5
$t+4$	-1.02***	-0.92***	-0.29	-0.78***	-1.02***	-0.77	-0.61***	-0.45***	-0.85***
	(0.16)	(0.12)	(0.36)	(0.19)	(0.23)	(0.48)	(0.17)	(0.10)	(0.12)
Obs	18.7	23.5	8.5	11.3	18.7	5.0	16.0	77.8	37.9
$t+5$	-1.24***	-1.11***	-1.15***	-1.01***	-1.24***	-0.92**	-0.79***	-0.73***	-1.18***
	(0.19)	(0.12)	(0.43)	(0.22)	(0.25)	(0.44)	(0.20)	(0.10)	(0.12)
Obs	16.7	21.1	7.3	10.2	16.7	5.0	14.3	69.7	34.6
$t+6$	-1.30***	-1.11***	-0.75	-1.05***	-1.30***	-0.53	-0.57***	-0.86***	-1.21***
	(0.20)	(0.13)	(0.48)	(0.23)	(0.27)	(0.46)	(0.22)	(0.10)	(0.12)
Obs	14.9	18.9	6.2	9.2	14.9	5.0	12.6	62.1	31.3
$t+7$	-2.06***	-1.52***	-2.33***	-1.85***	-2.06***	-0.99**	-1.38***	-0.90***	-1.50***
	(0.23)	(0.15)	(0.59)	(0.27)	(0.36)	(0.49)	(0.25)	(0.11)	(0.14)
Obs	13.2	17.0	5.2	8.2	13.2	5.0	11.1	55.2	28.4
$t+8$	-1.90***	-1.60***	-1.69**	-1.89***	-1.90***	-1.09**	-1.08***	-0.69***	-1.43***
	(0.25)	(0.16)	(0.71)	(0.29)	(0.46)	(0.51)	(0.27)	(0.13)	(0.16)
Obs	11.5	15.0	4.4	7.2	11.5	5.0	9.6	48.5	25.4
$t+9$	-1.93***	-1.35***	-2.15***	-1.78***	-1.93***	-1.60***	-1.09***	-1.00***	-1.65***
	(0.28)	(0.16)	(0.81)	(0.32)	(0.50)	(0.55)	(0.31)	(0.14)	(0.16)
Obs	9.9	13.1	3.8	6.2	9.9	5.0	8.2	41.8	22.4
$t+10$	-2.12***	-1.46***	-2.55**	-1.76***	-2.12***	-1.82***	-1.60***	-0.94***	-1.64***
	(0.32)	(0.19)	(1.02)	(0.37)	(0.33)	(0.54)	(0.38)	(0.15)	(0.18)
Obs	8.3	11.3	3.2	5.2	8.3	5.0	6.8	35.1	19.2

Notes: This table presents robustness exercises for the results from estimating equation (2.4). All specifications include importer-HS4-year, exporter-HS4-year, and importer-exporter-HS4 fixed effects, and the baseline pre-trend controls (one lag of each the log change in tariffs and trade) unless otherwise specified. Columns 2 and 3 vary the pre-trend controls (including alternatively zero lags or five lags of import growth and tariff changes). Column 4 reports the results when the sample is restricted to fixed-effects clusters with a minimum of 50 observations per cluster. Column 6 restricts the sample to a constant sample across horizons. Column 7 reports results where the control group only contains observations with zero tariff changes. Column 8 presents results including the extensive margin using the inverse hyperbolic sine transformation for trade flows, and all zero trade observations for importer-exporter-section pair with ever positive trade. Column 9 presents results including the extensive margin using the inverse hyperbolic sine transformation for trade flows, and only zero trade observations when trade switches from zero to positive, or vice versa. Standard errors are clustered at the importer-exporter-HS4 level, except in Column 5 where they are additionally clustered by year. ***, **, and * indicate significance at the 99, 95, and 90 percent level respectively. Observations are reported in millions.

Table B7: Trade Elasticity, Every Horizon, Robustness: Alternative Instruments, Outcomes, and Samples

	Baseline	All data/ MFN Tariffs	Top 5 Maj. Partners	Quantities	Unit Values	Weighted	SD1	PTA	TTB
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
t	-0.26***	-0.28***	-0.24***	-0.18*	-0.05	-0.24***	-0.31***	-0.24***	-0.26***
	(0.07)	(0.03)	(0.05)	(0.09)	(0.06)	(0.08)	(0.10)	(0.07)	(0.07)
Obs	31.7	57.1	39.0	31.7	31.7	31.6	28.7	31.8	31.7
$t+1$	-0.76***	-0.62***	-0.67***	-0.66***	-0.03	-0.82***	-0.89***	-0.73***	-0.76***
	(0.11)	(0.05)	(0.08)	(0.14)	(0.08)	(0.12)	(0.14)	(0.11)	(0.11)
Obs	26.2	47.2	32.1	26.2	26.2	26.2	23.8	26.3	26.2
$t+2$	-0.85***	-0.65***	-0.72***	-0.66***	-0.14	-0.94***	-0.86***	-0.83***	-0.84***
	(0.13)	(0.05)	(0.09)	(0.16)	(0.09)	(0.14)	(0.17)	(0.13)	(0.13)
Obs	23.3	42.3	28.6	23.3	23.3	23.3	21.1	23.4	23.3
$t+3$	-1.02***	-0.65***	-0.86***	-0.81***	-0.13	-1.05***	-1.23***	-0.97***	-1.02***
	(0.15)	(0.06)	(0.10)	(0.18)	(0.10)	(0.16)	(0.20)	(0.15)	(0.15)
Obs	20.8	38.2	25.6	20.8	20.8	20.8	18.9	20.9	20.8
$t+4$	-1.02***	-0.66***	-0.87***	-0.80***	-0.09	-1.08***	-1.17***	-0.98***	-1.02***
	(0.16)	(0.07)	(0.11)	(0.20)	(0.11)	(0.18)	(0.22)	(0.16)	(0.16)
Obs	18.7	34.4	23.0	18.7	18.7	18.7	16.9	18.8	18.7
$t+5$	-1.24***	-0.72***	-1.08***	-1.42***	0.29**	-1.21***	-1.18***	-1.12***	-1.24***
	(0.19)	(0.07)	(0.12)	(0.23)	(0.13)	(0.21)	(0.25)	(0.19)	(0.19)
Obs	16.7	30.9	20.6	16.7	16.7	16.7	15.1	16.8	16.7
$t+6$	-1.30***	-0.78***	-1.08***	-1.37***	0.13	-1.45***	-1.27***	-1.21***	-1.30***
	(0.20)	(0.08)	(0.13)	(0.24)	(0.13)	(0.22)	(0.26)	(0.20)	(0.20)
Obs	14.9	27.7	18.4	14.9	14.9	14.9	13.5	15.0	14.9
$t+7$	-2.06***	-0.94***	-1.53***	-2.17***	0.16	-2.14***	-1.99***	-1.97***	-2.06***
	(0.23)	(0.09)	(0.16)	(0.29)	(0.16)	(0.26)	(0.32)	(0.23)	(0.23)
Obs	13.2	24.6	16.3	13.2	13.2	13.2	12.0	13.3	13.2
$t+8$	-1.90***	-1.00***	-1.51***	-2.08***	0.20	-1.97***	-1.95***	-1.85***	-1.90***
	(0.25)	(0.10)	(0.17)	(0.32)	(0.17)	(0.28)	(0.35)	(0.25)	(0.25)
Obs	11.5	21.7	14.2	11.5	11.5	11.5	10.4	11.6	11.5
$t+9$	-1.93***	-0.97***	-1.58***	-1.66***	-0.18	-2.06***	-2.19***	-1.91***	-1.93***
	(0.28)	(0.11)	(0.19)	(0.35)	(0.19)	(0.32)	(0.39)	(0.29)	(0.28)
Obs	9.9	18.7	12.2	9.9	9.9	9.8	8.9	9.9	9.9
$t+10$	-2.12***	-0.87***	-1.48***	-1.76***	-0.08	-2.37***	-2.36***	-2.08***	-2.12***
	(0.32)	(0.12)	(0.22)	(0.41)	(0.22)	(0.37)	(0.44)	(0.33)	(0.32)
Obs	8.3	15.9	10.3	8.3	8.3	8.3	7.5	8.4	8.3

Notes: This table presents alternative estimates for the results from estimating equation (2.4), varying the instrument, outcome variable, or sample. All specifications include importer-HS4-year, exporter-HS4-year, and importer-exporter-HS4 fixed effects, and the baseline pre-trend controls (one lag of each the log change in tariffs and trade). Column 2 uses an alternative sample where all trade partners subject to the MFN regime are included. Column 3 presents results where the sample excludes only the top-5 major MFN trade partners. Column 4 reports results for quantities, and column 5 the results for unit values. Column 6 presents results for a weighted specification where $t-1$ log trade values are used as weights. Column 7 reports the results based on a sample where tariffs do not vary within an importer-exporter-HS6-year observation. Column 8 presents results where we assign observations covered by a PTA listed in the WTO PTA Database to the control group. Column 9 reports the results after dropping country-pair-product-year observations where imports were subject to temporary trade barriers. Standard errors are clustered at the importer-exporter-HS4 level. ***, **, and * indicate significance at the 99, 95, and 90 percent level respectively. Observations are reported in millions.

Table B8: Trade Elasticity: Further Robustness

	Uruguay Round		HS6 Multilateral Effects		Distributed Lag
	All data/all tariffs 2SLS	Baseline IV	All data/all tariffs 2SLS	Baseline IV	Baseline IV
	(1)	(2)	(3)	(4)	(5)
t	-0.28	-0.18	-0.19***	0.08	-0.41
	(0.18)	(0.85)	(0.02)	(0.11)	(0.34)
Obs	0.9	0.6	54.3	30.2	6.1
$t+1$	-1.02*	-2.01	-0.26***	-0.68***	-0.52
	(0.61)	(2.39)	(0.02)	(0.13)	(0.47)
Obs	0.8	0.5	54.3	24.9	6.1
$t+2$	-0.63	-1.49	-0.28***	-0.60***	-0.92
	(0.71)	(2.66)	(0.03)	(0.16)	(0.59)
Obs	0.8	0.5	48.5	22.2	6.1
$t+3$	-1.42**	-5.09**	-0.29***	-0.59***	-1.58**
	(0.59)	(2.47)	(0.03)	(0.17)	(0.68)
Obs	0.8	0.5	43.7	19.8	6.1
$t+4$	-1.50**	-1.43	-0.37***	-0.77***	-1.60**
	(0.62)	(1.96)	(0.04)	(0.19)	(0.77)
Obs	0.8	0.5	39.5	17.8	6.1
$t+5$	-1.23*	-2.08	-0.41***	-1.04***	-2.10**
	(0.72)	(2.46)	(0.04)	(0.22)	(0.86)
Obs	0.7	0.4	35.6	15.9	6.1
$t+6$	-1.36**	-1.15	-0.45***	-1.09***	-2.18**
	(0.68)	(2.31)	(0.04)	(0.22)	(0.93)
Obs	0.7	0.4	31.9	14.2	6.1
$t+7$	-1.62*	0.26	-0.43***	-1.37***	-2.71***
	(0.88)	(2.90)	(0.05)	(0.27)	(1.02)
Obs	0.7	0.4	28.6	12.6	6.1
$t+8$	-1.90**	-4.74	-0.35***	-0.99***	-2.80**
	(0.86)	(2.93)	(0.05)	(0.29)	(1.11)
Obs	0.7	0.5	25.4	11.0	6.1
$t+9$	-1.07	-3.61	-0.41***	-0.98***	-3.08***
	(0.84)	(2.52)	(0.05)	(0.33)	(1.18)
Obs	0.7	0.5	22.2	9.4	6.1
$t+10$	-0.42	-2.97	-0.50***	-0.47	-3.17**
	(1.05)	(3.28)	(0.05)	(0.36)	(1.25)
Obs	0.6	0.4	19.0	8.0	6.1

Notes: This table presents the results from estimating the trade elasticity using both all data/all tariffs 2SLS (column 1) and the baseline instrument (column 2) for tariff changes only in years 1995-1997 ("Uruguay round"). These specifications include importer-HS4-year, exporter-HS4-year, and importer-exporter-HS4 fixed effects. Columns (3) and (4) present the all data/all tariffs 2SLS and baseline IV specifications when the multilateral resistance terms are country-HS6-year level. In these columns we drop the bilateral fixed effect. Columns (1) to (4) also include the baseline pre-trend controls (one lag). Column 5 presents results from a distributed lag model. This specification includes importer-HS4-year, exporter-HS4-year, and importer-exporter-HS4 fixed effects. Standard errors are clustered at the importer-exporter-HS4 level. ***, **, and * indicate significance at the 99, 95, and 90 percent level respectively. Observations are reported in millions.

Table B9: Gains from Trade

Country	$\theta = -1$	$\theta = -5$	$\theta = -10$
G7			
Canada	14.56%	2.76%	1.37%
France	11.28%	2.16%	1.07%
Germany	16.91%	3.17%	1.57%
Italy	10.83%	2.08%	1.03%
Japan	4.78%	0.94%	0.47%
UK	12.51%	2.39%	1.19%
US	6.40%	1.25%	0.62%
Major Emerging Markets			
Brazil	3.58%	0.71%	0.35%
China	9.23%	1.78%	0.89%
India	7.27%	1.41%	0.70%
Mexico	9.09%	1.76%	0.87%
Russia	14.88%	2.81%	1.40%
Median, 43 Countries	16.83%	3.16%	1.57%

Notes: Data are from the 2006 World Input-Output Database for 43 countries. Gains from trade relative to autarky are computed using the formula $\lambda_{jj}^{1/\theta} - 1$, where λ_{jj} is 1 minus the import share.

Appendix C Partial Equilibrium Model

Notation Throughout this appendix, we let tildes denote percent deviations from steady state, e.g. $\tilde{v}_t = \ln v_t - \ln v = d\ln v_t = \frac{v_t - v}{v}$. Variables without subscripts denote steady state values.

For most of this appendix we suppress source and destination country as well as product subscripts for convenience. For clarity we provide an overview on the notation here:

- D_t denotes a demand shifter that varies by destination country and product, i.e. $D_t = D_{i,p,t}$
- c_t denotes domestic marginal costs of production that vary by source country and product, i.e. $c_t = c_{j,p,t}$
- τ_t denotes a tariff that varies by country-pair and product, i.e. $\tau_t = \tau_{i,j,p,t}$
- κ_t denotes iceberg non-tariff trade barriers that vary by country-pair and product, i.e. $\kappa_t = \kappa_{i,j,p,t}$
- ω_t denotes a taste shocks that varies by country-pair and product, i.e. $\omega_t = \omega_{i,j,p,t}$.

C.1 Model summary

The following system of equations characterizes the trade response to tariff shocks. The first set of equations is

$$p_t^x = p^x\left(c_t\kappa_t, \tau_t, \omega_t D_t\right), \tag{C.1}$$
$$q_t = q\left(p_t^x, \tau_t, \omega_t D_t\right), \tag{C.2}$$
$$\pi_t = \pi\left(c_t\kappa_t, \tau_t, \omega_t D_t\right), \tag{C.3}$$
$$X_t = q_t p_t^x n_t, \tag{C.4}$$

where p_t^x is the price of exports exclusive of tariffs, q_t is the quantity sold, π_t are flow profits, X_t is export revenue exclusive of tariffs, and n_t a generic mass. Let further v_t denote a generic value. The following dynamic system determines the evolution of v_t and n_t,

$$v_t = \frac{1}{1+r}\mathbb{E}_t\left[\pi\left(c_{t+1}\kappa_{t+1}, \tau_{t+1}, \omega_{t+1}D_{t+1}\right) + (1-\delta)\, v_{t+1}\right] \tag{C.5}$$
$$n_t = n_{t-1}(1-\delta) + G\left(v_{t-1}\right), \tag{C.6}$$

together with $\lim_{t\to\infty}\left(\frac{1-\delta}{1+r}\right)^t v_t = 0$, a given initial value for n_0, and stochastic processes for c_t, κ_t, τ_t, ω_t, and D_t, which are exogeneous in the partial equilibrium model.

We define the following constants

$$\eta_{q,p} := \frac{\partial \ln q}{\partial \ln p^x},\ \eta_{q,\tau} := \frac{\partial \ln q}{\partial \ln \tau},\ \eta_{p,\tau} := \frac{\partial \ln p^x}{\partial \ln \tau},\ \eta_{\pi,\tau} := \frac{\partial \ln \pi}{\partial \ln \tau}, \tag{C.7}$$

and assume that $\eta_{q,p} < 0$, $\eta_{q,\tau} < 0$, and $\eta_{\pi,\tau} < 0$. We also define $\chi := \frac{g(v)v}{G(v)}$ for a function $G(.)$ introduced below, and $g = G'$.

C.2 Microfoundations

We next show that three different frameworks generate the above system of equations.

C.2.1 A dynamic Arkolakis (2010) model

This model is a dynamic extension of the Arkolakis (2010) market penetration framework, where the number of customers adjusts gradually. The model also shares features with Fitzgerald, Haller, and Yedid-Levi (2016) and others.

A single representative firm sells its good in the foreign location, earning profits $\Pi_t = n_t \pi \left(c_t \kappa_t, \tau_t, \omega_t D_t\right)$. Here, n_t denotes the mass of foreign consumers that the firm reaches in the foreign location. Further, $\pi \left(c_t \kappa_t, \tau_t, \omega_t D_t\right)$ denotes flow profits per unit mass of foreign consumers reached, and is a function of the exporter's costs c_t, non-tariff iceberg trade costs κ_t, tariffs τ_t, and the demand shifters $\omega_t D_t$.

The mass of foreign consumers available for the firm to sell to evolves according to the accumulation equation

$$n_{t+1} = n_t \left(1 - \delta\right) + a_t, \tag{C.8}$$

where a_t is the mass of newly added customers in the foreign country. Note that mass n_t is predetermined in the current period, so that adding new consumers this period only affects next period's mass of consumers n_{t+1}. We assume that adding a_t new customers requires a payment of $f(a_t)$, where $f' > 0$, $f'' > 0$, $\lim_{a \to 0} f'(a) = 0$, $\lim_{a \to \infty} f'(a) = \infty$, and that the existing mass of consumers already reached by the firm depreciates at rate δ.

The firm discounts at interest rate r and maximizes the present discounted value of future profits,

$$\max_{\{a_t\}_{t=0}^{\infty}} \mathbb{E}_0 \sum_{t=0}^{\infty} \left(\frac{1}{1+r}\right)^t \left[n_t \pi \left(c_t \kappa_t, \tau_t, \omega_t D_t\right) - f\left(a_t\right)\right].$$

Denoting by v_t the multiplier on constraint (C.8), the current value Lagrangian is

$$\mathcal{L} = \mathbb{E}_0 \sum_{t=0}^{\infty} \left(\frac{1}{1+r}\right)^t \left[n_t \pi \left(c_t \kappa_t, \tau_t, \omega_t D_t\right) - f\left(a_t\right) + v_t \left(n_t \left(1 - \delta\right) + a_t - n_{t+1}\right)\right].$$

The first order necessary conditions are

$$\begin{aligned} f'\left(a_t\right) &= v_t, \\ v_t &= \frac{1}{1+r} \mathbb{E}_t \left[\pi \left(c_{t+1} \kappa_{t+1}, \tau_{t+1}, \omega_{t+1} D_{t+1}\right) + \left(1 - \delta\right) v_{t+1}\right], \end{aligned}$$

and the transversality condition $\lim_{t \to \infty} \left(\frac{1}{1+r}\right)^t v_t n_t = 0$, which implies that $\lim_{t \to \infty} \left(\frac{1-\delta}{1+r}\right)^t v_t = 0$. The firm chooses its investment into accumulating new consumers such that the marginal benefit v_t equals the marginal cost $f'(a_t)$. The shadow value v_t, in turn, is the expected present value of profits generated by each consumer reached in the foreign market.

Note that the above problem is reminiscent of a standard investment problem with convex adjustment costs, except that flow profits are a linear function of n_t, the analogue of the capital stock. This linearity greatly improves the tractability of the problem and permits analytical solutions.

Letting $q_t = q\left(p_t^x, \tau_t, \omega_t D_t\right)$ denote foreign demand per unit mass of consumers, and letting $p_t^x = p^x\left(c_t \kappa_t, \tau_t\right)$ denote the price set by the representative firm, exports are $X_t = q_t p_t^x n_t$. After substituting out a_t, the accumulation equation (C.8) becomes

$$n_t = n_{t-1}\left(1-\delta\right) + \left(f'\right)^{-1}\left(v_{t-1}\right).$$

For $G \equiv \left(f'\right)^{-1}$, the model is described by the set of equations in Section C.1.

C.2.2 A dynamic Krugman (1980) model

We next present a dynamic partial equilibrium version of the Krugman (1980) model. The model also shares features with Costantini and Melitz (2007), Ruhl (2008), and many others.

There is a continuum of firms, and each exporting firm receives flow profits $\pi\left(c_t \kappa_t, \tau_t, \omega_t D_t\right)$ from exporting. Further, exporters exit the bilateral trade relationship with probability δ per period. The value of an exporting firm at the end of period t is

$$v_t = \frac{1}{1+r} E_t\left[\pi\left(c_{t+1}\kappa_{t+1}, \tau_{t+1}, \omega_{t+1} D_{t+1}\right) + \left(1-\delta\right) v_{t+1}\right],$$

where we assume that the value of a non-exporting firm is zero. We also require that $\lim_{t\to\infty}\left(\frac{1-\delta}{1+r}\right)^t v_t = 0$, which follows from the transversality condition of the firms' owner(s).

In every period, a unit mass of firms receives the opportunity to begin exporting to the foreign location. Each of these firms receive idiosyncratic i.i.d. sunk cost draw ξ_t^s, drawn from distribution G, and then decide whether to start exporting. Each firm solves

$$\max\left\{v_t - \xi_t^s, 0\right\},$$

so a firm enters if and only if $\xi_t^s \leq v_t$. Note that a firm entering this period begins to receive profits from exporting only in the next period. The mass of firms entering into exporting in period t is thus $G\left(v_t\right)$. The mass of exporting firms at the end of period t is denoted by n_t, and it evolves according to

$$n_{t+1} = n_t\left(1-\delta\right) + G\left(v_t\right).$$

Letting $q_t = q\left(p_t^x, \tau_t, \omega_t D_t\right)$ denote foreign demand per unit mass of firms, and letting $p_t^x = p^x\left(c_t \kappa_t, \tau_t\right)$ denote the price set by each firm, exports are $X_t = q_t p_t^x n_t$. It is clear that this model is nested by the set of equations in Section C.1.

C.2.3 A dynamic Melitz (2003) model

Consider a version of the Melitz (2003) model, with a two-stage entry problem. In the first stage of the entry problem, firms do not know their productivity of producing the exported good. Further, they pay a sunk cost to obtain the *right to export on a per-period basis*. Having paid this sunk cost, they learn their productivity and face the following static decision problem going forward: As long as the firm maintains its right to export on a per-period basis, it can pay a fixed cost to obtain the profit of exporting for one period.

First stage Let $\pi(c_t\kappa_t, \tau_t, \omega_t D_t)$ denote *expected* flow profits from exporting in stage one of the entry problem. The remainder of this stage is isomorphic to the dynamic Krugman (1980) model described above. Firms lose their right to export on a per-period basis with probability δ per period. The expected value of exporting at the end of period t is

$$v_t = \frac{1}{1+r} E_t \left[\pi\left(c_{t+1}\kappa_{t+1}, \tau_{t+1}, \omega_{t+1} D_{t+1}\right) + (1-\delta)\, v_{t+1}\right],$$

where we assume that the value of a non-exporting firm is zero. We also require that $\lim_{t\to\infty}\left(\frac{1-\delta}{1+r}\right)^t v_t = 0$, which follows from the transversality condition of the firms' owner(s).

In every period, a unit mass of firms faces the first stage of the entry problem. Each of these firms receives an idiosyncratic i.i.d. sunk cost ξ_t^s draw from distribution G, and then decides whether to enter into the second stage. Each firm solves

$$\max\left\{v_t - \xi_t^s, 0\right\},$$

so a firm enters if and only if $\xi_t^s \le v_t$. Note that a firm entering this period faces the second stage of the entry problem only in the next period. The mass of firms entering into the second stage in period t is $G(v_t)$. The mass of firms with the right to export on a per-period basis is denoted by n_t, and evolves according to

$$n_{t+1} = n_t(1-\delta) + G(v_t).$$

Foreign consumer We assume that foreign demand takes the form $Q_t = (P_t^c)^{-\sigma}\omega_t D_t$, where $P_t^c = \tau_t P_t^x$ is the price the consumer pays for the export bundle, so that $Q_t = (\tau_t P_t^x)^{-\sigma}\omega_t D_t$. The quantity aggregate of firm-level exports Q_t takes the CES form

$$Q_t = \left(\int_{\iota\in\mathcal{I}_t} q_t(\iota)^{\frac{\sigma-1}{\sigma}}\, d\iota\right)^{\frac{\sigma}{\sigma-1}}, \tag{C.9}$$

where ι indexes exporting firms and $\mathcal{I}_t$ is the set of exporting firms. Profit maximization implies that

$$q_t(\iota) = Q_t\left(\frac{p_t^x(\iota)}{P_t^x}\right)^{-\sigma}, \tag{C.10}$$

where

$$P_t^x = \left(\int_{j\in J_t} \left(p_t^x(\iota)\right)^{1-\sigma} d\iota\right)^{\frac{1}{1-\sigma}}. \tag{C.11}$$

Measured exports exclusive of tariffs are $X_t = Q_t P_t^x$.

Second stage Once a firm has paid the sunk entry cost, it draws its productivity φ from distribution F, which we assume to be independent of the sunk cost draw ξ_t^s. A firm's marginal costs are $\frac{\kappa_t c_t}{\varphi}$. Each firm faces demand function (C.10). Profit maximization implies that

$$p_t^x(\iota) = \frac{\sigma}{\sigma-1}\frac{\kappa_t c_t}{\varphi(\iota)},$$

and yields flow profits from exporting

$$\begin{aligned}\pi_t(\iota) &= q_t(\iota)\left(p_t^x(\iota) - \frac{\kappa_t c_t}{\varphi(\iota)}\right) - \xi \\ &= \frac{1}{\sigma}\left(\frac{\sigma}{\sigma-1}\frac{\kappa_t c_t}{\varphi(\iota)}\right)^{1-\sigma} Q_t (P_t^x)^\sigma - \xi,\end{aligned}$$

where ξ denotes the per-period fixed cost of exporting, which is common across firms.

A firm exports in period t if $\pi_t(\iota) \geq 0$, and the marginal firm has productivity

$$\varphi_t^m = \frac{\sigma}{\sigma-1}\kappa_t c_t \left(\frac{\sigma\xi}{Q_t (P_t^x)^\sigma}\right)^{\frac{1}{\sigma-1}}.$$

Note that Q_t and P_t^x depend on τ_t and hence changes in tariffs will affect the composition of firms that export in a given period.

Following Melitz (2003), we write the price index (C.11) as

$$\begin{aligned}P_t^x &= \left(\int_{\varphi_t^m}^{\infty} (p_t^x(\varphi))^{1-\sigma} n_t dF(\varphi)\right)^{\frac{1}{1-\sigma}} \\ &= n_t^{\frac{1}{1-\sigma}} \frac{\sigma}{\sigma-1}\kappa_t c_t \left(\int_{\varphi_t^m}^{\infty} \varphi^{\sigma-1} dF(\varphi)\right)^{\frac{1}{1-\sigma}} \\ &= n_t^{\frac{1}{1-\sigma}} \frac{\sigma}{\sigma-1}\frac{\kappa_t c_t}{\tilde{\varphi}_t}\end{aligned}$$

where

$$\tilde{\varphi}_t = \left(\int_{\varphi_t^m}^{\infty} \varphi^{\sigma-1} dF(\varphi)\right)^{\frac{1}{\sigma-1}}. \tag{C.12}$$

Note that $\tilde{\varphi}_t$ denotes an *aggregate* productivity measure of exporting firms, and not an *average*.

Now letting

$$p_t^x(\tilde{\varphi}_t) = \frac{\sigma}{\sigma-1}\frac{\kappa_t c_t}{\tilde{\varphi}_t}, \tag{C.13}$$

we have

$$P_t^x = n_t^{\frac{1}{1-\sigma}} p_t^x(\tilde{\varphi}_t).$$

Again following Melitz (2003), and noting that $q_t(\varphi) = Q_t\left(\frac{p_t^x(\varphi)}{P_t^x}\right)^{-\sigma}$ and

$$q_t(\tilde{\varphi}_t) = Q_t\left(\frac{p_t^x(\tilde{\varphi}_t)}{P_t^x}\right)^{-\sigma}, \tag{C.14}$$

we have that $q_t(\varphi) = \left(\frac{\varphi_t}{\tilde{\varphi}_t}\right)^{\sigma} q(\tilde{\varphi}_t)$. We can then write the quantity index (C.9) as

$$\begin{aligned}
Q_t &= \left(\int_{\varphi_t^m}^{\infty} q_t(\varphi)^{\frac{\sigma-1}{\sigma}} n_t dF(\varphi)\right)^{\frac{\sigma}{\sigma-1}} \\
&= n_t^{\frac{\sigma}{\sigma-1}} q_t(\tilde{\varphi}_t).
\end{aligned}$$

Now the total value of exports is

$$\begin{aligned}
X_t &= Q_t P_t^x \\
&= n_t^{\frac{\sigma}{\sigma-1}} q(\tilde{\varphi}_t) n_t^{\frac{1}{1-\sigma}} p^x(\tilde{\varphi}_t) \\
&= n_t q_t(\tilde{\varphi}_t) p_t^x(\tilde{\varphi}_t),
\end{aligned}$$

where $\tilde{\varphi}_t$, $p_t^x(\tilde{\varphi}_t)$, and $q_t(\tilde{\varphi}_t)$ are defined in equations (C.12), (C.13), and (C.14).

Lastly, expected profits can be written as

$$\pi_t = \frac{1}{\sigma} Q_t (P_t^x)^{\sigma} \left(\frac{\sigma}{\sigma-1}\frac{\kappa_t c_t}{\tilde{\varphi}_t}\right)^{1-\sigma} - \xi(1 - F(\varphi_t^m)).$$

Since our assumptions on foreign demand imply that $Q_t (P_t^x)^{\sigma} = (\tau_t)^{-\sigma}\omega_t D_t$, we can write

$$\begin{aligned}
p_t^x(\tilde{\varphi}_t) &= \frac{\sigma}{\sigma-1}\frac{\kappa_t c_t}{\tilde{\varphi}_t} \\
q_t(\tilde{\varphi}_t) &= (p_t^x(\tilde{\varphi}_t))^{-\sigma}(\tau_t)^{-\sigma}\omega_t D_t \\
\pi_t &= \frac{1}{\sigma}(\tau_t)^{-\sigma}\omega_t D_t \left(\frac{\sigma}{\sigma-1}\frac{\kappa_t c_t}{\tilde{\varphi}_t}\right)^{1-\sigma} - \xi(1 - F(\varphi_t^m))
\end{aligned}$$

where $\tilde{\varphi}_t$ is given by equation (C.12) and

$$\varphi_t^m = \frac{\sigma}{\sigma-1}\kappa_t c_t \left(\frac{\sigma\xi}{(\tau_t)^{-\sigma}\omega_t D_t}\right)^{\frac{1}{\sigma-1}}.$$

It is now easy to see that the above functions take the forms assumed in equations (C.1)-(C.4).

While the exact values of elasticities (C.7) depend on the distribution F, it is always true that $\frac{\partial \ln \varphi_t^m}{\partial \ln \tau_t} = \frac{\sigma}{\sigma-1} > 0$, $\frac{\partial \ln \tilde{\varphi}_t}{\partial \ln \tau_t} < 0$, and hence $\frac{\partial \ln p_t^x}{\partial \ln \tau_t} = -\frac{\partial \ln \tilde{\varphi}_t}{\partial \ln \tau_t} > 0$. Further, $\frac{\partial \ln q_t}{\partial \ln \tau_t} = -\sigma$.

C.3 Model solution

Global solution Solving equation (C.5) forward gives, after imposing the transversality condition,

$$v_t = \frac{1}{1+r}\mathbb{E}_t\left[\sum_{\ell=0}^{\infty}\left(\frac{1-\delta}{1+r}\right)^{\ell}\pi_{t+\ell+1}\right].$$

Further, solving equation (C.6) backwards gives

$$n_t = \sum_{k=0}^{t-1}(1-\delta)^k G\left(v_{t-1-k}\right) + (1-\delta)^t n_0.$$

The model solution is unique: for any sequence of $\pi_{t+\ell+1}$'s, the first equation yields a unique v_t, and for any sequence of v_t's, the second equation yields a unique n_t.

Nonstochastic steady state Suppose all exogenous driving forces are constant so that $c_t = c$, $\kappa_t = \kappa$, $\tau_t = \tau$, $\omega_t = \omega$ and $D_t = D$. Then $\pi_t = \pi$, and v_t immediately collapses to

$$v = \frac{\pi}{r+\delta}.$$

Further, n_t converges to

$$n = \frac{G\left(v\right)}{\delta}.$$

These two equations characterize the non-stochastic steady state.

Long-run trade elasticity The long-run trade elasticity is

$$\begin{aligned}\frac{d\ln X}{d\ln\tau} &= \frac{d\ln q}{d\ln\tau} + \frac{d\ln p^x}{d\ln\tau} + \frac{d\ln n}{d\ln\tau}\\ &= \varepsilon^0 + \frac{d\ln n}{d\ln\tau},\end{aligned}$$

where

$$\frac{d\ln n}{d\ln\tau} = \frac{d\ln n}{d\ln v}\frac{d\ln v}{d\ln\tau} = \chi\frac{d\ln\pi}{d\ln\tau} = \chi\eta_{\pi,\tau},$$

and

$$\chi := \frac{d\ln n}{d\ln v} = \frac{d\ln G\left(v\right)}{d\ln v} = \frac{g\left(v\right)v}{G\left(v\right)}.$$

Monotone convergence If $c_t = c$, $\kappa_t = \kappa$, $\tau_t = \tau$, $\omega_t = \omega$ and $D_t = D$, then $v_t = v = \frac{\pi}{r+\delta}$. It then follows from equation (C.6) above that

$$\begin{aligned}n_t - n &= (1-\delta)\left(n_{t-1} - n\right) + G\left(v\right) - \delta n\\ &= (1-\delta)\left(n_{t-1} - n\right),\end{aligned}$$

so convergence is monotone.

Linearized economy We characterize all impulse response functions and trade elasticities up to a first order approximation. Letting tildes denote percent deviations from steady state, e.g. $\tilde{v}_t = \ln v_t - \ln v = d \ln v_t = \frac{v_t - v}{v}$, these are

$$\begin{aligned} \tilde{v}_t &= \mathbb{E}_t \left[\frac{\delta + r}{1+r} \tilde{\pi}_{t+1} + \frac{1-\delta}{1+r} \tilde{v}_{t+1} \right], \\ \tilde{n}_t &= \tilde{n}_{t-1} (1-\delta) + \delta \chi \tilde{v}_{t-1}, \end{aligned} \tag{C.15}$$

in recursive form and

$$\begin{aligned} \tilde{v}_t &= \frac{\delta + r}{1+r} \mathbb{E}_t \left[\sum_{\ell=0}^{\infty} \left(\frac{1-\delta}{1+r} \right)^{\ell} \tilde{\pi}_{t+\ell+1} \right], \\ \tilde{n}_t &= \delta \chi \sum_{k=0}^{t-1} (1-\delta)^{t-1-k} \tilde{v}_k + (1-\delta)^t \tilde{n}_0, \end{aligned} \tag{C.16}$$

when solved forwards and backwards, respectively.

Further, the static model block (C.1)-(C.4) takes the form

$$\tilde{p}^x_t = \eta_{p,c} (\tilde{c}_t + \tilde{\kappa}_t) + \eta_{p,\tau} \tilde{\tau}_t + \eta_{p,D} \left(\tilde{\omega}_t + \tilde{D}_t \right), \tag{C.17}$$

$$\tilde{q}_t = \eta_{q,p} \tilde{p}^x_t + \eta_{q,\tau} \tilde{\tau}_t + \eta_{q,D} \left(\tilde{\omega}_t + \tilde{D}_t \right), \tag{C.18}$$

$$\tilde{\pi}_t = \eta_{\pi,c} (\tilde{c}_t + \tilde{\kappa}_t) + \eta_{\pi,\tau} \tilde{\tau}_t + \eta_{\pi,D} \left(\tilde{\omega}_t + \tilde{D}_t \right), \tag{C.19}$$

$$\tilde{X}_t = \tilde{q}_t + \tilde{p}^x_t + \tilde{n}_t,$$

where, analogously to (6.1), $\eta_{a,b} := \frac{\partial \ln a}{\partial \ln b}$ for any a, b.

C.4 Proofs of propositions and examples

C.4.1 Proof of Proposition 1

Proposition 1. *Consider an arbitrary evolution of tariffs* $\left\{ \frac{d \ln \tau_{t_0+\ell}}{d \ln \tau_{t_0}} \right\}_{\ell=1}^{\infty}$ *after the shock at* t_0. *The impulse response function of* $\ln n_t$ *at horizon* $h = 0, 1, 2, \ldots$ *is*

$$\frac{d \ln n_{t_0+h}}{d \ln \tau_{t_0}} = \chi \eta_{\pi,\tau} \frac{\delta + r}{1+r} \delta \sum_{k=0}^{h-1} (1-\delta)^{h-1-k} \mathbb{E}_{t_0+k} \left[\sum_{\ell=0}^{\infty} \left(\frac{1-\delta}{1+r} \right)^{\ell} \frac{d \ln \tau_{t_0+k+\ell+1}}{d \ln \tau_{t_0}} \right].$$

Proof. Combining equation (C.16) as of time $t_0 + k$ with the fact that $\tilde{\pi}_t = \eta_{\pi,\tau} \tilde{\tau}_t$ in the version of the model with tariff shocks only (see C.19) gives

$$\tilde{v}_{t_0+k} = \eta_{\pi,\tau} \frac{\delta + r}{1+r} \mathbb{E}_{t_0+k} \left[\sum_{\ell=0}^{\infty} \left(\frac{1-\delta}{1+r} \right)^{\ell} \tilde{\tau}_{t_0+k+\ell+1} \right]. \tag{C.20}$$

Next take equation (C.15) at time $t_0 + h$ and solve it backwards until period t_0. This gives

$$\tilde{n}_{t_0+h} = \delta\chi \sum_{k=0}^{h-1} (1-\delta)^{h-1-k}\, \tilde{v}_{t_0+k} + (1-\delta)^h\, \tilde{n}_{t_0} \tag{C.21}$$

Now plugging (C.20) into (C.21) gives

$$\tilde{n}_{t_0+h} = \eta_{\pi,\tau}\chi\frac{\delta+r}{1+r}\delta\sum_{k=0}^{h-1}(1-\delta)^{h-1-k}\,\mathbb{E}_{t_0+k}\left[\sum_{\ell=0}^{\infty}\left(\frac{1-\delta}{1+r}\right)^{\ell}\tilde{\tau}_{t_0+k+\ell+1}\right] + (1-\delta)^h\,\tilde{n}_{t_0}.$$

Lastly, replace $\tilde{n}_{t_0+h}$ with $d\ln n_{t_0+h}$, etc., differentiate with respect to $d\ln\tau_{t_0}$, and note that $\frac{d\ln n_{t_0}}{d\ln\tau_{t_0}} = 0$.

□

C.4.2 Proof of Proposition 2

Proposition 2. *If* $\lim_{h\to\infty}\frac{d\ln\tau_{t_0+h}}{d\ln\tau_{t_0}} \neq 0$ *and is finite, then* $\lim_{h\to\infty}\varepsilon^h = \varepsilon$.

Proof. We first show that $\{\tilde{v}_{t_0+h}\}_{h=0}^{\infty}$ converges to $\eta_{\pi,\tau}\tilde{\tau}$. Fix an arbitrary $\psi > 0$. Since $\{\tilde{\tau}_{t_0+h}\}_{h=0}^{\infty}$ converges to $\tilde{\tau}$, there exists a h_ψ such that for $\forall h \geq h_\psi : |\tilde{\tau}_{t_0+h} - \tilde{\tau}| < \frac{\psi}{|\eta_{\pi,\tau}|}$. Next note that

$$\tilde{v}_{t+h} - \eta_{\pi,\tau}\tilde{\tau} = \frac{\delta+r}{1+r}\mathbb{E}_{t+h}\left[\sum_{\ell=0}^{\infty}\left(\frac{1-\delta}{1+r}\right)^{\ell}\eta_{\pi,\tau}\left(\tilde{\tau}_{t+h+\ell+1}-\tilde{\tau}\right)\right].$$

Then, for $h \geq h_\psi$, and using Jensen's and the triangle inequality,

$$\begin{aligned}
|\tilde{v}_{t+h} - \eta_{\pi,\tau}\tilde{\tau}| &\leq \frac{\delta+r}{1+r}\mathbb{E}_{t+h}\left[\sum_{\ell=0}^{\infty}\left(\frac{1-\delta}{1+r}\right)^{\ell}\left|\eta_{\pi,\tau}\left(\tilde{\tau}_{t+h+\ell+1}-\tilde{\tau}\right)\right|\right] \\
&< \frac{\delta+r}{1+r}\mathbb{E}_{t+h}\left[\sum_{\ell=0}^{\infty}\left(\frac{1-\delta}{1+r}\right)^{\ell}\psi\right] = \psi,
\end{aligned}$$

and hence $\{\tilde{v}_{t_0+h}\}_{h=0}^{\infty}$ converges to $\eta_{\pi,\tau}\tilde{\tau}$.

We next show that $\{\tilde{n}_{t_0+h}\}$ converges to $\chi\eta_{\pi,\tau}\tilde{\tau}$. Fix an arbitrary $\psi > 0$. Since $\{\tilde{v}_{t_0+h}\}_{h=0}^{\infty}$ converges to $\eta_{\pi,\tau}\tilde{\tau}$, there exists a h_ψ such that for $\forall h \geq h_\psi : |\tilde{v}_{t_0+h} - \eta_{\pi,\tau}\tilde{\tau}| < \frac{\psi}{2\chi}$. Next note that for $h > h_\psi$,

$$\begin{aligned}
\tilde{n}_{t_0+h} &= \delta\chi\sum_{k=0}^{h-1}(1-\delta)^{h-1-k}\,\tilde{v}_{t_0+k} + (1-\delta)^h\,\tilde{n}_{t_0} \\
&= \delta\chi\sum_{k=h_\psi}^{h-1}(1-\delta)^{h-1-k}\,\tilde{v}_{t_0+k} + \delta\chi\left(1-\delta_\psi\right)^{h-h_\psi}\sum_{k=0}^{h_\psi-1}(1-\delta)^{h_\psi-1-k}\,\tilde{v}_{t_0+k} + (1-\delta)^h\,\tilde{n}_{t_0}.
\end{aligned}$$

Then, for $h > h_\psi$,

$$\begin{aligned}
\tilde{n}_{t_0+h} - \chi\eta_{\pi,\tau}\tilde{\tau} =& \delta\chi \sum_{k=h_\psi}^{h-1} (1-\delta)^{h-1-k} \left(\tilde{v}_{t_0+k} - \eta_{\pi,\tau}\tilde{\tau} + \eta_{\pi,\tau}\tilde{\tau}\right) - \chi\eta_{\pi,\tau}\tilde{\tau} \\
&+ \delta\chi \left(1-\delta_\psi\right)^{h-h_\psi} \sum_{k=0}^{h_\psi-1} (1-\delta)^{h_\psi-1-k} \tilde{v}_{t_0+k} + (1-\delta)^h \tilde{n}_{t_0} \\
=& \delta\chi \sum_{k=h_\psi}^{h-1} (1-\delta)^{h-1-k} \left(\tilde{v}_{t_0+k} - \eta_{\pi,\tau}\tilde{\tau}\right) + \delta\chi\eta_{\pi,\tau}\tilde{\tau} \sum_{k=h_\psi}^{h-1} (1-\delta)^{h-1-k} - \chi\eta_{\pi,\tau}\tilde{\tau} \\
&+ \delta\chi \left(1-\delta_\psi\right)^{h-h_\psi} \sum_{k=0}^{h_\psi-1} (1-\delta)^{h_\psi-1-k} \tilde{v}_{t_0+k} + (1-\delta)^h \tilde{n}_{t_0} \\
=& \delta\chi \sum_{k=h_\psi}^{h-1} (1-\delta)^{h-1-k} \left(\tilde{v}_{t_0+k} - \eta_{\pi,\tau}\tilde{\tau}\right) \\
&- \chi\eta_{\pi,\tau}\tilde{\tau} (1-\delta)^{h-h_\psi} + \delta\chi \left(1-\delta_\psi\right)^{h-h_\psi} \sum_{k=0}^{h_\psi-1} (1-\delta)^{h_\psi-1-k} \tilde{v}_{t_0+k} + (1-\delta)^h \tilde{n}_{t_0},
\end{aligned}$$

where we used that $\sum_{k=h_\psi}^{h-1} (1-\delta)^{h-1-k} = \frac{1-(1-\delta)^{h-h_\psi}}{\delta}$. Next note that

$$\begin{aligned}
\left|\delta\chi \sum_{k=h_\psi}^{h-1} (1-\delta)^{h-1-k} \left(\tilde{v}_{t_0+k} - \eta_{\pi,\tau}\tilde{\tau}\right)\right| &\leq \delta\chi \sum_{k=h_\psi}^{h-1} (1-\delta)^{h-1-k} \left|\tilde{v}_{t_0+k} - \eta_{\pi,\tau}\tilde{\tau}\right| \\
&< \delta\chi \sum_{k=h_\psi}^{h-1} (1-\delta)^{h-1-k} \frac{\psi}{2\chi} = \frac{\psi}{2}\left[1-(1-\delta)^{h-h_\psi}\right].
\end{aligned}$$

Hence,

$$\begin{aligned}
\left|\tilde{n}_{t_0+h} - \chi\eta_{\pi,\tau}\tilde{\tau}\right| <& \frac{\psi}{2}\left[1-(1-\delta)^{h-h_\psi}\right] + (1-\delta)^{h-h_\psi} \left|\chi\eta_{\pi,\tau}\tilde{\tau}\right| \\
&+ \left(1-\delta_\psi\right)^{h-h_\psi} \left|\delta\chi \sum_{k=0}^{h_\psi-1} (1-\delta)^{h_\psi-1-k} \tilde{v}_{t_0+k}\right| + (1-\delta)^h \left|\tilde{n}_{t_0}\right|.
\end{aligned}$$

Now choosing $h_\psi^* > h_\psi$ such that for all $h > h_\psi^*$ the last three terms are smaller than $\frac{\psi}{2}$, implies that $\tilde{n}_{t_0+h}$ converges to $\chi\eta_{\pi,\tau}\tilde{\tau}$.

Lastly note that $\tilde{X}_{t_0+h} = \varepsilon^0 \tilde{\tau}_{t_0+h} + \tilde{n}_{t_0+h}$, and hence $\lim_{h\to\infty} \tilde{X}_{t_0+h} = \varepsilon^0\tilde{\tau} + \chi\eta_{\pi,\tau}\tilde{\tau} = \varepsilon\tilde{\tau}$. Since $\tilde{\tau} \neq 0$, $\lim_{h\to\infty} \varepsilon^h = \lim_{h\to\infty} \frac{\tilde{X}_{t_0+h}}{\tilde{\tau}_{t_0+h}} = \varepsilon$.

□

C.4.3 Details on Example 1

Plug $\Delta \ln \tau_{>t_0}$ into equation (6.10). This gives

$$\frac{d \ln n_{t_0+h}}{d \ln \tau_{t_0}} = \chi \eta_{\pi,\tau} \Delta \ln \tau_{>t_0} \delta \sum_{k=0}^{h-1} (1-\delta)^{h-1-k}$$
$$= \chi \eta_{\pi,\tau} \left[1 - (1-\delta)^h \right] \Delta \ln \tau_{>t_0}.$$

The claim now follows immediately.

C.4.4 Details on Example 2

Tariffs follow a first or autoregressive process with autoregressive root ρ. Then

$$\mathbb{E}_{t_0+k} \left[\frac{d \ln \tau_{t_0+k+\ell+1}}{d \ln \tau_{t_0}} \right] = \rho^{\ell+k+1}.$$

Plugging this expression into (6.10) gives

$$\frac{d \ln n_{t_0+h}}{d \ln \tau_{t_0}} = \chi \eta_{\pi,\tau} \frac{\delta + r}{1+r} \delta \sum_{k=0}^{h-1} (1-\delta)^{h-1-k} \sum_{\ell=0}^{\infty} \left(\frac{1-\delta}{1+r} \right)^{\ell} \rho^{\ell+k+1}$$
$$= \chi \eta_{\pi,\tau} \frac{\delta + r}{1+r} \delta \sum_{k=0}^{h-1} (1-\delta)^{h-1-k} (\rho)^{k+1} \left[\sum_{\ell=0}^{\infty} \left(\frac{1-\delta}{1+r} \rho \right)^{\ell} \right]$$
$$= \chi \eta_{\pi,\tau} \frac{\delta + r}{1 + r - (1-\delta)\rho} \delta \rho^h \sum_{k=0}^{h-1} \left(\frac{1-\delta}{\rho} \right)^{h-1-k}$$
$$= \chi \eta_{\pi,\tau} \frac{\delta + r}{1 + r - (1-\delta)\rho} \delta \rho^h \frac{1 - \left(\frac{1-\delta}{\rho} \right)^h}{1 - \frac{1-\delta}{\rho}}.$$

Since

$$\frac{\frac{d \ln n_{t_0+h}}{d \ln \tau_{t_0}}}{\frac{d \ln \tau_{t_0+h}}{d \ln \tau_{t_0}}} = \chi \eta_{\pi,\tau} \frac{(\delta + r)\delta}{[1 + r - (1-\delta)\rho] \left(1 - \frac{1-\delta}{\rho} \right)} \left(1 - \left(\frac{1-\delta}{\rho} \right)^h \right),$$

the claim follows immediately.

C.4.5 Proof of Proposition 3

Proposition 3. *The model delivers estimating equation* (2.2)*, where*

$$\beta_X^h = \chi \eta_{\pi,\tau} \frac{r+\delta}{1+r} \delta \sum_{k=0}^{h-1} (1-\delta)^{h-1-k} \sum_{\ell=0}^{\infty} \left(\frac{1-\delta}{1+r} \right)^{\ell} \beta_{\tau}^{k+\ell+1} + \varepsilon^0 \beta_{\tau}^h.$$

β_τ^h is defined as the regression coefficient of $\Delta_h \ln \tau_{i,j,p,t}$ on $\Delta_0 \ln \tau_{i,j,p,t}$ in the population, and can be estimated from equation (2.3).

The fixed effects $\delta_{j,p,t}^{s,X,h}$ and $\delta_{i,p,t}^{d,X,h}$ capture a weighted sum of past, present, and expected future changes in interest rates, demand, the cost of production, the cost of entry, and non-tariff trade barriers that vary at the exporter-product-time (j,p,t) and importer-product-time (i,p,t) level, respectively, in model extensions in which these vary over time. The error term includes past, present, and expected future time-varying importer-exporter-product-specific demand shocks and non-tariff trade barriers, as well as the initial state.

Proof. We consider a model extension given by equations (C.1) through (C.4) together with

$$\begin{aligned} v_t &= \frac{1}{1+r_t}\mathbb{E}_t\left[\pi_{t+1} + (1-\delta)\, v_{t+1}\right], \\ n_t &= n_{t-1}(1-\delta) + G\left(\frac{v_{t-1}}{c_{t-1}^e}\right). \end{aligned}$$

Relative to the version of the model stated above, the interest rate r_t now exogenously varies with time, and we allow for exogenous variation in the cost of entry c_t^e. We assume that the interest rate is specific to the source country, so that $r_t = r_{j,t}$, and that the time-varying component of entry cost varies by source country and product, that is, $c_t^e = c_{j,p,t}^e$. Initially, we suppress these subscripts. The linearized versions of these two equations are

$$\tilde{v}_t = \frac{r+\delta}{1+r}\mathbb{E}_t\left[\tilde{\pi}_{t+1}\right] + \frac{1-\delta}{1+r}\mathbb{E}_t\left[\tilde{v}_{t+1}\right] - \frac{1}{1+r}dr_t, \tag{C.22}$$

$$\tilde{n}_t = (1-\delta)\,\tilde{n}_{t-1} + \delta\chi\left(\tilde{v}_{t-1} - \tilde{c}_{t-1}^e\right). \tag{C.23}$$

In equation (C.22) dr_t denotes the absolute deviation of the interest rate from its steady state value, that is $dr_t = r_t - r$.

Using equations (C.18) and (C.17), and the definition of $\varepsilon^0 = (1+\eta_{q,p})\,\eta_{p,\tau} + \eta_{q,\tau}$ (equation 6.6), we have

$$\begin{aligned} \tilde{q}_{t+h} - \tilde{q}_{t-1} + \tilde{p}_{t+h}^x - \tilde{p}_{t-1}^x = {} & \varepsilon^0\left(\tilde{\tau}_{t+h} - \tilde{\tau}_{t-1}\right) \\ & + (1+\eta_{q,p})\,\eta_{p,c}\left(\tilde{\kappa}_{t+h} - \tilde{\kappa}_{t-1}\right) + \left[(1+\eta_{q,p})\,\eta_{p,D} + \eta_{q,D}\right]\left(\tilde{\omega}_{t+h} - \tilde{\omega}_{t-1}\right) \\ & + (1+\eta_{q,p})\,\eta_{p,c}\left(\tilde{c}_{t+h} - \tilde{c}_{t-1}\right) \\ & + \left[(1+\eta_{q,p})\,\eta_{p,D} + \eta_{q,D}\right]\left(\tilde{D}_{t+h} - \tilde{D}_{t-1}\right). \end{aligned}$$

Next, note that solving (C.22) forward gives

$$\tilde{v}_{t+k} = \sum_{\ell=0}^{\infty}\left(\frac{1-\delta}{1+r}\right)^{\ell}\left(\frac{r+\delta}{1+r}\mathbb{E}_{t+k}\left[\tilde{\pi}_{t+k+\ell+1}\right] - \frac{1}{1+r}\mathbb{E}_{t+k}\left[dr_{t+k+\ell}\right]\right),$$

and solving (C.23) backwards gives

$$\tilde{n}_{t+h} = (1-\delta)^h \tilde{n}_t + \delta\chi \sum_{k=0}^{h-1} (1-\delta)^{h-1-k} \left(\tilde{v}_{t+k} - \tilde{c}^e_{t+k}\right).$$

Combining these two equations yields

$$\begin{aligned}
\tilde{n}_{t+h} - \tilde{n}_{t-1} = {} & \chi\frac{r+\delta}{1+r}\delta \sum_{k=0}^{h-1} (1-\delta)^{h-1-k} \mathbb{E}_{t+k}\left[\sum_{\ell=0}^{\infty}\left(\frac{1-\delta}{1+r}\right)^{\ell}(\tilde{\pi}_{t+k+\ell+1} - \tilde{\pi}_{t-1})\right] \\
& - \frac{1}{1+r}\delta\chi \sum_{k=0}^{h-1} (1-\delta)^{h-1-k} \mathbb{E}_{t+k}\left[\sum_{\ell=0}^{\infty}\left(\frac{1-\delta}{1+r}\right)^{\ell} dr_{t+k+\ell}\right] \\
& - \delta\chi\left[\sum_{k=0}^{h-1} (1-\delta)^{h-1-k} \tilde{c}^e_{t+k}\right] + \chi\left[1-(1-\delta)^h\right]\tilde{\pi}_{t-1} + (1-\delta)^h \tilde{n}_t - \tilde{n}_{t-1}.
\end{aligned}$$

From (C.19) we obtain

$$\begin{aligned}
\tilde{\pi}_{t+k+\ell+1} - \tilde{\pi}_{t-1} = {} & \eta_{\pi,c}\left(\tilde{c}_{t+k+\ell+1} - \tilde{c}_{t-1}\right) + \eta_{\pi,c}\left(\tilde{\kappa}_{t+k+\ell+1} - \tilde{\kappa}_{t-1}\right) + \eta_{\pi,\tau}\left(\tilde{\tau}_{t+k+\ell+1} - \tilde{\tau}_{t-1}\right) \\
& + \eta_{\pi,D}\left(\tilde{\omega}_{t+k+\ell+1} - \tilde{\omega}_{t-1}\right) + \eta_{\pi,D}\left(\tilde{D}_{t+k+\ell+1} - \tilde{D}_{t-1}\right).
\end{aligned}$$

Now putting the pieces together, and adding the subscripts back in, we have that

$$\begin{aligned}
\Delta_h \ln X_{i,j,p,t} = {} & \varepsilon^0 \Delta_h \ln \tau_{i,j,p,t} + \eta_{\pi,\tau}\chi\frac{r+\delta}{1+r}\delta \sum_{k=0}^{h-1}(1-\delta)^{h-1-k}\mathbb{E}_{t+k}\left[\sum_{\ell=0}^{\infty}\left(\frac{1-\delta}{1+r}\right)^{\ell}\Delta_{k+\ell+1}\ln\tau_{i,j,p,t}\right] \\
& + \delta^{s,X,h}_{j,p,t} + \delta^{d,X,h}_{i,p,t} + u^{X,h}_{i,j,p,t},
\end{aligned}$$

where we used the notation that for a generic variable x_t, $\Delta_h x_t = x_{t+h} - x_{t-1}$, and

$$\begin{aligned}
\delta^{s,X,h}_{j,p,t} := {} & (1+\eta_{q,p})\,\eta_{p,c}\left(\tilde{c}_{j,p,t+h} - \tilde{c}_{j,p,t-1}\right) \\
& + \eta_{\pi,c}\chi\frac{r+\delta}{1+r}\delta\sum_{k=0}^{h-1}(1-\delta)^{h-1-k}\mathbb{E}_{t+k}\left[\sum_{\ell=0}^{\infty}\left(\frac{1-\delta}{1+r}\right)^{\ell}\left(\tilde{c}_{j,p,t+k+\ell+1} - \tilde{c}_{j,p,t-1}\right)\right] \\
& - \frac{1}{1+r}\delta\chi\sum_{k=0}^{h-1}(1-\delta)^{h-1-k}\mathbb{E}_{t+k}\left[\sum_{\ell=0}^{\infty}\left(\frac{1-\delta}{1+r}\right)^{\ell} dr_{j,p,t+k+\ell}\right] \\
& - \delta\chi\left[\sum_{k=0}^{h-1}(1-\delta)^{h-1-k}\tilde{c}^e_{j,p,t+k}\right],
\end{aligned} \tag{C.24}$$

$$\delta_{i,p,t}^{d,X,h} := [(1+\eta_{q,p})\,\eta_{p,D} + \eta_{q,D}]\left(\tilde{D}_{i,p,t+h} - \tilde{D}_{i,p,t-1}\right)$$
$$+ \eta_{\pi,D}\chi\frac{r+\delta}{1+r}\delta\sum_{k=0}^{h-1}(1-\delta)^{h-1-k}\,\mathbb{E}_{t+k}\left[\sum_{\ell=0}^{\infty}\left(\frac{1-\delta}{1+r}\right)^{\ell}\left(\tilde{D}_{i,p,t+k+\ell+1} - \tilde{D}_{i,p,t-1}\right)\right], \quad \text{(C.25)}$$

$$u_{i,j,p,t}^{X,h} := (1+\eta_{q,p})\,\eta_{p,c}\left(\tilde{\kappa}_{i,j,p,t+h} - \tilde{\kappa}_{i,j,p,t-1}\right)$$
$$+ \eta_{\pi,c}\chi\frac{r+\delta}{1+r}\delta\sum_{k=0}^{h-1}(1-\delta)^{h-1-k}\,\mathbb{E}_{t+k}\left[\sum_{\ell=0}^{\infty}\left(\frac{1-\delta}{1+r}\right)^{\ell}\left(\tilde{\kappa}_{i,j,p,t+k+\ell+1} - \tilde{\kappa}_{i,j,p,t-1}\right)\right]$$
$$+ [(1+\eta_{q,p})\,\eta_{p,D} + \eta_{q,D}]\left(\tilde{\omega}_{i,j,p,t+h} - \tilde{\omega}_{i,j,p,t-1}\right)$$
$$+ \eta_{\pi,D}\chi\frac{r+\delta}{1+r}\delta\sum_{k=0}^{h-1}(1-\delta)^{h-1-k}\,\mathbb{E}_{t+k}\left[\sum_{\ell=0}^{\infty}\left(\frac{1-\delta}{1+r}\right)^{\ell}\left(\tilde{\omega}_{i,j,p,t+k+\ell+1} - \tilde{\omega}_{i,j,p,t-1}\right)\right]$$
$$+ \chi\left[1-(1-\delta)^{h}\right]\tilde{\pi}_{i,j,p,t-1} + (1-\delta)^{h}\,\tilde{n}_{i,j,p,t} - \tilde{n}_{i,j,p,t-1}. \quad \text{(C.26)}$$

Next define the regression coefficient of $\Delta_h \ln \tau_{i,j,p,t}$ on $\Delta_0 \ln \tau_{i,j,p,t}$ as β_τ^h in the population, where we assume that $\Delta_0 \ln \tau_{i,j,p,t}$ is an exogenous tariff shock. Clearly, β_τ^h can be estimated from equation (2.3). Then the estimating equation becomes

$$\Delta_h \ln X_{i,j,p,t} = \beta_X^h \Delta_0 \ln \tau_{i,j,p,t} + \delta_{i,p,t}^{d,X,h} + \delta_{j,p,t}^{s,X,h} + u_{i,j,p,t}^{X,h}.$$

where

$$\beta_X^h = \eta_{\pi,\tau}\chi\frac{r+\delta}{1+r}\delta\sum_{k=0}^{h-1}(1-\delta)^{h-1-k}\sum_{\ell=0}^{\infty}\left(\frac{1-\delta}{1+r}\right)^{\ell}\beta_\tau^{k+\ell+1} + \varepsilon^0\beta_\tau^h.$$

Note that β_τ^h is a constant for all $h = 0, 1, \ldots$, so the expectation drops out.

As equation (C.24) shows, the source-product-time fixed effects $\delta_{j,p,t}^{s,X,h}$ absorb variation in lagged, current, and future cost of production $c_{j,p,t}$, interest rates $r_{j,t}$, and the cost of entry $c_{j,p,t}^e$. Equation (C.25) shows that the destination-product-time fixed effects $\delta_{i,p,t}^{d,X,h}$ absorb variation in lagged, current, and future demand $D_{i,p,t}$. Lastly, equation (C.26) shows that the error term $u_{i,j,p,t}^{X,h}$ includes variation in lagged, current, and future bilateral and product-specific demand shocks $\omega_{i,j,p,t}$ and iceberg non-tariff trade barriers $\kappa_{i,j,p,t}$, as well as initial conditions.

□

C.5 Estimation in long differences

Proposition C.1. *(Part 1) Estimation as a horizon-h difference does generally not identify the horizon-h trade elasticity.*

(Part 2) If tariffs follow a random walk, a regression of $\Delta_h \ln X_t$ on $\Delta_h \ln \tau_t$ identifies the simple average of horizon-0 to horizon-h trade elasticities.

Proof. Since the first part of the proposition follows from the second part, we prove the second part. Tariffs follow a random walk,

$$\tilde{\tau}_t = \tilde{\tau}_{t-1} + \sigma_u u_t^\tau,$$

where u_t^τ is white noise with unit variance, and σ_u denotes the standard deviation of the innovation to tariffs. Then

$$\tilde{\tau}_{t+k} - \tilde{\tau}_{t-1} = \sigma_u \sum_{j=0}^{k} u_{t+j}^\tau.$$

Consider the projection of $\tilde{\tau}_{t+k} - \tilde{\tau}_{t-1}$ on $\tilde{\tau}_{t+h} - \tilde{\tau}_{t-1}$ (i.e. the OLS estimator),

$$\frac{\mathbb{C}ov\left[\tilde{\tau}_{t+k} - \tilde{\tau}_{t-1}, \tilde{\tau}_{t+h} - \tilde{\tau}_{t-1}\right]}{\mathbb{V}\left[\tilde{\tau}_{t+h} - \tilde{\tau}_{t-1}\right]} = \frac{\mathbb{C}ov\left[\sum_{j=0}^{k} u_{t+k}^\tau, \sum_{j=0}^{h} u_{t+k}^\tau\right]}{\mathbb{V}\left[\sum_{j=0}^{h} u_{t+k}^\tau\right]} = \frac{k+1}{h+1}. \tag{C.27}$$

Next note that

$$\begin{aligned}\tilde{n}_{t+h} - \tilde{n}_{t-1} =& \chi \frac{\delta + r}{1+r} \delta \sum_{k=0}^{h-1} (1-\delta)^{h-1-k} \mathbb{E}_{t+k}\left[\sum_{\ell=0}^{\infty} \left(\frac{1-\delta}{1+r}\right)^{\ell} (\tilde{\pi}_{t+k+\ell+1} - \tilde{\pi}_{t-1})\right] \\ &+ \chi \tilde{\pi}_{t-1}\left[1 - (1-\delta)^h\right] + \tilde{n}_t (1-\delta)^h - \tilde{n}_{t-1},\end{aligned}$$

which implies, together with

$$\tilde{\pi}_{t+k+\ell+1} - \tilde{\pi}_{t-1} = \eta_{q,\tau} \left(\tilde{\tau}_{t+k+\ell+1} - \tilde{\tau}_{t-1}\right)$$

that

$$\begin{aligned}\tilde{n}_{t+h} - \tilde{n}_{t-1} =& \chi \eta_{q,\tau} \frac{\delta + r}{1+r} \delta \sum_{k=0}^{h-1} (1-\delta)^{h-1-k} \mathbb{E}_{t+k}\left[\sum_{\ell=0}^{\infty} \left(\frac{1-\delta}{1+r}\right)^{\ell} (\tilde{\tau}_{t+k+\ell+1} - \tilde{\tau}_{t-1})\right] \\ &+ \chi \tilde{\pi}_{t-1}\left[1 - (1-\delta)^h\right] + \tilde{n}_t (1-\delta)^h - \tilde{n}_{t-1}.\end{aligned}$$

Since $\mathbb{E}_{t+k}\left[\tilde{\tau}_{t+k+\ell+1}\right] = \tilde{\tau}_{t+k}$, this expression becomes

$$\begin{aligned}\tilde{n}_{t+h} - \tilde{n}_{t-1} =& \chi \eta_{q,\tau} \delta \sum_{k=0}^{h-1} (1-\delta)^{h-1-k} \left(\tilde{\tau}_{t+k} - \tilde{\tau}_{t-1}\right) \\ &+ \chi \tilde{\pi}_{t-1}\left[1 - (1-\delta)^h\right] + \tilde{n}_t (1-\delta)^h - \tilde{n}_{t-1}.\end{aligned}$$

Now

$$
\begin{aligned}
\tilde{X}_{t+h} - \tilde{X}_{t-1} =& \tilde{q}_{t+h} - \tilde{q}_{t-1} + \tilde{p}^x_{t+h} - \tilde{p}^x_{t-1} + \tilde{n}_{t+h} - \tilde{n}_{t-1} \\
=& \tilde{q}_{t+h} - \tilde{q}_{t-1} + \tilde{p}^x_{t+h} - \tilde{p}^x_{t-1} + \chi \eta_{q,\tau} \delta \sum_{k=0}^{h-1} (1-\delta)^{h-1-k} \left(\tilde{\tau}_{t+k} - \tilde{\tau}_{t-1}\right) \\
& + \chi \tilde{\pi}_{t-1} \left[1 - (1-\delta)^h\right] + \tilde{n}_t (1-\delta)^h - \tilde{n}_{t-1}
\end{aligned}
$$

and regressing this on $(\tilde{\tau}_{t+h} - \tilde{\tau}_{t-1})$ gives

$$
\begin{aligned}
& \frac{\mathbb{C}ov\left(\tilde{X}_{t+h} - \tilde{X}_{t-1}, \tilde{\tau}_{t+h} - \tilde{\tau}_{t-1}\right)}{\mathbb{V}\left(\tilde{\tau}_{t+h} - \tilde{\tau}_{t-1}, \tilde{\tau}_{t+h} - \tilde{\tau}_{t-1}\right)} \qquad \text{(C.28)} \\
=& \frac{\mathbb{C}ov\left(\tilde{q}_{t+h} - \tilde{q}_{t-1} + \tilde{p}^x_{t+h} - \tilde{p}^x_{t-1} + \chi \eta_{q,\tau} \delta \sum_{k=0}^{h-1} (1-\delta)^{h-1-k} \left(\tilde{\tau}_{t+k} - \tilde{\tau}_{t-1}\right), \tilde{\tau}_{t+h} - \tilde{\tau}_{t-1}\right)}{\mathbb{V}\left(\tilde{\tau}_{t+h} - \tilde{\tau}_{t-1}, \tilde{\tau}_{t+h} - \tilde{\tau}_{t-1}\right)} \\
=& \frac{\mathbb{C}ov\left(\tilde{q}_{t+h} - \tilde{q}_{t-1} + \tilde{p}^x_{t+h} - \tilde{p}^x_{t-1}, \tilde{\tau}_{t+h} - \tilde{\tau}_{t-1}\right)}{\mathbb{V}\left(\tilde{\tau}_{t+h} - \tilde{\tau}_{t-1}, \tilde{\tau}_{t+h} - \tilde{\tau}_{t-1}\right)} + \frac{\mathbb{C}ov\left(\chi \eta_{q,\tau} \delta \sum_{k=0}^{h-1} (1-\delta)^{h-1-k} \left(\tilde{\tau}_{t+k} - \tilde{\tau}_{t-1}\right), \tilde{\tau}_{t+h} - \tilde{\tau}_{t-1}\right)}{\mathbb{V}\left(\tilde{\tau}_{t+h} - \tilde{\tau}_{t-1}, \tilde{\tau}_{t+h} - \tilde{\tau}_{t-1}\right)} \\
=& \varepsilon^0 + \chi \eta_{q,\tau} \delta \sum_{k=0}^{h-1} (1-\delta)^{h-1-k} \frac{\mathbb{C}ov\left(\tilde{\tau}_{t+k} - \tilde{\tau}_{t-1}, \tilde{\tau}_{t+h} - \tilde{\tau}_{t-1}\right)}{\mathbb{V}\left(\tilde{\tau}_{t+h} - \tilde{\tau}_{t-1}, \tilde{\tau}_{t+h} - \tilde{\tau}_{t-1}\right)} \\
=& \varepsilon^0 + \chi \eta_{q,\tau} \delta \sum_{k=0}^{h-1} (1-\delta)^{h-1-k} \frac{k+1}{h+1} \qquad \text{(C.29)}
\end{aligned}
$$

where the last equality uses equation (C.27) above.

Next note that

$$\sum_{k=0}^{h-1}(1-\delta)^{h-1-k}\frac{k+1}{h+1} = (1-\delta)^{h-1}\frac{1}{h+1} + (1-\delta)^{h-2}\frac{2}{h+1} + ... + (1-\delta)\frac{h-1}{h+1} + \frac{h}{h+1}$$
$$= \frac{1}{h+1}[1]$$
$$+ \frac{1}{h+1}[1+(1-\delta)]$$
$$+ ...$$
$$+ \frac{1}{h+1}\left[1+(1-\delta)+...+(1-\delta)^{h-2}\right]$$
$$+ \frac{1}{h+1}\left[1+(1-\delta)+...+(1-\delta)^{h-2}+(1-\delta)^{h-1}\right]$$
$$= \frac{1}{h+1}\sum_{k=0}^{h-1}\sum_{j=0}^{k}(1-\delta)^j$$
$$= \frac{1}{h+1}\sum_{k=0}^{h-1}\frac{1-(1-\delta)^{k+1}}{\delta}.$$

Plugging this expression into equation (C.29) gives

$$\frac{\mathbb{C}ov\left(\tilde{X}_{t+h}-\tilde{X}_{t-1}, \tilde{\tau}_{t+h}-\tilde{\tau}_{t-1}\right)}{\mathbb{V}\left(\tilde{\tau}_{t+h}-\tilde{\tau}_{t-1}, \tilde{\tau}_{t+h}-\tilde{\tau}_{t-1}\right)} = \varepsilon^0 + \chi\eta_{q,\tau}\delta\frac{1}{h+1}\sum_{k=0}^{h-1}\frac{1-(1-\delta)^{k+1}}{\delta}$$
$$= \varepsilon^0 + \chi\eta_{q,\tau}\frac{1}{h+1}\sum_{k=0}^{h-1}\left[1-(1-\delta)^{k+1}\right]$$
$$= \varepsilon^0 + \chi\eta_{q,\tau}\frac{1}{h+1}\sum_{k=0}^{h}\left[1-(1-\delta)^{k}\right]$$
$$= \frac{1}{h+1}\sum_{k=0}^{h}\varepsilon^k$$

where we used that $\varepsilon^h = \varepsilon^0 + \chi\eta_{q,\tau}\left(1-(1-\delta)^h\right)$, see equation (6.11) of Example 1.

□

C.6 Non-tariff trade barrier elasticities

As is conventional, we model non-tariff trade barriers κ_t as cost shifters in an iceberg form, which are specific to serving a particular destination (see Appendix C.1).

Short-run elasticity to non-tariff trade barriers The short-run non-tariff trade barrier elasticity is

$$\varepsilon_{\kappa}^{0} := \frac{d\ln X_{t_0}}{d\ln\kappa_{t_0}} = \frac{d\ln q_{t_0}}{d\ln\kappa_{t_0}} + \frac{d\ln p_{t_0}^{x}}{d\ln\kappa_{t_0}} = \left(1+\eta_{q,p}\right)\eta_{p,c}, \tag{C.30}$$

where $\eta_{p,c} := \frac{\partial\ln p}{\partial\ln c}$. In the CES demand case $\eta_{p,c}=1$ and $\eta_{q,p}=-\sigma$, so that $\varepsilon_{\kappa}^{0}=1-\sigma$.

Long-run elasticity to non-tariff trade barriers The long-run non-tariff trade barrier elasticity is

$$\begin{aligned}
\varepsilon_{\kappa} := \frac{d\ln X}{d\ln\kappa} &= \frac{d\ln q}{d\ln\kappa} + \frac{d\ln p^{x}}{d\ln\kappa} + \frac{d\ln n}{d\ln\kappa} \\
&= \varepsilon_{\kappa}^{0} + \frac{d\ln n}{d\ln v}\frac{d\ln v}{d\ln\kappa} \\
&= \varepsilon_{\kappa}^{0} + \chi\frac{d\ln\pi}{d\ln\kappa} \\
&= \varepsilon_{\kappa}^{0} + \chi\eta_{\pi,c},
\end{aligned} \tag{C.31}$$

where $\eta_{\pi,c} := \frac{\partial\ln\pi}{\partial\ln c}$. In the CES case $\varepsilon_{\kappa}^{0}=1-\sigma$ and $\eta_{\pi,c}=1-\sigma$, so $\varepsilon_{\kappa}=-\left(\sigma-1\right)\left(1+\chi\right)$.

The horizon-h elasticity to non-tariff trade barriers We proceed analogously to the tariff shock discussed in Section 6.1. Consider an impulse response to a non-tariff trade barrier shock at time t_0, denoted by $\left\{\frac{d\ln\kappa_{t_0+\ell}}{d\ln\kappa_{t_0}}\right\}_{\ell=1}^{\infty}$. The horizon-$h$ impulse response function of trade is

$$\frac{d\ln X_{t_0+h}}{d\ln\kappa_{t_0}} = \varepsilon_{\kappa}^{0}\frac{d\ln\kappa_{t_0+h}}{d\ln\kappa_{t_0}} + \frac{d\ln n_{t_0+h}}{d\ln\kappa_{t_0}}. \tag{C.32}$$

The horizon-h non-tariff trade barrier elasticity is then defined as

$$\varepsilon_{\kappa}^{h} := \frac{\frac{d\ln X_{t_0+h}}{d\ln\kappa_{t_0}}}{\frac{d\ln\kappa_{t_0+h}}{d\ln\kappa_{t_0}}} = \varepsilon_{\kappa}^{0} + \frac{\frac{d\ln n_{t_0+h}}{d\ln\kappa_{t_0}}}{\frac{d\ln\kappa_{t_0+h}}{d\ln\kappa_{t_0}}}. \tag{C.33}$$

Analogous to Proposition 1, it is straightforward to show that to a first order approximation around the steady state, the impulse response function of $\ln n_t$ at horizon h is

$$\frac{d\ln n_{t_0+h}}{d\ln\tau_{t_0}} = \chi\eta_{\pi,c}\frac{r+\delta}{1+r}\delta\sum_{k=0}^{h-1}\left(1-\delta\right)^{h-1-k}\mathbb{E}_{t_0+k}\left[\sum_{\ell=0}^{\infty}\left(\frac{1-\delta}{1+r}\right)^{\ell}\frac{d\ln\kappa_{t_0+k+\ell+1}}{d\ln\kappa_{t_0}}\right], \tag{C.34}$$

for $h=0,1,2,\ldots$. Notice that in the CES case we have $\eta_{\pi,c}=1-\sigma$.

Discussion While non-tariff trade barrier elasticities generally differ from tariff elasticities, the two are closely related in commonly used models, such as most static trade models and the class of dynamic models we consider. The mapping between the trade elasticity to tariffs and to non-tariff trade barriers in static models is well understood (see Section 6.1 for a discussion). Table C1 provides a summary for the dynamic models we consider, both for the general case and under CES demand.

Table C1: Tariff versus non-tariff trade barrier elasticities

Panel A: General case		
	Tariff elasticity	Non-tariff trade barrier elasticity
Short-run	$\varepsilon^0 = (1+\eta_{q,p})\,\eta_{p,\tau} + \eta_{q,\tau}$	$\varepsilon_\kappa^0 = (1+\eta_{q,p})\,\eta_{p,c}$
Long-run	$\varepsilon = \varepsilon^0 + \chi\eta_{\pi,\tau}$	$\varepsilon_\kappa = \varepsilon_\kappa^0 + \chi\eta_{\pi,c}$
Horizon-h	eqns (6.8), (6.9), (6.10)	eqns (C.32), (C.33), (C.34)

Panel B: CES case		
	Tariff elasticity	Non-tariff trade barrier elasticity
Short-run	$\varepsilon^0 = -\sigma$	$\varepsilon_\kappa^0 = -(\sigma-1)$
Long-run	$\varepsilon = -\sigma(1+\chi)$	$\varepsilon_\kappa = -(\sigma-1)(1+\chi)$
Horizon-h	eqns (6.8), (6.9), (6.10) with $\eta_{\pi,\tau} = -\sigma$	eqns (C.32), (C.33), (C.34) with $\eta_{\pi,c} = -(\sigma-1)$

As above, these elasticities are of trade exclusive of tariffs, consistent with our empirical estimation.

The differences between these two sets of elasticities arise from the fact that non-tariff trade barriers are typically modeled as affecting the cost of delivering the goods to the importing consumer, while tariffs represent a wedge between the exporter price and the price faced by the importer. Importantly, tariffs leave the exporter's cost of serving the foreign market unchanged. This distinction matters both in the short run and in the long run.

For concreteness, we describe the CES case in detail. Beginning with the short run, tariff shocks have no impact on export prices $\eta_{p,\tau} = 0$. Trade flows are only affected by the direct effect of the tariff on import quantities, so that $\varepsilon^0 = \eta_{q,\tau} = -\sigma$. In contrast, a change in non-tariff trade barriers affects the cost of serving the foreign market and hence the exporter price: $\eta_{p,c} = 1$. The short-run trade response is then $\varepsilon_\kappa^0 = 1 + \eta_{q,p} = 1 - \sigma$. Note that the price change for the importer is identical in both cases. In addition to the short run, these calculations also apply to the static trade models.

In the long run, elasticities for tariffs and iceberg trade costs differ also because the elasticity of profits with respect to tariffs differs from the elasticity of profits with respect to iceberg trade costs. In the CES case where profits are proportional to sales, higher tariffs reduce the quantity while leaving the exporter price unchanged. As a result, the elasticity of flow profits with respect to tariffs is $\eta_{\pi,\tau} = -\sigma$. Higher non-tariff trade costs have the same effect on the quantity, but also lead exporters to charge higher prices. As a result, $\eta_{\pi,c} = -\sigma + 1$. The responsiveness of the mass n to changes in the value v as captured by elasticity $\frac{d\ln n}{d\ln v} = \chi$ is independent of the shock.

We next turn to the horizon-h specific elasticities. If tariffs and non-tariff trade costs have the same impulse response function after an initial unitary impulse, that is, $\left\{\frac{d\ln\kappa_{t_0+\ell}}{d\ln\kappa_{t_0}}\right\}_{\ell=1}^{\infty} = \left\{\frac{d\ln\tau_{t_0+\ell}}{d\ln\tau_{t_0}}\right\}_{\ell=1}^{\infty}$, the shape of the impulse response function of trade is identical. To see this, note that the only difference between equations (6.10) and (C.34) is that the former is scaled by $\eta_{\pi,\tau}$ while the latter is scaled by $\eta_{\pi,c}$.

Most importantly, our estimates provide sufficient information to discipline both σ and χ (see also Section 6.1), and hence our model can be used to make predictions about non-tariff elasticities as well. Specifically, for a given σ and a given χ, the model can be used to construct predictions about the short-run non-tariff trade barrier elasticity based on equation (C.30), the long-run non-tariff trade barrier elasticity based on equation (C.31), and the entire time path (equations C.32-C.34).

Appendix D General Equilibrium Model

D.1 Model setup

We consider a multi-country, multi-sector dynamic Krugman economy with N countries indexed by i and j and P sectors indexed by p.

D.1.1 Households

Intertemporal problem Let $C_{j,t}$ denote consumption in country j, β the discount factor, and γ the coefficient of relative risk aversion. Consumers in country j maximize

$$\max_{\{C_{j,t}\}} \sum_{t=0}^{\infty} \beta^t \frac{C_{j,t}^{1-\gamma}}{1-\gamma}$$

subject to the budget constraint

$$P_{j,t}C_{j,t} + \frac{B_{j,t}}{1+r_{j,t}^n} = w_{j,t}L_j + \Pi_{j,t} + R_{j,t} + B_{j,t-1}.$$

In this budget constraint, $P_{j,t}$, $B_{j,t}$, $r_{j,t}^n$, $w_{j,t}$, L_j, $\Pi_{j,t}$, and $R_{j,t}$ denote, respectively, the price index, a risk-free bond, the nominal interest rate, the nominal wage, the labor endowment, profits, and a rebate from the government in country j.

Taking prices as given, optimal household behavior requires that

$$C_{j,t}^{-\gamma} = (1 + r_{j,t})\,\beta C_{j,t+1}^{-\gamma},$$

where $r_{j,t}$ is the real interest rate, defined as

$$1 + r_{j,t} := \left(1 + r_{j,t}^n\right) \frac{P_{j,t}}{P_{j,t+1}}.$$

Consumption over sectors The consumption aggregate is Cobb-Douglas over sectors, so that

$$C_{j,t} = \prod_p q_{j,p,t}^{\alpha_{j,p}},$$

where $q_{j,p,t}$ denotes the quantity of product p that country j consumes, and $\alpha_{j,p} > 0$ are parameters such that $\sum_p \alpha_{j,p} = 1$ for all j. Taking prices as given, households minimize costs

$$\min_{\{q_{j,p,t}\}} \sum_p P_{j,p,t} q_{j,p,t},$$

where $P_{j,p,t}$ is the price index of sector p in country j. Optimal behavior requires that

$$P_{j,p,t}q_{j,p,t} = \alpha_{j,p}C_{j,t}P_{j,t},$$

where the aggregate price index $P_{j,t}$ satisfies

$$P_{j,t} = \prod_p \left(\frac{P_{j,p,t}}{\alpha_{j,p}} \right)^{\alpha_{j,p}} .$$

Note that since nominal objects are not determined in this model, we often express the aggregate price index of country j relative to the US price index below. We denote the price index for the US as $P_{1,t} = P_{US,t}$.

D.1.2 Sectors

A sectoral aggregate combines varieties from potentially all countries i serving market j in sector p. In each sector p, there is a mass of firms $n_{j,i,p,t}$ that serves market j from country i at time t. With some abuse of notation, let $n_{i,j,p,t}$ denote both the measure of firms and the set of firms. Sectoral output is a constant elasticity of substitution (CES) aggregate of firm-level sales

$$q_{j,p,t} = \left(\sum_i \omega_{j,i,p,t}^{\frac{1}{\sigma}} \int_{\iota \in n_{j,i,p,t}} q_{j,i,p,t} \left(\iota \right)^{\frac{\sigma-1}{\sigma}} d\iota \right)^{\frac{\sigma}{\sigma-1}} , \tag{D.1}$$

where $q_{j,i,p,t} \left(\iota \right)$ is the quantity supplied by firm ι in country i to market j, and $\omega_{j,i,p,t}$ is a potentially time-varying taste shifter in j for products p coming from i. We assume that these shifters sum to unity across source countries in the steady state, that is $\forall j, p : \sum_i \omega_{j,i,p} = 1$. Parameter σ is the elasticity of substitution across varieties.

Denoting by $p^d_{j,i,p,t}$ the price paid in the destination, and taking prices as given, the aggregating firm in each sector solves

$$\max_{\{q_{j,i,p,t}(\iota)\}} P_{j,p,t} q_{j,p,t} - \sum_i \int_{\iota \in n_{j,i,p,t}} p^d_{j,i,p,t} \left(\iota \right) q_{j,i,p,t} \left(\iota \right) d\iota$$

subject to equation (D.1).

Optimal behavior yields the demand functions

$$q_{j,i,p,t} \left(\iota \right) = \omega_{j,i,p,t} q_{j,p,t} \left(\frac{p^d_{j,i,p,t} \left(\iota \right)}{P_{j,p,t}} \right)^{-\sigma} ,$$

where the sector-specific price index is

$$P_{j,p,t} = \left(\sum_i \omega_{j,i,p,t} \int_{\iota \in n_{j,i,p,t}} p^d_{j,i,p,t} \left(\iota \right)^{1-\sigma} d\iota \right)^{\frac{1}{1-\sigma}} .$$

D.1.3 Firms

Technology and trade costs Firms operate a linear technology

$$q_{j,i,p,t}(\iota) = \frac{z_{i,p,t}}{\kappa_{j,i,p,t}} l_{j,i,p,t}(\iota),$$

where $z_{i,p,t}$ is the technology common to all firms in sector p of country i, $\kappa_{j,i,p,t}$ are non-tariff trade costs of the iceberg type associated with serving country j, and $l_{j,i,p,t}(\iota)$ denotes the labor input. The unit cost of serving market j is therefore $\kappa_{j,i,p,t}\frac{w_{i,t}}{z_{i,p,t}}$.

In addition to the non-tariff trade barriers $\kappa_{j,i,p,t}$, which are associated with the loss of output during shipment, international trade is subject to tariffs. Tariffs represent a wedge between the price paid in the destination, $p^d_{j,i,p,t}(\iota)$, and the price received by producers, $p^x_{j,i,p,t}(\iota)$, that is, $p^d_{j,i,p,t}(\iota) = p^x_{j,i,p,t}(\iota)\,\tau_{j,i,p,t}$. As specified below, tariff revenue collected by an importer's government will be rebated to the domestic consumer.

Price setting, sales, and profits A firm ι's profits from serving market j are

$$\pi_{j,i,p,t}(\iota) = \max_{p_{j,i,p,t}(\iota)} \left(p^x_{j,i,p,t}(\iota) - \kappa_{j,i,p,t}\frac{w_{i,t}}{z_{i,p,t}}\right) q_{j,i,p,t}(\iota),$$

where the maximization is subject to the demand curve

$$q_{j,i,p,t}(\iota) = \omega_{j,i,p,t}\alpha_{j,p}\left(\frac{\tau_{j,i,p,t}p^x_{j,i,p,t}(\iota)}{P_{j,p,t}}\right)^{-\sigma}\frac{P_{j,t}}{P_{j,p,t}}C_{j,t}.$$

The producer's optimal price is

$$p^x_{j,i,p,t}(\iota) = p^x_{j,i,p,t} = \frac{\sigma}{\sigma-1}\frac{\kappa_{j,i,p,t}}{z_{i,p,t}}w_{i,t}.$$

Note that since this price is common across firms ι, quantities $q_{j,i,p,t}(\iota)$ are also common across firms and we henceforth drop the index ι.

Individual firms' sales exclusive of tariffs are

$$x_{j,i,p,t} := p^x_{j,i,p,t}q_{j,i,p,t} = (\tau_{j,i,p,t})^{-\sigma}\left(\frac{\sigma}{\sigma-1}\frac{\kappa_{j,i,p,t}}{P_{j,p,t}}\frac{w_{i,t}}{z_{i,p,t}}\right)^{1-\sigma}\omega_{j,i,p,t}\alpha_{j,p}P_{j,t}C_{j,t}.$$

Further, individual profits and payments to labor are, respectively,

$$\begin{aligned}\pi_{j,i,p,t} &= \frac{1}{\sigma}x_{j,i,p,t},\\ w_{i,t}l_{j,i,p,t} &= \frac{\sigma-1}{\sigma}x_{j,i,p,t}.\end{aligned} \tag{D.2}$$

Dynamic part of firm problem Each period, there is a unit mass of potential entrants from country i and sector p into each destination market j (including the home market). In order to sell to a market starting next period, the entrant must pay a sunk cost $\xi_{j,i,p,t}(\iota)$ this period, which is measured in units of labor and drawn from distribution G. Once selling to a market, the firm exits exogenously with probability δ. The value (in nominal terms) of entering market j for a firm from i selling product p is

$$v^n_{j,i,p,t} = \frac{1}{1 + r^n_{i,t}} \left[\pi_{j,i,p,t+1}(\iota) + (1 - \delta)\, v^n_{j,i,p,t+1} \right].$$

Potential entrant ι enters whenever $w_{i,t}\xi_{j,i,p,t}(\iota) \le v^n_{j,i,p,t}$. Thus, the mass of new entrants at t of firms from i serving j in p is $G(\frac{v^n_{j,i,p,t}}{w_{i,t}})$. The mass of firms from i serving destination j with product p then evolves according to

$$n_{j,i,p,t+1} = (1 - \delta)\, n_{j,i,p,t} + G\left(\frac{v^n_{j,i,p,t}}{w_{i,t}} \right).$$

Letting $v_{j,i,p,t} := \frac{v^n_{j,i,p,t}}{P_{i,t}}$, the value of exporting can be written as

$$v_{j,i,p,t} = \frac{1}{1 + r_{i,t}} \left[\frac{\pi_{j,i,p,t+1}}{P_{i,t+1}} + (1 - \delta)\, v_{j,i,p,t+1} \right],$$

where we used the definition of the real interest rate in country i, and the law of motion becomes

$$n_{j,i,p,t+1} = (1 - \delta)\, n_{j,i,p,t} + G\left(\frac{v_{j,i,p,t}}{\frac{w_{i,t}}{P_{i,t}}} \right).$$

The aggregate sunk costs of entry in country i period t in units of labor are

$$S_{i,t} = \sum_p \sum_j \int_{-\infty}^{\frac{v_{j,i,p,t}}{\frac{w_{i,t}}{P_{i,t}}}} \xi dG\left(\xi\right).$$

We will assume throughout that the distribution $G\left(\cdot\right)$ is inverse Pareto so that

$$G\left(\xi\right) = \left(b\xi\right)^{\chi} \text{ for } \xi \le \frac{1}{b},$$

for some $b > 0$. Note that, as in Appendix C, this assumption implies that

$$\frac{g\left(\xi\right)\xi}{G\left(\xi\right)} = \chi,$$

where g is the density of G.

D.1.4 Government

The government in country j rebates its tariff revenues to households. The aggregate rebate is

$$R_{j,t} = \sum_p \sum_i (\tau_{j,i,p,t} - 1)\, n_{j,i,p,t} x_{j,i,p,t}.$$

D.1.5 Market clearing

Labor market Labor market clearing in country i requires

$$L_{i,t} = \sum_p \sum_j n_{j,i,p,t} l_{j,i,p,t} + S_{i,t}.$$

Bond market We consider the case of financial autarky so that for every country i and time t, $B_{i,t} = 0$.

D.2 Equilibrium

For a given calibration, and given sequences of exogenous processes $\{\omega_{j,i,p,t}\}$, $\{\kappa_{j,i,p,t}\}$, $\{\tau_{j,i,p,t}\}$, and $\{z_{i,p,t}\}$, the equilibrium consists of sequences of prices and quantities $\{C_{i,t}\}$, $\left\{\frac{w_{i,t}}{P_{i,t}}\right\}$, $\left\{\frac{P_{i,t}}{P_{US,t}}\right\}$, $\{S_{i,t}\}$, $\left\{\frac{P_{i,p,t}}{P_{i,t}}\right\}$, $\left\{\frac{x_{j,i,p,t}}{P_{i,t}}\right\}$, $\{v_{j,i,p,t}\}$, $\{n_{j,i,p,t}\}$ for $i = 1, ...N$, $j = 1, ..., N$, $p = 1, ..., P$, and $t = 0, 1, ...$, such that the following equations hold:

Trade balance: for all i and t

$$\sum_p \sum_j \frac{\frac{P_{j,t}}{P_{US,t}}}{\frac{P_{i,t}}{P_{US,t}}} n_{i,j,p,t} \frac{x_{i,j,p,t}}{P_{j,t}} = \sum_p \sum_j n_{j,i,p,t} \frac{x_{j,i,p,t}}{P_{i,t}}.$$

Aggregate price index: for all i and t

$$1 = \prod_p \left(\frac{1}{\alpha_{i,p}} \frac{P_{i,p,t}}{P_{i,t}} \right)^{\alpha_{i,p}}.$$

Sector-specific price index: for all j, p, and t

$$\frac{P_{j,p,t}}{P_{j,t}} = \left(\sum_i \omega_{j,i,p,t} n_{j,i,p,t} \left(\frac{\sigma}{\sigma - 1} \frac{\tau_{j,i,p,t} \kappa_{j,i,p,t}}{z_{i,p,t}} \frac{w_{i,t}}{P_{i,t}} \frac{\frac{P_{i,t}}{P_{US,t}}}{\frac{P_{j,t}}{P_{US,t}}} \right)^{1-\sigma} \right)^{\frac{1}{1-\sigma}}.$$

Bilateral product-specific trade flows per firm: for all j, i, p, and t

$$\frac{x_{j,i,p,t}}{P_{i,t}} = \left(\tau_{j,i,p,t}\right)^{-\sigma} \left(\frac{\sigma}{\sigma-1}\frac{\kappa_{j,i,p,t}}{z_{i,p,t}}\frac{\frac{w_{i,t}}{P_{i,t}}}{\frac{P_{j,p,t}}{P_{j,t}}}\right)^{1-\sigma} \omega_{j,i,p,t}\alpha_{j,p}\left(\frac{\frac{P_{i,t}}{P_{US,t}}}{\frac{P_{j,t}}{P_{US,t}}}\right)^{-\sigma} C_{j,t}. \tag{D.3}$$

Value of exporting: for all j, i, p, and t

$$v_{j,i,p,t} = \beta\frac{C_{i,t+1}^{-\gamma}}{C_{i,t}^{-\gamma}}\left[\frac{1}{\sigma}\frac{x_{j,i,p,t+1}}{P_{i,t+1}} + (1-\delta)\, v_{j,i,p,t+1}\right]. \tag{D.4}$$

Law of motion of mass of firms: for all j, i, p, and t

$$n_{j,i,p,t+1} = (1-\delta)\, n_{j,i,p,t} + (b)^{\chi}\left(\frac{v_{j,i,p,t}}{\frac{w_{i,t}}{P_{i,t}}}\right)^{\chi}. \tag{D.5}$$

Labor market clearing: for all i, and t

$$L_{i,t} = \frac{\sigma-1}{\sigma}\frac{1}{\frac{w_{i,t}}{P_{i,t}}}\sum_p\sum_j n_{j,i,p,t}\frac{x_{j,i,p,t}}{P_{i,t}} + S_{i,t}.$$

Sunk costs: for all i, and t

$$S_{i,t} = \frac{\chi\,(b)^{\chi}}{\chi+1}\sum_p\sum_j\left(\frac{v_{j,i,p,t}}{\frac{w_{i,t}}{P_{i,t}}}\right)^{\chi+1}.$$

Initial values of $n_{j,i,p,0}$ are given for all i, j, p and $v_{j,i,p,t}$ satisfy a transversality condition for all i, j, p.

D.3 Mapping between partial and general equilibrium model

This model collapses to a version of our partial equilibrium model in Section 6.1 and Appendix C when aggregate general equilibrium objects are held constant. To see this, first note that product-specific bilateral trade in this model is

$$\frac{X_{j,i,p,t}}{P_{i,t}} = \frac{x_{j,i,p,t}}{P_{i,t}} n_{j,i,p,t}, \tag{D.6}$$

where $x_{j,i,p,t} = p^x_{j,i,p,t} q_{j,i,p,t}$. The trade flow $X_{j,i,p,t}$ is the model analogue of measured trade in the data. In this appendix we express $X_{j,i,p,t}$ and other nominal objects relative to the exporter's price index $P_{i,t}$, since nominal objects are not determined in this general equilibrium model. When mapping this general equilibrium model to the partial equilibrium model in Section 6.1 and Appendix C, $P_{i,t}$ must be held constant—as would be the case in a regression with source-country time fixed effects, which absorb this variation.

Next note that in this model $\frac{x_{j,i,p,t}}{P_{i,t}}$ is given by equation (D.3), showing that $\eta_{p,\tau} = 0$ and $\eta_{q,p} =$

$\eta_{q,\tau} = \eta_{\pi,\tau} = -\sigma$ (profits per firm are proportional to sales per firm, see equation D.2). Other than tariffs, all determinants of $\frac{x_{j,i,p,t}}{P_{i,t}}$ according to equation (D.3) above are held constant in the partial equilibrium model.

Equation (6.2) in the text follows from equation (D.4) and noting that in the partial equilibrium model the discount rate

$$\frac{1}{1+r_{i,t}} = \beta \frac{C_{i,t+1}^{-\gamma}}{C_{i,t}^{-\gamma}}$$

is held constant and that individual firms' profits are $\frac{\pi_{j,i,p,t}}{P_{i,t}} = \frac{1}{\sigma}\frac{x_{j,i,p,t}}{P_{i,t}}$, see equation (D.2).

Equation (6.3) follows from equation (D.5), if the real wage is held constant at $\frac{w_i}{P_i}$ and

$$G\left(v_{j,i,p,t}\right) = (b)^{\chi}\left(\frac{v_{j,i,p,t}}{\frac{w_i}{P_i}}\right)^{\chi}.$$

D.4 Estimating equation and partial versus total elasticity

While the trade elasticity can be defined as a partial or a total elasticity, we estimated a partial elasticity in this paper. Specifically, our baseline estimates hold exporter-product-time and importer-product-time variation fixed by including the appropriate fixed effects in the regression. Similar to Proposition 3, we next show what precisely this partial elasticity captures in the context of this specific model and which determinants of bilateral trade flows are absorbed by the fixed effects.

To do so, consider the linearized versions of equations (D.6), (D.3), (D.5), and (D.4) above. Using tildes to denote relative deviations from steady state, these are

$$\begin{aligned}
\widetilde{\frac{X_{j,i,p,t}}{P_{i,t}}} &= \tilde{n}_{j,i,p,t} + \widetilde{\frac{x_{j,i,p,t}}{P_{i,t}}}, \\
\widetilde{\frac{x_{j,i,p,t}}{P_{i,t}}} &= -\sigma\tilde{\tau}_{j,i,p,t} + \tilde{m}_{i,p,t}^{s,1} + \tilde{m}_{j,p,t}^{d} + \tilde{\epsilon}_{j,i,p,t}, \\
\tilde{v}_{j,i,p,t} &= \tilde{m}_{i,t}^{s,2} + (1-\beta(1-\delta))\widetilde{\frac{x_{j,i,p,t+1}}{P_{i,t+1}}} + \beta(1-\delta)\tilde{v}_{j,i,p,t+1}, \\
\tilde{n}_{j,i,p,t+1} &= (1-\delta)\tilde{n}_{j,i,p,t} + \chi\delta\tilde{v}_{j,i,p,t} - \tilde{m}_{i,t}^{s,3},
\end{aligned}$$

where we defined

$$\tilde{m}^{s,1}_{i,p,t} := (\sigma-1)\,\tilde{z}_{i,p,t} - (\sigma-1)\,\widetilde{\frac{w_{i,t}}{P_{i,t}}} - \sigma\widetilde{\frac{P_{i,t}}{P_{US,t}}},$$
$$\tilde{m}^{s,2}_{i,t} := -\gamma\tilde{C}_{i,t+1} + \gamma\tilde{C}_{i,t},$$
$$\tilde{m}^{s,3}_{i,t} := \chi\delta\widetilde{\frac{w_{i,t}}{P_{i,t}}},$$
$$\tilde{m}^{d}_{j,p,t} := (\sigma-1)\,\widetilde{\frac{P_{j,p,t}}{P_{j,t}}} + \sigma\widetilde{\frac{P_{j,t}}{P_{US,t}}} + \tilde{C}_{j,t},$$
$$\tilde{\epsilon}_{j,i,p,t} := -\,(\sigma-1)\,\tilde{\kappa}_{j,i,p,t} + \tilde{\omega}_{j,i,p,t}.$$

To understand the motivation for this notation, note that $\tilde{m}^{s,1}_{i,p,t}$, $\tilde{m}^{s,2}_{i,t}$, $\tilde{m}^{s,3}_{i,t}$, and $\tilde{m}^{d}_{j,p,t}$ will ultimately be absorbed by the exporter-product-time and importer-product time fixed effects. The specific meaning of these terms is as follows. The term $\tilde{m}^{s,1}_{i,p,t}$ captures supply conditions in the source country, such as productivity $\tilde{z}_{i,p,t}$ and the real wage $\widetilde{\frac{w_{i,t}}{P_{i,t}}}$. The term $\tilde{m}^{s,2}_{i,t}$ captures time variation in the discount rate, which affects the value of exporting. Next, the term $\tilde{m}^{s,3}_{i,t}$ also reflects variation in the real wage $\widetilde{\frac{w_{i,t}}{P_{i,t}}}$. It is relevant here, because the sunk costs of exporting are denominated in units of labor and, all else equal, a higher real wage raises the costs of entering a new market. Lastly, the term $\tilde{m}^{d}_{j,p,t}$ captures demand shifters in the destination. Also note that the real exchange rate between country i and j is broken up into two terms. The exporter's price index relative to the US $\widetilde{\frac{P_{i,t}}{P_{US,t}}}$ enters $\tilde{m}^{s,1}_{i,p,t}$, and the price index of the importer relative to the US $\widetilde{\frac{P_{j,t}}{P_{US,t}}}$ is included in $\tilde{m}^{d}_{j,p,t}$. The time-varying bilateral and product-specific components of $\tilde{\epsilon}_{j,i,p,t}$, which include non-tariff trade barriers and demand shocks, will enter the error term.

It is now straightforward to repeat the derivations from Proposition 3 in the context of this specific model. Doing so yields the estimating equation for trade flows

$$\begin{aligned}\widetilde{\frac{X_{j,i,p,t+h}}{P_{i,t+h}}} - \widetilde{\frac{X_{j,i,p,t-1}}{P_{i,t-1}}} =& -\sigma\left(\tilde{\tau}_{j,i,p,t+h} - \tilde{\tau}_{j,i,p,t-1}\right) \\ & - \sigma\left(1-\beta\left(1-\delta\right)\right)\delta\chi\sum_{k=0}^{h-1}\left(1-\delta\right)^{h-1-k}\sum_{\ell=0}^{\infty}\left(\beta\left(1-\delta\right)\right)^{\ell}\left(\tilde{\tau}_{j,i,p,t+k+\ell+1} - \tilde{\tau}_{j,i,p,t-1}\right) \\ & + \delta^{s,X,h}_{i,p,t} + \delta^{d,X,h}_{j,p,t} + u^{X}_{j,i,p,t}, \qquad \text{(D.7)}\end{aligned}$$

where the fixed effects are

$$\delta^{s,X,h}_{i,p,t} := \left(\tilde{m}^{s,1}_{i,p,t+h} - \tilde{m}^{s,1}_{i,p,t-1}\right) + \left(1-\beta\left(1-\delta\right)\right)\delta\chi\sum_{k=0}^{h-1}\left(1-\delta\right)^{h-1-k}\sum_{\ell=0}^{\infty}\left(\beta\left(1-\delta\right)\right)^{\ell}\tilde{m}^{s,1}_{i,p,t+k+\ell+1}$$
$$+\delta\chi\sum_{k=0}^{h-1}\left(1-\delta\right)^{h-1-k}\sum_{\ell=0}^{\infty}\left(\beta\left(1-\delta\right)\right)^{\ell}\tilde{m}^{s,2}_{i,t+k+\ell} - \sum_{k=0}^{h-1}\left(1-\delta\right)^{h-1-k}\tilde{m}^{s,3}_{i,t+k},$$
$$\delta^{d,X,h}_{j,p,t} := \left(\tilde{m}^{d}_{j,p,t+h} - \tilde{m}^{d}_{j,p,t-1}\right) + \left(1-\beta\left(1-\delta\right)\right)\delta\chi\sum_{k=0}^{h-1}\left(1-\delta\right)^{h-1-k}\sum_{\ell=0}^{\infty}\left(\beta\left(1-\delta\right)\right)^{\ell}\tilde{m}^{d}_{j,p,t+k+\ell+1},$$

and the error term includes initial conditions, as well as leads and lags of $\tilde{\epsilon}_{j,i,p,t}$. Specifically,

$$u^{X}_{j,i,p,t} := -\sigma\chi\left(1-\left(1-\delta\right)^{h}\right)\tilde{\tau}_{j,i,p,t-1} + \left(1-\delta\right)^{h}\tilde{n}_{j,i,p,t} - \tilde{n}_{j,i,p,t-1}$$
$$+\left(\tilde{\epsilon}_{j,i,p,t+h} - \tilde{\epsilon}_{j,i,p,t-1}\right) + \left(1-\beta\left(1-\delta\right)\right)\delta\chi\sum_{k=0}^{h-1}\left(1-\delta\right)^{h-1-k}\sum_{\ell=0}^{\infty}\left(\beta\left(1-\delta\right)\right)^{\ell}\tilde{\epsilon}_{j,i,p,t+k+\ell+1}.$$

The partial elasticity implied by equation (D.7) thus holds $\delta^{s,X,h}_{i,p,t}$ and $\delta^{d,X,h}_{j,p,t}$ fixed when subjecting trade flows to a trade shock at t_0. This amounts to holding supply conditions in the source country and demand conditions in the destination country fixed. When mapping to the partial equilibrium framework in Section 6.1, a sufficient condition for this is that the terms $\tilde{z}_{i,p,t} = \widetilde{\frac{w_{i,t}}{P_{i,t}}} = \widetilde{\frac{P_{i,t}}{P_{US,t}}} = \tilde{C}_{i,t} = 0$ for all $t \geq t_0$ in the source country i and sector p, and that $\widetilde{\frac{P_{j,p,t}}{P_{j,t}}} = \widetilde{\frac{P_{j,t}}{P_{US,t}}} = \tilde{C}_{j,t} = 0$ for all $t \geq t_0$ in the destination country j and sector p.

The importer-product-time effects $\delta^{d,X,h}_{j,p,t}$ and exporter-product-time effects $\delta^{s,X,h}_{i,p,t}$ absorb both the exogenous (shocks) and endogenous (general-equilibrium) shifts in demand and supply. In particular, $\delta^{d,X,h}_{j,p,t}$ contains log-differences of the past, present, and expected future foreign demand shifters $\tilde{m}^{d}_{j,p,t}$, which are made up of the aggregate expenditures and the price levels in the destination j. Thus, the $\delta^{d,X,h}_{j,p,t}$s absorb any effect of a change in tariffs on the demand faced by exporter i through general-equilibrium effects in the importing country, such as the importer's prices and wages. Importer and third-country productivity shocks are absorbed by the importer-product-time effects, as they are part of the demand shifter $\tilde{m}^{d}_{j,p,t}$ (recall that $\tilde{m}^{d}_{j,p,t}$ includes the price level in destination j, and thus is a function of the productivities of all countries serving j, including j itself). Taste shocks that vary by destination (but not by destination-source) at the product level are also absorbed by the importer-time effects.

The exporter-product-time effects $\delta^{s,X,h}_{i,p,t}$ absorb the exogenous shocks and general-equilibrium effects in the exporting country, as it is made up of log-differences in current and expected future unit costs of production and entry. Thus, $\delta^{s,X,h}_{i,p,t}$s control for any general-equilibrium effect of a tariff change on wages of the exporter. In addition, exporter-product-specific productivity shocks are absorbed by the $\delta^{s,X,h}_{i,p,t}$s, as they manifest themselves in shifts in $\tilde{m}^{s,1}_{i,p,t}$, and in wages and prices indirectly. Trade cost shocks that vary either by destination-product-time or source-product-time are similarly absorbed by $\delta^{s,X,h}_{i,p,t}$ and $\delta^{d,X,h}_{j,p,t}$. On the other hand, taste and trade cost shocks that vary at the destination-source-product-time level $\omega_{i,j,p,t}$ and $\kappa_{i,j,p,t}$ are in the error term and if correlated to tariff changes, present a threat to identification.

While the intuition is generally similar to the role of multilateral resistance terms in static trade models (Anderson and van Wincoop, 2003), there are slight differences. For instance, the exporter-product-time fixed effect also absorbs variation in the discount rate, captured here by time variation in consumption of the source country, which affects the export entry decision of firms.

In contrast to the partial elasticity estimated in the data, the total trade response or total trade elasticity also takes general equilibrium effects of the tariff change into account. We compute it numerically below.

D.5 Calibration and model solution

The calibration of the model is parsimonious and uses readily available data. Data on real GDP comes from the Penn World Tables v.9.1 for 2006 and disciplines country size parameters (L_i). Specifically, we choose L_i such that relative steady state consumption C_i in the countries is equal to relative GDP in the data. Preference parameters in the final goods aggregator $\alpha_{i,p}$ are determined by sectoral expenditure share data for 2006 from KLEMS. In the model, import shares are determined by several parameters – tariffs $\tau_{i,j,p}$, productivity $z_{i,p}$, non-tariff trade barriers $\kappa_{i,j,p}$, and preference parameters $\omega_{i,j,p}$. We choose tariffs $\tau_{i,j,p}$ to be equal to the average import tariff set by i across all products belonging to sector p exported by j in 2006 in our data. The productivity parameters $z_{i,p}$ are chosen to match sectoral value added per worker from KLEMS in 2006. We cannot separately identify $\kappa_{i,j,p}$ and $\omega_{i,j,p}$. We therefore choose $\omega_{i,j,p} = \frac{1}{N}$ and then choose $\kappa_{i,j,p}$ to match observed 2006 import shares given the values of $\tau_{i,j,p}$, $z_{i,p}$, and $\omega_{i,j,p}$.

We parameterize the distribution of sunk entry costs in the model by assuming they are distributed inverse Pareto with an upper bound $b = 1$ and curvature parameter χ. In this dynamic Krugman model, the choice of σ and χ pins down the long run elasticity. Given a short run elasticity σ of 1.1, we choose $\chi = 0.82$ for the baseline calibration such that the long run elasticity is 2. Finally, our model also requires the calibration of several standard parameters summarized in Table D1.

Our quantitative exercises fall into two categories. For the first, we linearize the GE model and compute the partial and general equilibrium impulse responses to tariff changes under a variety of scenarios. For this exercise, we choose $N = 6$ and $P = 5$ (a six-country and five-sector model). These choices are largely determined by the scale of a model that can be solved using standard computational software. In this setting, the economies we use as calibration targets are the US, Europe, China, Canada, Japan and a rest-of-the world aggregate. The sectors we choose are services (largely non-traded), three manufacturing sectors (upstream, non-durable, and machinery), and one non-manufacturing traded sector including agriculture and other traded non-manufacturing goods. We use this calibration for the exercises underlying Figures 6 and B6.

In the second exercise, we compute the dynamic welfare gains from trade country-by-country. We use a standard shooting algorithm for this exercise. For simplicity, we consider one country at a time as well as a rest-of-the-world aggregate, so that $N = 2$. We also collapse the sectoral dimension to $P = 2$, with one traded and one non-traded sector. For this exercise, therefore, we compute 23 different versions of the model, and in each case $N = 2$ and $P = 2$.

The gains from trade are then computed as follows. We first compute the steady states under autarky (A) and the observed level of trade (T) and infer the change in non-tariff trade costs $\kappa^T_{j,i,p} - \kappa^A_{j,i,p}$ required to generate the difference in trade across steady states observed in the data. All other parameters remain unchanged in this exercise. We then consider a one-time unexpected permanent non-tariff trade cost change of the required magnitude, occurring at the beginning of period 0, and compute the transition path from autarky to the new steady state.

The remaining calculations are analogous to the Lucas welfare cost of business cycles calculation. In general, the value of consumption is

$$V_{j,0} = \sum_{t=0}^{\infty} \beta^t \frac{(C_{j,t})^{1-\gamma}}{1-\gamma}.$$

Consider the transition path from the autarky steady state to the new steady state with trade. Since the shock occurs at the beginning of $t = 0$, we can compute the value as

$$V^T_{j,0} = \sum_{t=0}^{\infty} \beta^t \frac{\left(C^T_{j,t}\right)^{1-\gamma}}{1-\gamma}.$$

Next, consider an equivalent value arising under the thought experiment where the household receives a consumption equivalent $C^{T,e}_j$ for all $t \geq 0$ going forward,

$$V^{T,e}_{j,0} = \sum_{t=0}^{\infty} \beta^t \frac{\left(C^{T,e}_j\right)^{1-\gamma}}{1-\gamma}.$$

Setting $V^T_{j,0} = V^{T,e}_{j,0}$ gives

$$C^{T,e}_j = \left((1-\beta)\sum_{t=0}^{\infty} \beta^t \left(C^T_{j,t}\right)^{1-\gamma}\right)^{\frac{1}{1-\gamma}}.$$

The dynamic welfare gains are then computed as

$$\mathrm{GFT}_j = \frac{C^{T,e}_j - C^A_j}{C^A_j},$$

where C^A_j is consumption in the autarky steady state. This exercise delivers Figure B8.

Table D1: Parameterization

Parameter(s)	Value /Target /Source	Notes
β	0.97	Discount factor
γ	2	Relative risk aversion
δ	0.25	Exit rate
b	1	Inverse Pareto upper bound
$\alpha_{i,p}$	KLEMS	Expenditure shares
$\tau_{j,i,p}$	TRAINS	Average bilateral tariffs
$z_{i,p}$	KLEMS	Sectoral value added per worker
$\omega_{j,i,p}$	$\frac{1}{N}$	Preference parameters
$\kappa_{j,i,p}$	WIOD import shares	Non-tariff trade costs
L_i	PWT	Chosen to match relative real GDP
Elasticity Parameters: Baseline calibration		
σ	1.1	Short-run trade elasticity
χ	0.82	Pareto curvature parameter
Elasticity Parameters: High elasticity calibration		
σ	3	Short-run trade elasticity
χ	1	Pareto curvature parameter

Notes: This table summarizes calibration of the dynamic Krugman model. All data used are for year 2006. Our quantitative exercises either have countries $N = 2$ and sectors $P = 2$ or countries $N = 6$ and sectors $P = 5$. When $N = 2$, $P = 2$ we (i) normalize value added per worker in the traded sector in the country of interest equal to 1; (ii) choose L_i in the country of interest such that real GDP in the country of interest is 1 in the steady state with trade. When $N = 6$, $P = 5$ we (i) normalize value added per worker in the machinery sector in the United States equal to 1; (ii) choose L_{US} such that real GDP in the US is equal to 1.