Trade Costs and Inflation Dynamics[*]

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Abstract

We explore how shocks to trade costs affect inflation dynamics in a global economy. We identify trade costs by exploiting bilateral trade flows for final and intermediate goods and the structure of static trade models that deliver structural gravity equations. We then use a local projections approach to assess the effects of estimated trade cost shocks on countries' consumer price (CPI) inflation and other macroeconomic variables. Higher trade costs lead to increases in inflation and dampen economic activity. We propose a multi-country New-Keynesian model featuring international trade in final and intermediate goods that replicates the inflation responses we identify in the data, with larger but less-persistent inflation effects when trade costs increase for final goods than for intermediate goods. We use the model to explore the drivers of U.S. inflation in the aftermath of the COVID-19 pandemic.

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[*] The views in this paper are solely the responsibility of the authors and should not be interpreted as reflecting the views of the Board of Governors of the Federal Reserve System or of any other person associated with the Federal Reserve System.

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1 Introduction

Over the past half-century, the world economy experienced a process of globalization. Countries are now markedly more interconnected than fifty years ago, particularly in terms of the amount of goods and services that they trade with each other. For instance, world exports as a share of world GDP almost doubled over this period, going from an average of 16 percent in the 1970s to 29 percent in the late 2010s.[1] This surge in trade was not entirely driven by countries actively trading in the 1970s. Emerging economies played a prominent role in the globalization process as they experienced high growth rates and became increasingly open to trade.[2] China is a clear example of such an economy. The Chinese economy experienced fast economic growth starting in the 1990s and increased its presence in world markets by joining the World Trade Organization (WTO) in 2001. Thus, globalization has led to clear changes in the structure of the world economy over the past fifty years.

The current global economic landscape implies that shocks to trade linkages can have important macroeconomic consequences. Clearly, in a world featuring a larger number of countries engaged in sizable transactions, the scope for large effects of disruptions to trade relationships increases. That is, shocks to trade costs can potentially affect various macroeconomic outcomes and further transmit across countries over time. Recent examples of trade cost shocks with important macroeconomic consequences include changes in trade policies—particularly in the case of the U.S. during the Trump administration—and the effects of the COVID-19 epidemic on shipping costs. It is evident that these shocks had important implications for inflation dynamics in many countries. However, studies on the macroeconomic consequences, those on inflation in particular, of broadly-defined "trade cost shocks," are scarce.[3] Recent work has aimed at understanding how trade costs can affect particular macroeconomic outcomes (Fitzgerald, 2012; Eaton et al., 2016b; Reyes-Heroles, 2017; Alessandria and Choi, 2021), but the literature has largely overlooked the effects on inflation. While this fact may seem puzzling given the policy relevance of inflation, it is also understandable given the focus of existing trade models on real outcomes and the divergence of these models from the New Keynesian framework that provides the benchmark approach to studying inflation dynamics.[4]

In this paper, we study how shocks to trade costs affect inflation dynamics in a global economy. Our study proceeds in two steps. First, we exploit final and intermediate goods' bilateral trade flows and the structure of static gravity-type models of trade (Head and Mayer, 2014) to identify bilateral trade

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[1] World Development Indicators (WDI), World Bank: `https://data.worldbank.org/indicator/NE.EXP.GNFS.ZS`.

[2] Reyes-Heroles et al. (2020) document the rise of Emerging Market Economies in trade since the mid-1990s.

[3] A large literature has focused on the transmission and implications of productivity shocks (Backus et al., 1992; Heathcote and Perri, 2002), and some works have added demand shocks (Stockman and Tesar, 1995; Bai and Ríos-Rull, 2015).

[4] Some important exceptions to this dichotomy include the works by Comin and Johnson (2020) and Barattieri et al. (2021).

costs. Armed with our estimates, we then empirically assess the effects of trade cost shocks on countries' consumer price inflation and other macroeconomic variables. Our estimates show that increases in trade costs translate into higher inflation. In the second part of the paper, we propose a multi-country New Keynesian model featuring international trade in final and intermediate goods to explore the mechanisms through which trade cost shocks transmit into inflation and other macroeconomic variables. We show that the model can replicate the response of inflation and other macroeconomic variables to trade cost shocks.

Section 2 constructs bilateral trade costs and presents some stylized facts on the evolution of trade costs over time and their correlation with CPI inflation. We construct bilateral trade flows for intermediate and final goods for a set of 41 countries considered in the World Input-Output Database (WIOD) over the period 1995-2014. Given the data for bilateral trade flows, we rely on the ratio-type estimation proposed by Head and Ries (2001), which delivers measures of structural trade costs—more precisely, measures of trade integration between any two countries—under the assumption of symmetric trade costs. We refer to these measures of trade costs for any pair of countries in any given year as Head-Ries indices Head and Mayer (2014). We rely on these indices to construct country-specific trade costs and show that our estimated trade costs for final and intermediate goods (i) declined significantly from 1995 to 2014 and (ii) that they correlate positively with CPI inflation.

In Section 3, we move on to explore the causal relationship between changes in trade costs, inflation, and other macroeconomic variables. To do so, we follow the local projections method approach by Jordà (2005). We focus on the effects of trade costs on inflation and find that higher trade costs in both final and intermediate goods translate to a sizable increase in inflation, and that the inflation effects are more persistent when the increase in trade costs affects intermediate goods than when it affects final goods.

Next, we describe our proposed model and our calibration strategy in detail in Section 4. We propose an open economy multi-country New Keynesian model with trade in final and intermediate goods. A unit continuum of firms in each country produces differentiated varieties using labor and intermediate inputs. A representative firm, the final good producer, buys these varieties and aggregates them into a single tradable good that is differentiated across countries. These goods are traded across borders and can be used for final consumption or as an intermediate input in production. Similar to Comin and Johnson (2020), we model static trade across countries in an Armington fashion. That is, we assume that consumers and firms aggregate differentiated tradable goods across countries according to constant elasticity of substitution (CES) aggregators. Trade is subject to iceberg-type trade costs that are use-specific and vary in a stochastic fashion over time. These features of our model imply that, at any given point in time, trade across countries is described by gravity-type equations consistent with our empirical strategy to identify trade costs in the data. We assume that firms adjust prices infrequently, as in standard New Keynesian models, implying sluggish price movements. Moreover, we consider nominal wage rigidities in labor markets.

In Section 6, we calibrate our model to mimic trade linkages in final and intermediate goods across five regions: the U.S., China, advanced non-U.S. economies, Asian emerging market economies (EMEs) excluding China, and other EMEs. We use the model to explore the transmission mechanisms of changes in trade costs. We find that the model implies inflation effects of final and intermediate trade cost shocks that are qualitatively consistent with the empirical responses, with rises in intermediate good trade costs leading to smaller but more-persistent inflation effects that occur due to a persistent rise in marginal costs. We also use the model to provide estimates of the effects on the U.S. economy of a trade cost shock sized to match the increase in U.S.-China trade tensions in 2018-19. Finally, we use the model to analyze the drivers of the recent surge in inflation in the U.S.

Related Literature This paper relates to multiple strands of the international macroeconomics and trade literature. First, this paper is closely related to the papers that explore the macroeconomic consequences of international trade costs. The seminal work of Obstfeld and Rogoff (2000) posited how costs to trade in goods could help explain several international macroeconomic puzzles. More recent work has taken a more quantitative perspective to explore the role of trade costs not only in these puzzles (Eaton et al., 2016a), but also in other macroeconomic phenomena like risk sharing (Fitzgerald, 2012), trade imbalances (Reyes-Heroles, 2017; Alessandria and Choi, 2021), and the Global Recession (Eaton et al., 2016b), among others.[5] Our work is most closely related to Comin and Johnson (2020), who explore the role of increasing trade in driving the long-run trend in U.S. inflation. We contribute to this literature in two dimensions. First, we exploit panel data to document how cost shocks for trade in final and intermediate goods affect inflation and provide novel evidence that these shocks are inflationary. Second, we develop and estimate a multi-country general equilibrium New-Keynesian model to explore the mechanisms behind our estimated effects in an increasingly interconnected world.

This paper is also related to the recent literature studying the role of trade openness in shaping business cycles through the lens of open economy New-Keynesian models. For instance, Caldara et al. (2020) explore the economic effects of trade policy uncertainty, Ho et al. (2022) analyze multilateral comovement, and Erceg et al. (2023) explore the interactions between trade policies and fiscal devaluations.[6] Our work is most closely related to Barattieri et al. (2021) who identify changes in protectionist measures in the

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[5] Alessandria and Choi (2014), Alessandria and Mix (2021), and Alessandria et al. (2023) are additional works focusing on how shocks to trade costs, trade policy, and supply chains can have aggregate effects.

[6] Other work like Hottman and Reyes-Heroles (2023) exploit regional U.S. data and follow a less model-dependent approach to estimate the effects of more openness on inflation dynamics and the slope of the Phillips curve in the U.S.

data and study the consequences of changes in these measures on business cycles. We contribute to this literature by focusing on the effects of inflation of shocks to broadly defined trade barriers consistent with the structure of gravity models of international trade. Moreover, in line with our empirical approach, our framework considers more than two countries, which allows us to consider the effects of trade diversion as a result of trade cost shocks.

Lastly, this paper is also related to the literature on international trade that has exploited static gravity models of trade to estimate trade costs. Head and Mayer (2014) review various approaches to estimate trade costs. Fitzgerald (2012); Eaton et al. (2016b,a); Reyes-Heroles (2017) are some papers that exploit the fact that dynamic models can deliver static gravity conditional on aggregate data to identify trade costs given an estimate of the trade elasticity. We contribute to this literature by exploring the correlation between measured trade costs with inflation and other macroeconomic variables and documenting causal relationships.

2 Trade Costs Across Time and Space

2.1 Measuring Trade Costs

2.1.1 A Static Armington Model of Trade and Structural Gravity

Trade costs are the centerpiece of our analysis. Observing or directly measuring the overall costs of shipping goods across borders is impossible (Anderson and van Wincoop, 2004). Therefore, to measure these costs we follow the extensive literature in international trade that estimates trade costs based on the structure of static trade models that deliver gravity equations (Head and Mayer, 2014). In this section, we consider an Armington model of trade that gives rise to bilateral trade flows across countries in a given point in time in line with gravity.[7] The equilibrium of the model delivers predictions for bilateral trade flows for different types of goods conditional on aggregate spending on such goods. We show how the model's equilibrium conditions can be inverted so that we can measure bilateral trade costs as functions of observable data. Later in the paper, we embed the exact structure of this static model of trade into a dynamic stochastic general equilibrium model that we use to analyze the mechanisms through which shocks to trade costs affect inflation.[8]

Consider a world comprised of multiple countries indexed by $i, h \in \mathcal{I} = \{1, \ldots, N\}$ in period t. Each country produces a unique tradable good sourced to all other countries—that is, there is *national product differentiation*. Goods produced in each country can be either bought by households for final

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[7] Our model is isomorphic to one in which trade arises from Ricardian comparative advantages as in Eaton and Kortum (2002).

[8] In the dynamic model, aggregate spending on different types of goods is endogenously determined.

consumption or by firms as intermediate inputs in every country. We assume that households and firms in country i aggregate goods across sources into a single nontradable composite consumption good, $C_{i,t}$, or intermediate input, $M_{i,t}$, respectively. This aggregation is done according to a constant elasticity of substitution (CES) aggregator given by

$$Q_{i,t} = \left(\sum_h (\omega_{ih}^Q)^{\frac{1}{\eta_Q}} (Q_{ih,t})^{\frac{\eta_Q - 1}{\eta_Q}} \right)^{\frac{\eta_Q}{\eta_Q - 1}} \tag{1}$$

where $Q \in \{C, M\}$, $\eta_Q > 1$, and $\sum_{h=1}^N \omega_{ih}^Q = 1$. In (1), $Q_{ih,t}$ denotes the use by country i of goods of type $Q \in \{C, M\}$ produced in h at time t.

Let $P_{i,t}$ denote the price of the good both produced and sold in country i expressed in terms of local currency units. If $\mathcal{E}_{ih,t}$ denotes the nominal bilateral exchange rate between countries i and h expressed in terms of country i's currency units per unit of country h's currency, then the price that country i has to pay for one unit of country h's good to be produced is given by $P_{ih,t} \equiv \mathcal{E}_{ih,t} P_{h,t}$ in terms of i's currency. However, trade across countries is subject to iceberg-type trade costs given by $\tau_{ih,t}^Q \geq 1$, implying that for one unit of good of type $Q \in \{C, M\}$ produced in h to be delivered to i, $\tau_{ih,t}^Q$ units have to be shipped at time t. That is, $\tau_{ih,t}^Q - 1$ units of the good disappear when this is shipped internationally from country h to country i. We normalize domestic trade costs such that $\tau_{ii,t}^Q = 1$ from every i and $Q \in \{C, M\}$. Therefore, the price in local currency units that country i has to pay to acquire one unit of goods of typ $Q \in \{C, m\}$ produced in country h is given by

$$P_{ih,t}^Q \equiv \tau_{ih,t}^Q P_{ih,t}. \tag{2}$$

Households and firms in country i seek to minimize expenditure on final consumption goods and intermediate inputs, respectively, when choosing $\{Q_{ih,t}\}_h$. The solution to this minimization problem deliver conditional demand functions for goods of type $Q \ in\{C, M\}$ given by

$$Q_{ih,t} = \left(\frac{\tau_{ih,t}^Q P_{ih,t}}{P_{i,t}^Q} \right)^{-\eta_Q} Q_{i,t}, \tag{3}$$

where

$$P_{i,t}^Q \equiv \left(\sum_h \left(\tau_{ih,t}^Q P_{ih,t} \right)^{1-\eta_Q} \right)^{\frac{1}{1-\eta_Q}} \tag{4}$$

denotes the ideal price index for composite good Q. Let $\lambda_{ih,t}^Q$ denote the share of expenditure by country

i on goods of type Q produced in country h, $\lambda^Q_{ih,t} \equiv \frac{P^Q_{ih,t} Q_{ih,t}}{P^Q_{i,t} Q_{i,t}}$. Equation (3) implies that these shares are given by

$$\lambda^Q_{ih,t} = \left(\frac{\tau^Q_{ih,t} P_{ih,t}}{P^Q_{i,t}} \right)^{-(\eta_Q - 1)}, \tag{5}$$

which are in line with gravity-type equations that express bilateral trade flows between two countries in terms of importer i characteristics, exporter h characteristics, and a measure of bilateral trade costs that summarize all frictions that impede trade across two countries. Our object of interest in (3) is $\tau^Q_{ih,t}$ and the trade elasticity in this model is given by $\eta_Q - 1$.

How can one use the equilibrium conditions of the model to infer bilateral trade costs? Note that the equilibrium conditions imply that we can use a country's domestic sourcing share, $\lambda_{ii,t}$, to control for exporter characteristics. More specifically, given (3) for importer i and exporter h, we can express bilateral trade costs between these countries as a function of its bilateral trade share, the exporter's domestic sourcing share, and prices as follows:

$$\tau^Q_{ih,t} = \left(\frac{\lambda^Q_{ih,t}}{\lambda^Q_{hh,t}} \right)^{-\frac{1}{\eta_Q - 1}} \frac{P^Q_{i,t}}{P^Q_{h,t}}. \tag{6}$$

Hence, the equilibrium of our model implies that, given data on bilateral trade shares, domestic sourcing shares, and relative prices across countries for each type of good $Q \in \{C, M\}$, we can recover bilateral trade costs in any given period t conditional on a value of the parameter $\eta_Q > 1$ capturing the model's trade elasticity.[9]

Given the scarcity of data on relative prices across countries, it is useful to switch the role of the importing and exporting countries to control for relative price differences. In this way, we can obtain a simple indicator of trade frictions between individual country pairs. The literature refers to this indicator as the Head-Ries index (Head and Ries, 2001; Eaton et al., 2016b) and it provides an approximation to bilateral trade frictions for our model in period t. In particular, (6) implies that we can let

$$HR^Q_{ih,t} \equiv (\tau^Q_{ih,t} \tau^Q_{hi,t})^{\frac{1}{2}} = \left(\frac{\lambda_{ih,t}}{\lambda_{hh,t}} \frac{\lambda_{hi,t}}{\lambda_{ii,t}} \right)^{-\frac{1}{2(\eta_Q - 1)}}. \tag{7}$$

which defines the Head-Ries index for pair of countries (i, h). Note that this measure is given by the geometric mean of bilateral iceberg-trade cost $\tau^j_{ih,t}$ for a pair of countries. Moreover, $HR_{ii,t} = 1$, which is consistent with the notion that trade with oneself is costless. In addition, under the assumption of

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[9] See Reyes-Heroles (2017) for an application of this procedure.

symmetric trade costs, the index becomes the actual trade cost. Hence, this measure of bilateral trade frictions has multiple appealing features.

It worth noting that, even though this measure of bilateral trade frictions only requires data on bilateral trade flows and not on prices, it does require each country's "bilateral" trade with itself. Let $X^Q_{ih,t} \equiv P^Q_{ih,t} Q_{ih,t}$ for $Q \in \{C, M\}$ denote expenditure by country i on goods good of type Q produced in h. Then, $X^Q_{ih,t} \equiv \sum_{h=1}^{N} X^Q_{ih,t}$ defines total expenditure by country i on type Q goods and is such that $X^Q_{i,t} = P^Q_{i,t} Q_{i,t}$. Note that to compute (7) we need data on $X^Q_{ii,t}$ which is not provided by the more common datasets for bilateral trade flows. In the following section we describe multiple datasets that allow us to construct our measure of bilateral trade flows for a large number of countries and going back in time three decades.

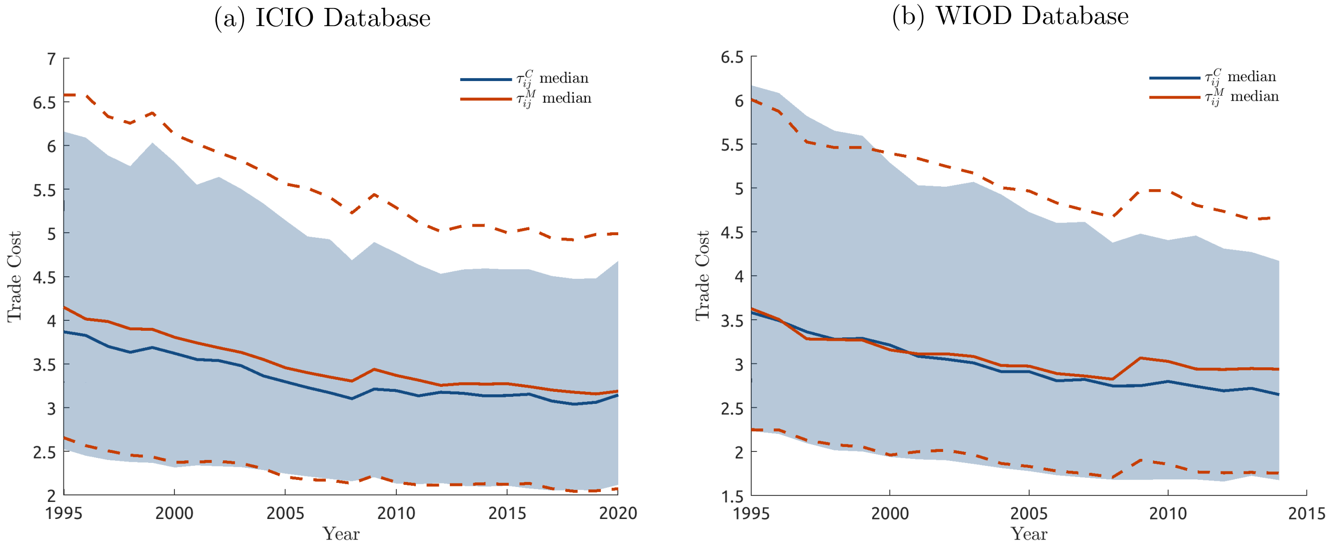
2.1.2 Data Sources

We collect input-output data to quantify final goods and intermediate input demands across countries. Towards this end, we employ the World Input-Output Database (WIOD) that provides yearly input-output tables between 1995 and 2014 for a group of 41 countries.[10] The WIOD tables record transactions across 35 sectors for 2000-2011 and 56 sectors for 2012-2014 of each economy within itself and with the same sectors in other countries. To measure trade costs, we focus only on 16 non-service sectors and then aggregate the sectoral demands for intermediate inputs (M) and final consumption goods (C) to obtain country-by-country bilateral trade flows in these two categories. After aggregating intermediate and final consumption demands across non-service sectors, we can compute the import demand of country i of goods of type, $j = \{C, M\}$, sourced from country h in period t, which we denote as $X^j_{ih,t}$. We rely on these data to construct Head-Ries indices in line with equation (7). For each country i, we then aggregate HR indices across all bilateral sources weighting by imports in order to construct a single measure of import costs for country i. In our baseline exercise, we set $\eta = 3$, consistent with estimates from Simonovska and Waugh (2014). However, given the evidence of lower estimates for the long-run trade elasticity documented in Boehm et al. (2023), in Section B.2, we explore the robustness of our main results to different values of the trade elasticity.

2.2 Trade Costs Across Space

[TBC]

Figure 1: **Evolution of global trade costs**


(a) ICIO Database

(b) WIOD Database

Note: data comes from WIOD database. The 2011-2014 numbers have been taken from the WIOD 2016 database and stitched to the WIOD 2013 numbers.

2.3 Trade Costs Across Time

Figure 1 shows our baseline estimates of the HR indices between 1995 and 2014. The left panel corresponds to the HR index for final consumption goods, and the right panel depicts the HR index for intermediate inputs. The solid lines show the cross-country median and the dashed and dashed-dotted lines correspond to the 20th and 80th percentiles, respectively. Based on our calculated HR indices, trade costs significantly declined during this period. For instance, at the beginning of our sample, the median value of the final consumption HR index is 1.1, which implies that trade costs are roughly 100 percent of the final sale price. Toward the end of our sample, the median trade cost declined to around 90 percent. Also, there is substantial variation in trade costs across countries. The trade costs in the 80th percentile were around 130 percent of the final sale price in 2014, whereas for the countries in the bottom 20th percentile, trade costs were around 70 percent of the final sale price in the same year.

2.4 Trade Costs and Inflation

To relate inflation with trade costs, we collect yearly data on inflation for the 41 countries included in the World Development Indicators (WDI) database. We measure inflation as the year-on-year change in the Consumer Price Index (CPI). Because our period of analysis includes some high inflation episodes due to other factors unrelated to trade costs, such as currency crises or macroeconomic turmoil due to pro-market reforms in Eastern Europe, we restrict attention to country-year observation where the inflation is below

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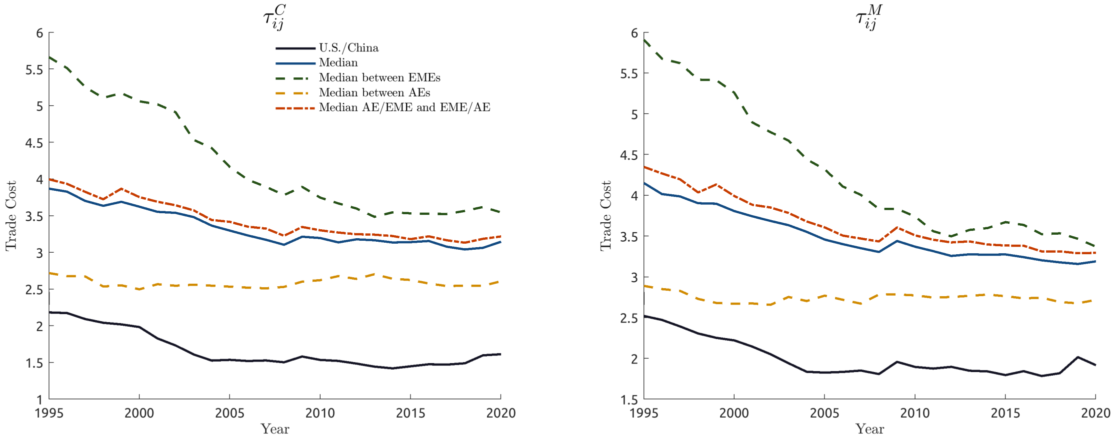
[10] Timmer et al. (2015)

Figure 2: Trade Costs for Selected Regions



10 percent.

Figure 3 shows a scatter plot between trade costs and CPI inflation. The left panel shows the relation between trade costs in final consumption goods and inflation. The right panel shows trade costs in intermediate inputs and inflation. Each dot corresponds to a country-year observation where we relate trade costs in year t with the average CPI inflation observed in the subsequent four years, up to $t+4$. The relation between contemporaneous inflation and trade costs is similar, but it is instructive to show future average inflation to abstract from variation in inflation that may be unrelated to current trade costs. Visual inspection suggests a positive correlation between higher trade costs, as measured by our HR index, and future CPI inflation. The scatter plot also reveals substantial dispersion in the inflation rate, particularly for country-year observations where trade costs are above 100 percent. Uncovering the causal effect and the magnitude of higher trade costs on inflation requires controlling for unobserved factors driving the positive correlation in this simple scatter plot. We turn to this analysis in the next section.

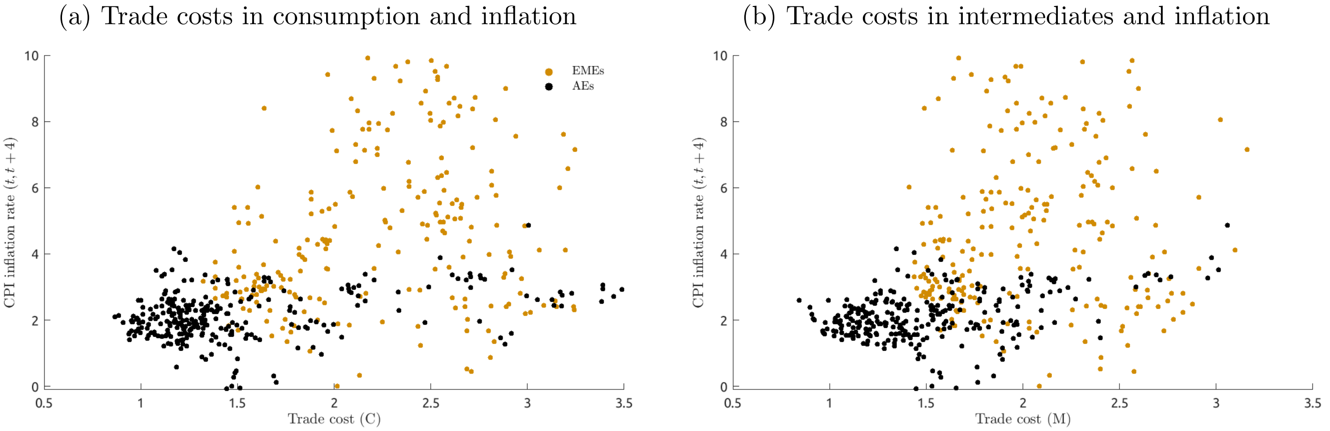
3 Estimating the Effect of Trade Costs on Inflation

3.1 Estimation Strategy

We turn to analyzing the response of inflation and the domestic sourcing share to higher trade costs. For our empirical strategy, we use local projections as in Jordà (2005) and estimate the following panel specification:

$$y_{i,t+h} = \alpha_i + \gamma_t + \beta_h^y \tau_{i,t}^j + A_h Z_{i,t} + \varepsilon_{i,t+h} \qquad \text{for } h \geq 0, \tag{8}$$

Figure 3: Trade Costs and Inflation in the Data


(a) Trade costs in consumption and inflation

(b) Trade costs in intermediates and inflation

Note: trade cost data comes from WIOD database, inflation data comes from the WDI database.

where $y_{i,t+h}$ is the dependent variable of interest for country i in period $t+h$: for instance, we begin our analysis considering the domestic sourcing share ($s_{i,t}$) and the CPI inflation rate ($\pi_{i,t}$); thus we have $y_{i,t} = \{s_{i,t}, \pi_{i,t}\}$. To isolate the effect of trade costs, $\tau_{i,t}$ on the variables of interest, we control for unobserved sources of variation that are time-invariant but specific to each country. We capture these factors through the country-fixed effect term α_i. We also include the time-fixed effect γ_t to control for time-varying factors that influence all countries equally.

The coefficient of interest in Equation 8 is β_h^y, which captures the average effect of trade costs h periods ahead. We use the vector, $Z_{i,t}$, to control for other observable characteristics of country i. In our baseline specification the vector $Z_{i,t}$ includes the first lag of the dependent variable, the first lag of the unemployment rate, and the first lag of GDP growth and the first lag of the level of GDP. Finally, to account for outliers related to macroeconomic events, such as currency or banking crisis that may lead to inflation surges, but are unrelated to changes in trade costs, we include country-year dummy observations related to inflationary episodes from the Global Crises Data database.[11]

Given our interpretation of the HR indices as trade costs relative to the final sale price, the coefficient β_h^y measures the effect of a 1 percentage point increase in trade costs. We scale the response coefficients such that total import costs, of final and intermediate goods increase by 10 percentage points, taking into account that trade in intermediate goods accounts for more than half of global trade.

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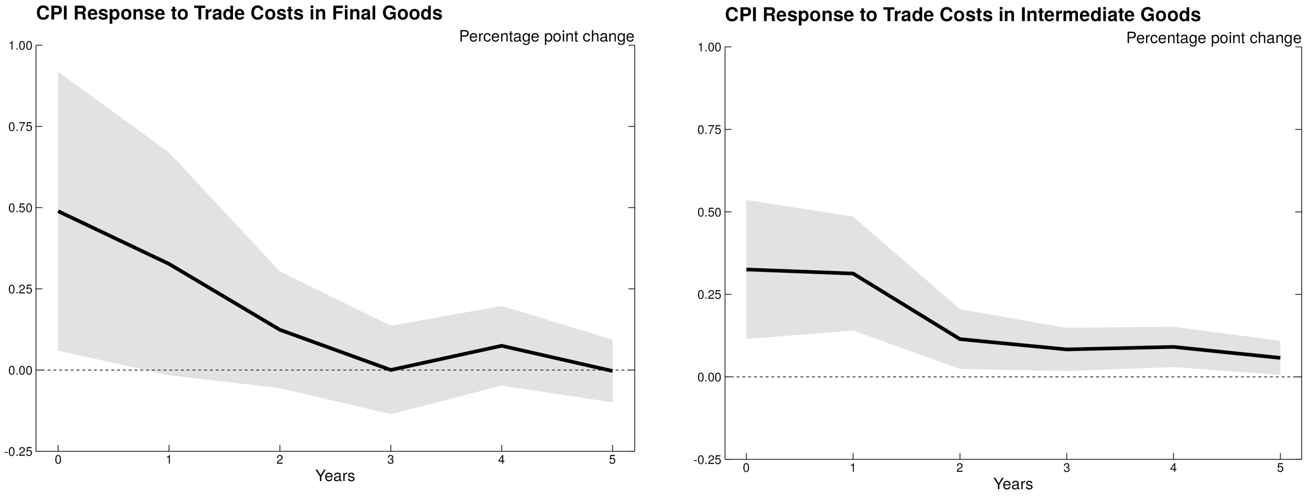
[11] See https://www.hbs.edu/behavioral-finance-and-financial-stability/data/Pages/global.aspx

3.2 Inflationary Effects

Now we turn to analyze the dynamic response of domestic sourcing shares and inflation to trade costs using our local projection estimates of Equation 8. We compute β_h^y for horizons $h = 1, \ldots, 5$ to capture the effects up to 5 years after the shock. Figure 4 shows our main results. The left panels show the response of CPI inflation to an increase in trade costs for final consumption goods. The right panel show the response of CPI inflation to an increase in trade costs for intermediate inputs. The black line corresponds to the average response in the panel. The shaded areas correspond to the 70% confidence interval.

We find that an increase in trade costs leads to a statistically significant rise of CPI inflation. According to our estimates, a 10 percentage point increase in a country's trade costs of intermediate goods from all its trading partners leads to a 0.3 percentage point increase in CPI inflation within the first year. An equally sized increase in trade costs in final goods leads to a 0.5 percentage point increase in CPI inflation. The persistence of the effects differs depending on the shock. Higher costs of final goods trade—say, due to tariffs imposed on goods like washing machines—lead to a larger but more short-lived effect on CPI inflation. Higher costs of intermediate goods trade—say, as a result of a shortage in semiconductors or of tariffs imposed on imported Chinese battery cells or boat motors—have somewhat more persistent effects on CPI inflation. Thus, taken together, a combination of an increase in trade costs for intermediate and final goods leads to a 0.8 percentage point increase in inflation that takes several years to peter out.

Figure 4: Response of Inflation to a 10% Increase in Trade Costs



Note: Note: The figure shows the consumer price index (CPI) response to a 10 percentage point increase in trade costs. Solid lines show the, average response across countries. Shaded areas show the 70 percent confidence intervals.

4 Model

We now explore the dynamic effects of shifts in trade costs inflation dynamics using a structural dynamic model. We build a multi-country New Keynesian model with trade in final consumption and intermediate inputs and with nominal price and wage rigidities. Our New Keynesian block is similar to canonical open economy models (see Corsetti et al. (2010) for a review). For our trade block, the central piece is the gravity equation as discussed in section 2.1.1.

We assume that each of the N countries has population ξ_i, for $i = 1, ..., N$, and we normalize world population to unity. We take country 1 to be the United States. In addition to trading goods, countries also engage in trade in financial assets. We assume an incomplete international financial markets setting in which countries can only trade internationally a risk-free international bond denominated in (real) dollars (country 1's currency). Aside from the fact that country 1's currency is the one used in international financial markets, countries are otherwise symmetric, and so we describe below the structure of a generic country i.

4.1 Households

The objective function of household ℓ in country i is

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{(C_{i,t} - hC_{i,t-1})^{1-\sigma} - 1}{1-\sigma} - \frac{{L^{\ell}_{i,t}}^{1+\varphi}}{1+\varphi} \right], \tag{9}$$

where $C_{i,t}$ is as in (1) for $Q = C$. As a reminder, $C_{i,t}$ is a CES aggregate of $C_{ih,t}$—country i household's consumption of the good produced in country h—across source countries $h = 1, \ldots, N$. In (9), $L^{\ell}_{i,t}$ denotes labor hours by household ℓ in country i, where heterogeneity in labor and wages across households is introduced to motivate nominal wage rigidity as in Erceg et al. (2000) (EHL henceforth).[12] Household ℓ in country i seeks to maximize (9) subject to

$$\sum_{h=1}^{N} \tau^{C}_{ih,t} P_{ih,t} C_{ih,t} + B_{ii,t} + B_{i1,t} \frac{1}{\mathcal{E}_{i1,t}} \leq W^{\ell}_{i,t} L^{\ell}_{i,t} + R_{i,t-1} B_{ii,t-1} + R_{1,t-1} \Psi_{i,t-1} B_{i1,t-1} \frac{1}{\mathcal{E}_{i1,t}} + T_{i,t} \tag{10}$$

for all t, where $B_{ii,t}$ denotes holdings of domestically-traded bonds for country i, $B_{i1,t}$ denotes holdings of country 1's bond, and $\mathcal{E}_{i1,t}$ denotes country i's nominal exchange rate against country 1 (expressed as units of country 1 currency per unit of country i's currency), with $\mathcal{E}_{11,t} = 1$. The variables $\tau^{C}_{ih,t}$ denote the trade costs associated to shipping goods across borders, and $T_{i,t}$ are transfers to households in country i.

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[12] As is standard in this class of models, complete financial markets within country i ensure that all households ℓ consume the same amount, so we omit the ℓ index in $C_{i,t}$.

We allow for *risk premia* to vary across countries such that $\Psi_{1,t-1} \geq 1$ with $\Psi_{1,t} = 1$. More specifically, we assume that

$$\Psi_{i,t} \equiv (1 - \psi \frac{b_{i1,t}}{\mathcal{Q}_{i1,t} Y_{i,t}}) \varepsilon^{\psi}_{i,t} \tag{11}$$

$$= (1 - \psi \frac{\frac{B_{i1,t}}{P^C_{1,t}}}{\frac{\mathcal{E}_{i1,t} P^C_{i,t}}{P^C_{1,t}} Y_{i,t}}) \varepsilon^{\psi}_{i,t} \tag{12}$$

for $i \neq 1$, where $b_{i1,t} \equiv \frac{B_{i1,t}}{P^C_{1,t}}$ denotes and $\varepsilon^{j}_{\psi,t}$ is an exogenous shock following a first-order autoregressive process.

We assume that these costs are comprised of exogenous iceberg trade costs, $d^C_{ih,t} \geq 1$ and exogenous add-valorem tariffs, $\kappa^C_{ih,t} \geq 0$ such that total trade costs are given by $\tau^C_{ih,t} = d^C_{ih,t}(1 + \kappa^C_{ih,t})$.

The first-order conditions determining consumption goods' demand are

$$C_{ih,t} = \omega^C_{ih} \left(\tau^C_{ih,t} p_{ih,t}\right)^{-\eta_C} C_{it} \tag{13}$$

for $h = 1, ...N$, where $p_{ih,t} \equiv \frac{P_{ih,t}}{P_{it}}$ denotes the real price of good h in terms of the price of country i's consumption basket, with P_{it} denoting the standard CES price index. Re-writing the latter, these real prices must satisfy

$$1 = \left[\sum_{h=1}^{N} \omega^C_{ih} (\tau_{ih,t} p_{ih,t})^{1-\eta_C} \right]^{\frac{1}{1-\eta_C}} \tag{14}$$

The consumption Euler equation is

$$U_{c,i,t} = R_{i,t} \mathbb{E}_t \beta \left(\frac{U_{c,i,t+1}}{\pi_{i,t+1}} \right), \tag{15}$$

where

$$U_{c,i,t} \equiv (C_{i,t} - C_{i,t-1})^{-\sigma} \tag{16}$$

and

$$\pi_{i,t} \equiv \frac{P_{i,t}}{P_{i,t-1}}. \tag{17}$$

For countries other than $i = 1$, the household's first-order conditions also include an "uncovered interest parity" condition:

$$R_{i,t}\mathbb{E}_t\left[\frac{1}{\pi_{i,t+1}}\Big(\frac{U_{c,i,t+1}/U_{c,i,t}}{\pi_{i,t+1}}\Big)\right] = R_{1,t}\Psi_{i,t}\mathbb{E}_t\left[\frac{1}{\pi_{i,t+1}}\Big(\frac{U_{c,i,t+1}/U_{c,i,t}}{\pi_{i,t+1}}\Big)\frac{\mathcal{Q}_{1i,t}}{\mathcal{Q}_{1i,t+1}}\right] \tag{18}$$

for $i = 2, ..., N$, expressed here in real terms, with the $\mathcal{Q}_{1i,t}$ denoting the real bilateral exchange rate between country i and country 1:

$$\mathcal{Q}_{1i,t} \equiv \frac{\mathcal{E}_{1i,t}P_{it}}{P_{1t}}. \tag{19}$$

4.2 Wage setting

We model wage rigidity as in EHL. A labor union in each country aggregates individual labor varieties:

$$L_{i,t} = \left(\int_0^1 L_{i,t}^{\ell}{}^{\frac{\epsilon_w-1}{\epsilon_w}} d\ell\right)^{\frac{\epsilon_w}{\epsilon_w-1}}, \tag{20}$$

where $L_{i,t}$ is the (homogeneous) aggregate labor input supplied to final producers. The resulting demand for labor variety ℓ is

$$L_{i,t}^{\ell} = \left(\frac{W_{i,t}^{\ell}}{W_{i,t}}\right)^{-\epsilon_w} L_{i,t}, \tag{21}$$

where

$$W_{i,t} = \left(\int_0^1 W_{i,t}^{\ell}{}^{1-\epsilon_w} d\ell\right)^{\frac{1}{1-\epsilon_w}} \tag{22}$$

Household ℓ can reset the nominal wage $W_{i,t}^{\ell}$ only with probability $1-\theta_w$, and with probability θ_w must set the previous-period nominal wage W_{it-1}^{ℓ}. The optimal reset nominal wage $\overline{W}_{i,t}$ is chosen to maximize

$$\mathbb{E}_t \sum_{k=0}^{\infty} \beta^k \theta_w^k \left(U_{c,i,t+k}\frac{\overline{W}_{i,t}}{P_{i,t+k}}L_{i,t+k|t} - \frac{L_{i,t+k|t}^{1+\varphi}}{1+\varphi}\right) \tag{23}$$

where

$$L_{i,t+k|t} = \left(\frac{\overline{W}_{i,t}}{W_{i,t+k}}\right)^{-\epsilon_w} L_{i,t+k} \tag{24}$$

denotes labor demand in period $t+k$ for a wage setter that last rest its wage in period t.

The resulting optimality condition is

$$\mathbb{E}_t \sum_{k=0}^{\infty} \beta^k \theta_w^k L_{i,t+k|t} U_{i,c,t+k} \left(\frac{\overline{W}_{i,t}}{P_{i,t+k}} - \frac{\epsilon_w}{\epsilon_w - 1} \frac{L_{i,t+k|t}^{\varphi}}{U_{i,c,t+k}} \right) = 0. \tag{25}$$

Since measure θ_w of firms keep their price unchanged and $1-\theta$ reset it optimally, W_t^j satisfies

$$W_{i,t}^{1-\epsilon_w} = \theta_w (W_{i,t-1})^{1-\epsilon_w} + (1-\theta_w)(\overline{W}_{i,t})^{1-\epsilon_w} \tag{26}$$

4.3 Firms

There is a continuum of measure 1 of differentiated retail firms within each country i. $Y_{i,t}^v$ denotes the quantity produced of variety v. These varieties are aggregated by competitive "final good producers" which produce homogeneous output of country $i's$ variety $Y_{i,t}$ by means of the production function

$$Y_{i,t} = \left(\int_0^1 {Y_{i,t}^v}^{\frac{\epsilon-1}{\epsilon}} dv \right)^{\frac{\epsilon}{\epsilon-1}} \tag{27}$$

This homogeneous output is then either consumed domestically (as either consumption good or input) or exported. The first-order condition for final good producers (associated with maximizing profit subject to (27)) is

$$Y_{i,t}^v = \left(\frac{P_{i,t}^v}{P_{ii,t}} \right)^{-\epsilon} Y_{i,t} \tag{28}$$

where

$$P_{ii,t} = \left[\int_0^1 {P_{i,t}^v}^{1-\epsilon} dv \right]^{\frac{1}{1-\epsilon}}, \tag{29}$$

with $P_{i,t}^v$ denoting the country-i-currency nominal price charged by firm v in country i, and $P_{ii,t}$ the country-i-currency price of the country-i homogeneous output.

4.3.1 Price setting

We assume producer currency pricing (PCP): home firms sets prices in dollars and let their prices in the foreign currencies adjust with the exchange rate. Let nominal marginal cost be $MC_{i,t}$ and let $\overline{P}_{ii,t}$ be country i firms' reset price, in country i currency. This price is set to maximize

$$\mathbb{E}_t \sum_{k=0}^{\infty} \frac{U_{i,c,t}}{P_{i,t+k}} \beta^k \theta^k \left(\overline{P}_{ii,t} - MC_{i,t+k} \right) \left(\frac{\overline{P}_{ii,t}}{P_{ii,t+k}} \right)^{-\epsilon} Y_{t+k}^j \tag{30}$$

FOC:

$$\mathbb{E}_t \sum_{k=0}^{\infty} \frac{U_{i,c,t}}{P_{i,t+j}} \beta^k \theta^k P_{ii,t+k}^{\epsilon} Y_{i,t+k} \left[\overline{P}_{ii,t} - \frac{\epsilon}{\epsilon-1} MC_{i,t+k} \right] = 0. \tag{31}$$

Since measure θ of firms keep their price unchanged and $1-\theta$ reset it optimally, $P_{ii,t}$ satisfies

$$P_{ii,t}^{1-\epsilon} = \theta P_{ii,t-1}^{1-\epsilon} + (1-\theta) \overline{P}_{ii,t}^{1-\epsilon} \tag{32}$$

Given PCP, the price of country $i's$ imports from any country h is given by price country h producers set domestically, adjusted for the exchange rate between the two countries. Accordingly,

$$P_{ih,t} = P_{hh,t} \mathcal{E}_{ih,t} \tag{33}$$

4.3.2 Cost minimization

The production function is[13]

$$Y_{i,t} = A_{i,t} \left[(1-\nu)^{\frac{1}{\varepsilon_y}} L_{i,t}^{\frac{\varepsilon_y - 1}{\varepsilon_y}} + \nu^{\frac{1}{\varepsilon_y}} M_{i,t}^{\frac{\varepsilon_y - 1}{\varepsilon_y}} \right]^{\frac{\varepsilon_y}{\varepsilon_y - 1}}, \tag{34}$$

where $A_{i,t}$ is exogenous productivity, $L_{i,t}$ is labor input, and $M_{i,t}$ is intermediates input. The latter is itself a CES aggregate of intermediates sourced domestically and from abroad:

$$M_{i,t} = \left[\sum_{h=1}^{N} {\omega_{ih}^{M}}^{\frac{1}{\eta_M}} {M_{ih,t}}^{1-\frac{1}{\eta_M}} \right]^{\frac{\eta_M}{\eta_M - 1}} \tag{35}$$

where $\sum_{h=1}^{N} \omega_{m,h}^{j} = 1$.

Imported inputs choice. The choice of usage of intermediate inputs $M_{ih,t}$ consists of minimizing

$$\sum_{h=1}^{N} \tau_{ih,t}^{M} P_{M,ih,t} M_{h,t}^{j} \tag{36}$$

subject to a (35) for a given M_t^j. The variables $\tau_{ih,t}^{M}$ are exogenous iceberg trade costs affecting trade in intermediates, which follow first-order autoregressive processes, with $\tau_{jj} = 1$.

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[13] We will restrict attention to a first-order approximation of the model, so we ignore second-order price dispersion terms and in this section treat the aggregate production function as being analogous to the individual-producer production function (the difference between the two arises from price dispersion and is therefore of second order).

The corresponding first-order conditions are

$$M_{ih,t} = \omega_{ih}^{M} \left(\frac{\tau_{ih,t}^{M} P_{M,ih,t}}{P_{M,i,t}} \right)^{-\eta_M} M_{it}, \tag{37}$$

with

$$P_{M,i,t} = \left[\sum_{h=1}^{N} \omega_{ih}^{M} (\tau_{ih,t}^{M} P_{M,ih,t})^{1-\eta_M} \right]^{\frac{1}{1-\eta_M}} . \tag{38}$$

Labor and intermediates choice. The choice of $L_{i,t}$ and $M_{i,t}$ consists of minimizing

$$W_{i,t} L_{i,t} + P_{M,i,t} M_{i,t} \tag{39}$$

subject to (34). The first-order conditions give one expression for nominal marginal cost MC_{it} and another linking the ratio of inputs to the ratio of input prices. Marginal cost:

$$MC_{it} = \frac{1}{A_{it}} \left[(1-\nu) {W_{i,t}}^{1-\varepsilon_y} + \nu {P_{M,i,t}}^{1-\varepsilon_y} \right]^{\frac{1}{1-\varepsilon_y}} . \tag{40}$$

Inputs ratio:

$$\frac{W_{i,t}}{P_{M,i,t}} = \left(\frac{1-\nu}{\nu} \right)^{\frac{1}{\varepsilon_y}} \left(\frac{L_{i,t}}{M_{i,t}} \right)^{-\frac{1}{\varepsilon_y}} . \tag{41}$$

4.4 Monetary policy

The central bank follows in each country follows a conventional inertial Taylor rule:

$$R_{i,t} = (R_{i,t-1})^{\phi_r} \left(\frac{1}{\beta} (\pi_{i,t})^{\phi_\pi} \left(\frac{Y_{i,t}}{Y_{i,0}} \right)^{\phi_y} \varepsilon_{r,i,t} \right)^{1-\phi_r} . \tag{42}$$

4.5 Market clearing and balance of payments

Goods with origin in country h are either consumed domestically, used as inputs for domestic firms, or exported, leading to the market clearing conditions

$$\xi^h Y_{h,t} = \sum_{i=1}^{N} \xi^i (C_{ih,t} + M_{ih,t}) \tag{43}$$

for $h = 1, ...N$, where the population terms ξ^j reflect the fact that all variables are expressed in per-capita terms.

For countries other than $i = 1$, by aggregating domestic budget constraints a balance of payments equation can be derived determining the evolution of these countries' holdings of the dollar-denominated international bond:

$$C_{i,t} + \frac{1}{\mathcal{Q}_{1i,t}} b_{i1,t} = \frac{1}{\mathcal{Q}_{1i,t}} \frac{R_{1t-1}\Psi_{it-1}}{\pi_{1,t}} b_{i1,t-1} + p_{ii,t} Y_{it} - p_{m,i,t} M_{i,t} \tag{44}$$

for $i = 2, .., N$.

5 Calibration

For the numerical experiments in the following section, we set $N = 5$ and calibrate regions 1, 2, 3, 4, and 5 to correspond to the United States, China, the advanced non-U.S. economies, the Asian emerging market economies, and the rest of emerging market economies, respectively. Table 1 lists the corresponding parameter values. The preference and technology parameters are standard, and similar to those in Comin and Johnson (2020). The population parameters ξ^j are set to replicate the weights of the five regions in world GDP. Because we assume trade is balanced in steady state, we can only calibrate half of the openness parameters for final consumption goods (ω^C) and for intermediate inputs (ω^M), with the rest determined by the restriction that trade must be balanced in steady state. Accordingly, we set four of these parameters for the U.S., three for China, and so on, and let the rest be determined by balanced trade in steady state. We set these parameters based on values we obtain from world input-output tables, shown in the bottom of table 1.

6 Model Experiments

We next perform a series of experiments aimed at illustrating the model's predictions on the effects of disruptions in trade. We first examine the effects of an increase in trade costs in the model, mimicking the empirical results described earlier. We next discuss the role of key model parameters. Finally, we consider the effects of an increase in bilateral trade costs between the U.S. and China.

6.1 Effects of increases in trade costs

Focusing on the United States (country 1 in our model), we begin by assuming a 10 percentage point increase in trade costs against all trading partners, mimicking the experiment in the empirical analysis

Table 1: Calibrated Parameters

Parameter	Description	Value
β	Discount factor	0.99
σ	Inverse IES	0.5
h	Habit	0.75
η	Trade substitution elasticity consumption	3
φ	Inverse labor supply elasticity	2
ϵ	Home varieties' substitution elasticity	6
ϵ_w	Labor varieties' substitution elasticity	6
θ	Price rigidity	0.80
θ_w	Wage rigidity	0.80
ι_w	Wage indexation to past inflation	0.05
ν	Intermediates weight in production	0.4
ε_y	Intermediates-labor substitution elasticity	0.5
η_m	Trade substitution elasticity intermediates	3
ϕ_π	Taylor rule inflation coefficient	1.5
ϕ_y	Taylor rule output coefficient	0
ϕ_r	Taylor rule inertia	0.75
ψ	Risk premium elasticity to NFA	0
ρ_τ	Trade cost shock autocorrelation	0.95
$[\xi_1, \xi_2, \xi_3, \xi_4, \xi_5]$	Region populations	[.20,.19,.19,.27,.14]
$[\omega_1^1, \omega_2^1, \omega_3^1, \omega_4^1]$	Consumption trade weights, country 1	[.94,.012,.004,.021]
$[\omega_{m,1}^1, \omega_{m,2}^1, \omega_{m,3}^1, \omega_{m,4}^1]$	Intermediates trade weights, country 1	[.88,.025,.007,.04]
$[\omega_2^2, \omega_3^2, \omega_4^2]$	Consumption trade weights, country 2	[.95,.009,.02]
$[\omega_{m,2}^2, \omega_{m,3}^2, \omega_{m,4}^2]$	Intermediates trade weights, country 2	[.94,.01,.014]
$[\omega_3^3, \omega_4^3]$	Consumption trade weights, country 3	[.94,.014]
$[\omega_{m,3}^3, \omega_{m,4}^3]$	Intermediates trade weights, country 3	[.81,.045]
ω_4^4	Consumption trade weights, country 4	.94
ω_4^4	Intermediates trade weights, country 4	.89

of section 2. Consistent with that empirical analysis, we assume here a commensurate increase in foreign trade costs of importing from the U.S., that is, we set $\tau_{ij}^Q = \tau_{ji}^Q$ for $Q \in \{C, M\}$. As in the data, we perform this experiment separately for trade costs affecting final consumption and intermediate goods.

Figure 5 shows the dynamic effects of the shock when it affects only final consumption goods (blue circled line) and when it affects only intermediates (red solid line). The key observation is that when trade costs increase for consumption goods, inflation rises by about 0.5 percentage points in the first year, very close to our empirical local projections; but that the effects are very short lived, with 4-quarter inflation back near steady state after four quarters. Thus, the effects are close to a one-time increase in the price level that materializes upon impact of the shock. In contrast, when the trade cost shock affects intermediate inputs, inflation initially rises 0.3 percentage points, but the effect is much more persistent—also in line with the empirical estimates.

This more-persistent inflation response reflects that an increase in these costs raises marginal cost for all domestic firms. As such, the effects are akin to an exogenous persistent fall in aggregate total factor productivity: Firms are able to substitute away from more-expensive foreign inputs and into domestic inputs (including labor), but these other inputs are imperfect substitutes. As a consequence, real marginal cost rises—in stark contrast to the consumption goods case, in which marginal cost falls due to lower domestic real wages. A persistent rise in real marginal cost then translates into persistently elevated inflation. GDP falls in both cases, but the decline is much more persistent in the intermediate goods case, reflecting a drag from tighter monetary policy policy (right panel) as well as lower export demand. Imports and exports fall sharply and by roughly the same amount in both cases, though in each case the decline is concentrated in the type of good (final consumption or intermediate) that is affected by the higher trade costs.

6.2 Role of parameters ν and ε_y for the effects of intermediate trade costs

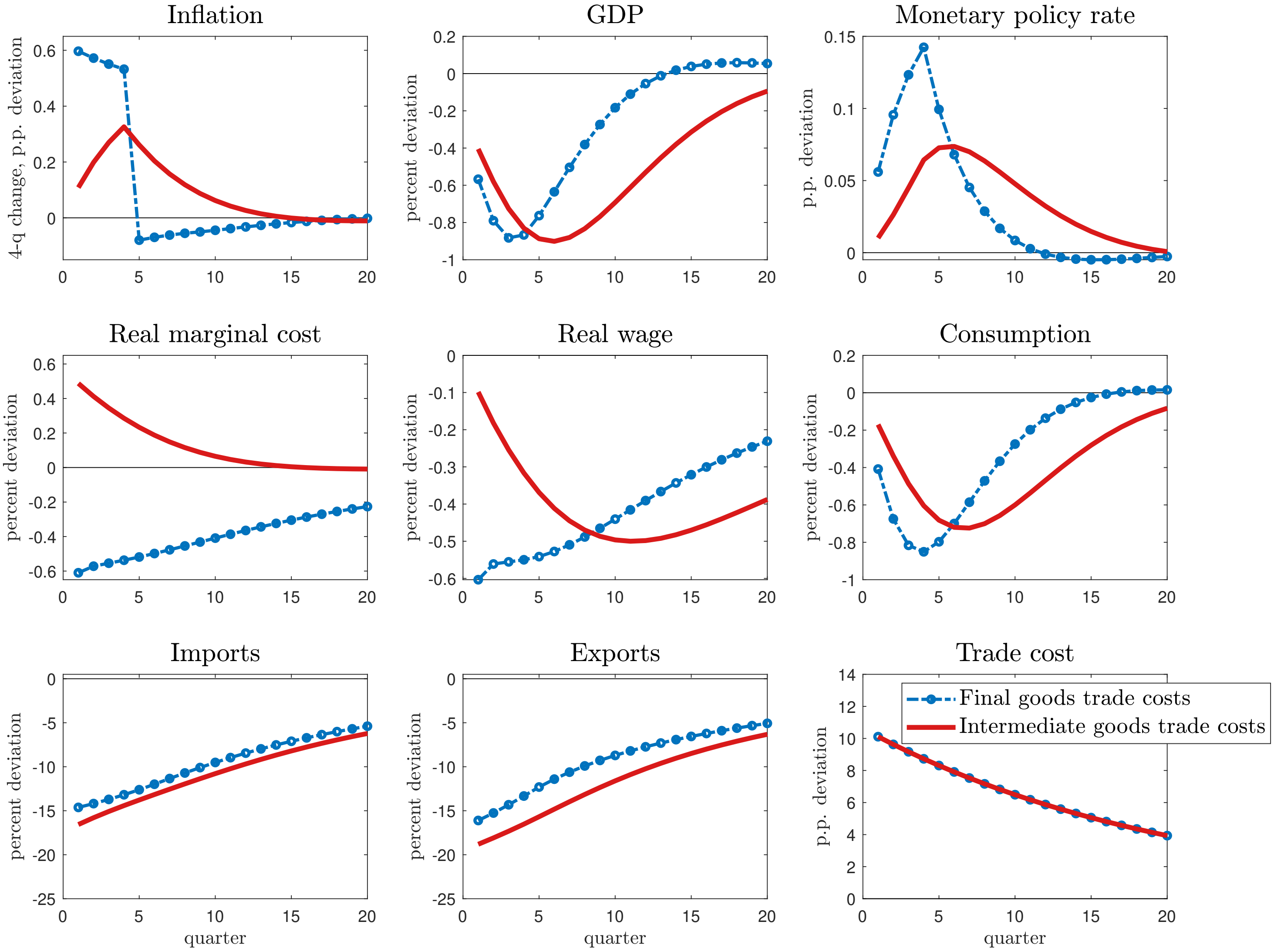
We highlight here two key parameters shaping the effects of an increase in trade costs affecting intermediate goods: The share of intermediates in firms' production function, governed by parameter ν, and the substitution elasticity between intermediate good inputs and labor, given by parameter ε_y.

Figure 6 contrasts the effects in our baseline calibration with $\nu = 0.4$, with the effects assuming a higher (0.5) and lower (0.3) value for this parameter. As made clear by the figure, higher values of ν imply a larger increase in inflation and a bigger decline in GDP. The magnitude of the difference is considerable: The increase in inflation roughly doubles, and the decline in GDP more than doubles, when ν increases from 0.3 to 0.5. Similarly, lower substitution elasticities between intermediates and labor are also associated with amplified GDP and inflation effects, though the range spanned by different values of the elasticity parameter is smaller. Taken together, the results indicate that economies with both higher ν (interpretable as greater prevalence of supply chains) and with lower substitutability between intermediate inputs and labor, would feature worsened monetary policy tradeoffs when hit by disruptions affecting intermediate goods trade.

6.3 U.S.-China trade tensions

We can also use our model to estimate the effects on the U.S. economy of an increase in trade tensions between the U.S. and China such as that observed in 2018-19. Thus, we construct a scenario in which trade costs between the U.S. and China increase for both final and intermediate goods. Specifically,

Figure 5: Effects on the U.S. of an increase in trade costs

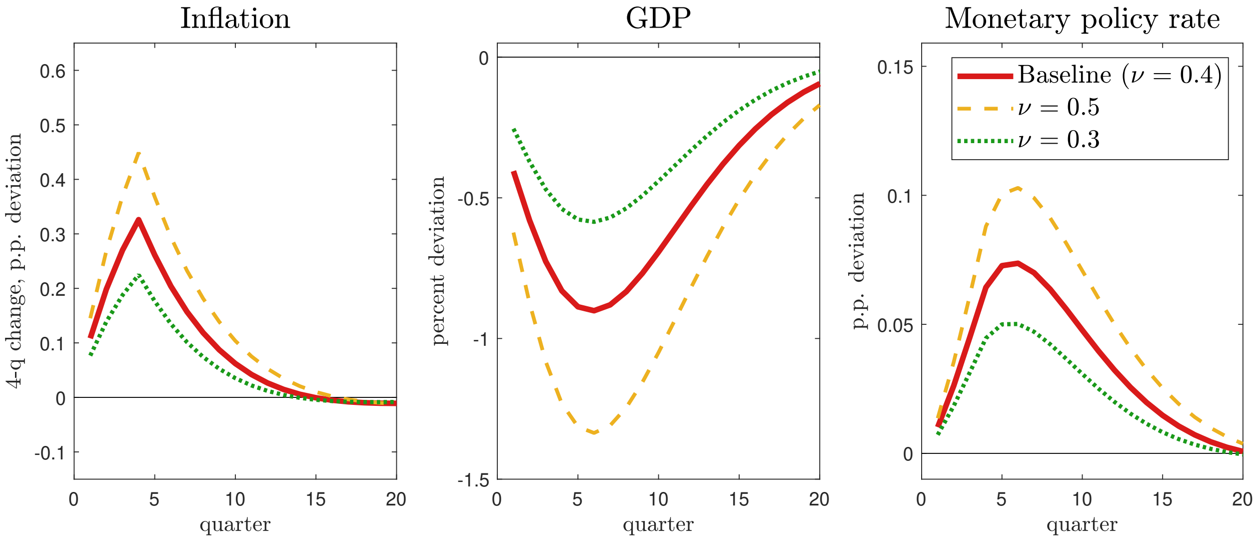


Note: Effects of a 10 percentage point increase in the U.S.'s trade costs from all trading partners on final consumption goods (blue circled line) and on intermediate inputs (red solid line).

we assume that U.S. trade costs for all Chinese imports increase 20 percentage points—capturing the imposition of U.S. tariffs on Chinese imports, to which China partially retaliates by raising tariffs on U.S. goods by 10 percentage points. The scenario is somewhat more severe than the 2018–19 U.S.–China trade war, when the U.S. imposed a tariff rate of a similar magnitude on a narrower set of imported goods. The increase in trade costs is expected to be highly persistent, in line with the persistence in our trade costs measure.

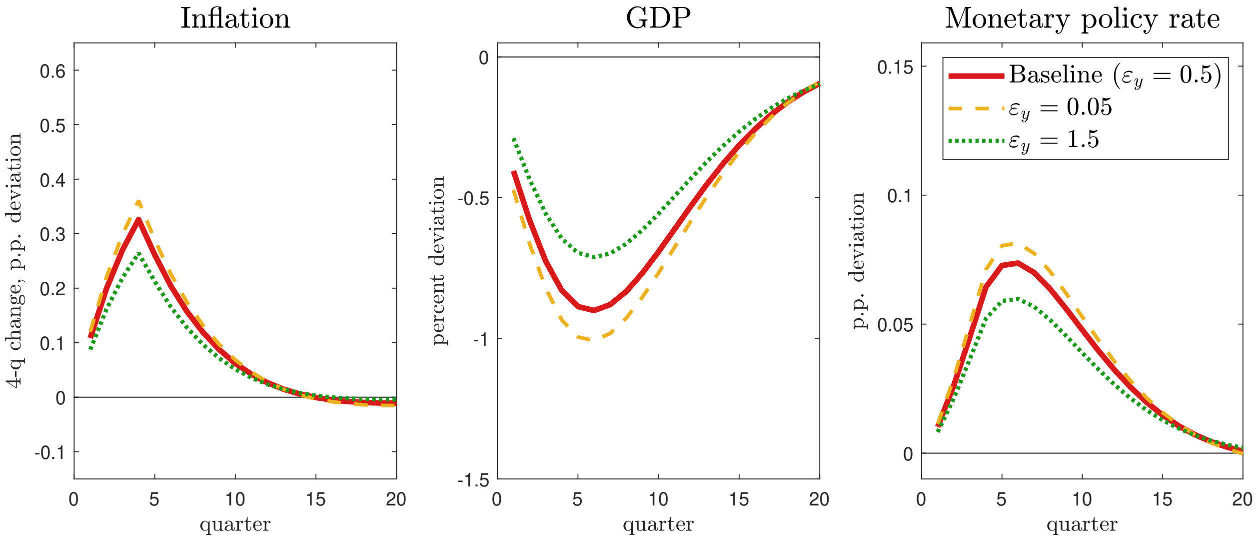
In the scenario, U.S. inflation rises and U.S. GDP growth slows (figure 8). The effect on inflation is significant: The increase in trade costs drives U.S. inflation up by 0.5 percentage point above the baseline and causes it to remain persistently elevated. The contribution of trade costs in final goods (the blue

Figure 6: Effects on the U.S. of an increase in intermediates trade costs, role of ν



Note: Effects of a 10 percentage point increase in the U.S.'s trade costs from all trading partners on intermediate inputs, baseline calibration with weight of intermediates in production $\nu = 0.4$ (red solid), $\nu = 0.5$ (yellow dashed), and $\nu = 0.3$ (green dotted).

Figure 7: Effects on the U.S. of an increase in intermediates trade costs, role of ε_y



Note: Effects of a 10 percentage point increase in the U.S.'s trade costs from all trading partners on intermediate inputs, baseline calibration with intermediates-labor substitution elasticity $\varepsilon_y = 0.5$ (red solid), $\varepsilon_y = 0.05$ (yellow dashed), and $\varepsilon_y = 1.5$ (green dotted).

bars) is short-lived and vanishes after a year. Thus, a hike in trade costs on final goods leads largely to a one-time step-up in the price level, without a persistent increase in the rate of inflation itself.[14]

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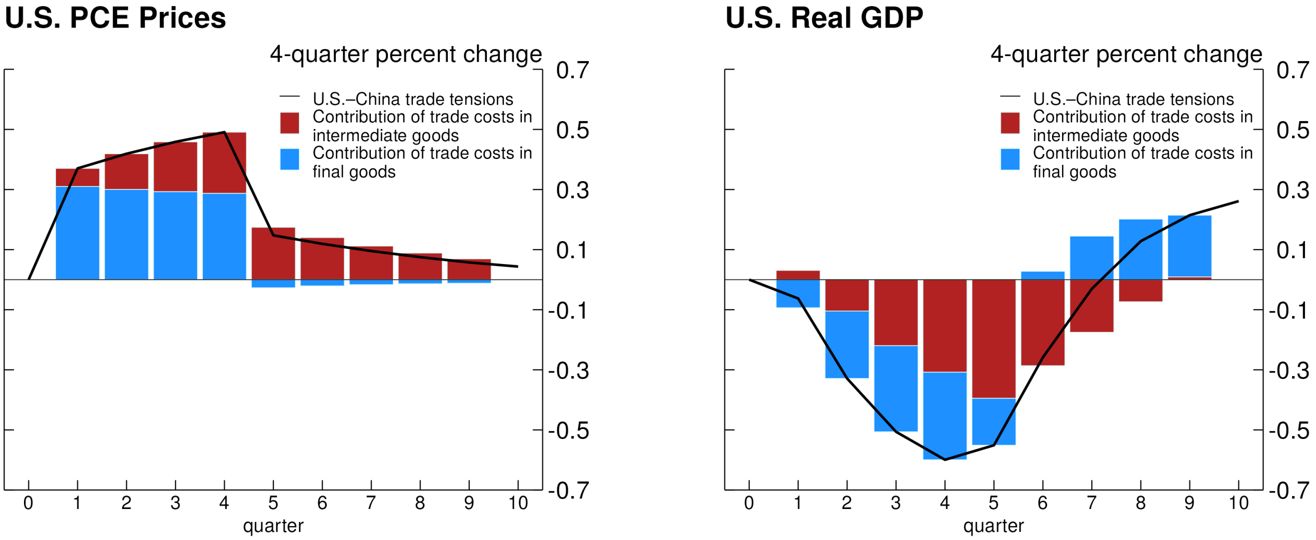
[14] Note that figure 4 shows four-quarter inflation rates. Therefore, a one-time rise in the price level occurring in initial quarter shows through as an increase in four-quarter inflation for four quarters.

Figure 8: Effects of 2018-19 U.S.-China trade tensions



Note: The figure shows the effects of an increase in trade costs between U.S. and China similar to that in 2018-19. The blue solid line shows the implied effect on U.S. inflation (left panel) and U.S. GDP growth (right panel). The blue bars show the contributions of final goods trade costs and the red bars show the contributions of intermediate goods trade costs.

By contrast, the contribution of higher trade costs in intermediates (the red bars) induces a persistently elevated inflation rate. As the costs of importing inputs from China rise, U.S. firms react by making greater use of inputs sourced from other regions, including the U.S. itself. These other inputs, however, are not perfect substitutes for inputs imported from China, leading to lower production efficiency for U.S. firms. As a consequence, U.S. marginal costs increase persistently, translating into higher inflation for longer. The associated higher policy rates contribute to a persistent drag on GDP growth relative to the baseline (right panel).

The effects on China (not shown) are qualitatively similar to those on the U.S., with a somewhat larger hit to GDP growth, reflecting that China's retaliation is only partial. Real GDP growth in the non-China foreign regions experiences a modest bump, as U.S. and Chinese firms and households partly divert trade flows toward imports from these countries.

7 Post-Pandemic Trade Costs

In this section we explore the contribution of trade cost shocks during the most recent surge in inflation in the U.S. during 2021-2022, in the aftermath of the COVID-19 pandemic. This period lends itself as a natural laboratory to explore the role of disruptions to trade flows resulting from several factors, but most prominently those related to supply chain disruptions, bottlenecks and higher shipping costs. We capture all these factors using the iceberg trade costs in our model and run a comparison with other supply and demand forces that were also at play during this period. We focus our analysis in a two-country version of the model presented in Section 6. We associate country one with the United States and country two with a Rest-of-World aggregate.

7.1 Data

For each country-block we associate six standard macroeconomic time series to model counterparts. In particular, we use the following aggregates: real GDP, real consumption, CPI inflation, and the Federal Funds Rate.

[TBC]

7.2 Model Solution and Inference

After calibrating the model, we estimate the remaining parameters using Bayesian methods. We estimate the parameters governing the evolution of six exogenous processes for: technology Z_t, domestic demand Z_t^D, domestic goods markups, Z_t^P, trade costs of imported final consumption, τ_{C_t}, trade costs of intermediate inputs, τ_{M_t}, and monetary policy shocks, Z_t^R. The exogenous variables follow an auto regressive process $x_t = \rho_x x_{t-1} + \sigma_x \epsilon_{x,t}$ for $x = Z, Z^D, Z^P, \tau^C, \tau^M\ Z^R$ and where $\varepsilon_{x,t} \sim N(0,1)$. We make the additional assumption that $\rho_{Z^R} = 0$. The Appendix provides details on prior distributions, observation equations and estimation results.

7.3 Counterfactual Analysis

Using the model we recover a time path for structural shocks, $\varepsilon^x_{1980Q1:2022Q4}$ where $x = Z, Z^D, Z^P, \tau^C, \tau^M\ Z^R$, that replicate the evolution of the series used in estimation. We focus on the evolution of inflation under a counterfactual path in which we set $\varepsilon^{\tau^M}_{2022Q1:2022Q4} = \varepsilon^{\tau^C}_{2022Q1:2022Q4} = 0$.

Figure **??** shows the evolution of CPI inflation in the data, shown as the solid green line, and a counterfactual path of inflation constructed using the model without the realized trade cost shocks in 2022.

We find that absent trade cost shocks, inflation in the U.S. would have been about 2 percentage points lower by the end of 2022. Our trade cost shocks likely capture the cumulative effect of a series of factors such as bottlenecks and supply chain disruptions that unwound since late 2021 and drove the inflation surge in 2022.

8 Conclusions

[TBC]

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A Measuring Trade Costs: The Head-Ries Index

Consider a static environment with multiple countries indexed by i, h. In period t, country i is endowed with $L_{i,t}$ units of labor that can be used to produce a unique good sourced to all other countries, that is, there is National Product Differentiation. The technology available to country i to produce this good is linear and given by

$$Y_{i,t} = Z_{i,t} L_{i,t}, \tag{45}$$

where $Z_{i,t}$ denotes labor productivity. The labor market in each country is perfectly competitive.

Let $q_{ih,t}$ denote the use by country i of goods produced in h at time t. These goods can be either used for final consumption or as intermediate goods in production. We focus on the case in which these goods have a single use. Each country i aggregates goods across sources into a single composite good according to constant elasticity of substitution (CES) aggregator given by

$$Q_{i,t} = \left(\sum_h (q_{ih,t})^{\frac{\eta-1}{\eta}} \right)^{\frac{\eta}{\eta-1}} \tag{46}$$

with $\eta > 1$.

Trade across countries is subject to iceberg-type trade costs given by $\tau_{ih,t} \geq 1$, implying that for one unit of good produced in h to be delivered to i, $\tau_{ih,t}$ units have to be shipped at time t. That is, $\tau_{ih,t} - 1$ units of the good disappear when this is shipped internationally from country h to country i. We normalize domestic trade costs such that $\tau_{ii,t} = 1$ from every i.

Let $p_{ih,t}$ denote the price paid by country i for goods bought from country h. Perfectly competitive good and labor markets imply that

$$p_{ih,t} = \tau_{ih,t} \frac{w_{h,t}}{Z_{h,t}}, \tag{47}$$

where $w_{h,t}$ is the wage in country h. Agents in country i seek to minimize expenditure when choosing $\{q_{ih,t}\}_h$, leading to the following conditional demand functions:

$$q_{ih,t} = \left(\frac{\tau_{ih,t} Z_{h,t}^{-1} w_{h,t}}{P_{i,t}} \right)^{-\eta} Q_{i,t}, \tag{48}$$

where

$$P_{i,t} \equiv \left(\sum_h \left(\tau_{ih,t} \frac{w_{h,t}}{Z_{h,t}} \right)^{1-\eta} \right)^{\frac{1}{1-\eta}} \tag{49}$$

denotes the ideal price index for composite good $Q_{i,t}$.

Let $\lambda_{ih,t}$ denote the share of expenditure by country i on goods produced in country h, $\lambda_{ih,t} \equiv \frac{p_{ih,t}q_{ih,t}}{P_{i,t}Q_{i,t}}$. Equation 48 implies that

$$\lambda_{ih,t} = \left(\frac{\tau_{ih,t} Z_{h,t}^{-1} w_{h,t}}{P_{i,t}} \right)^{-(\eta-1)}, \tag{50}$$

implying that the trade elasticity in this model is given by $\eta - 1$. Note then that

$$\frac{\lambda_{ih,t}}{\lambda_{hh,t}} = \left(\tau_{ih,t} \frac{P_{h,t}}{P_{i,t}} \right)^{-(\eta-1)} \tag{51}$$

and

$$\frac{\lambda_{ih,t}}{\lambda_{hh,t}} \frac{\lambda_{hi,t}}{\lambda_{ii,t}} = \left(\tau_{ih,t} \tau_{hi,t} \right)^{-(\eta-1)}. \tag{52}$$

Hence, if we have data on expenditure shares, we can recover the product of bilateral trade costs for a particular country pair as

$$\tau_{ih,t} \tau_{hi,t} = \left(\frac{\lambda_{ih,t}}{\lambda_{hh,t}} \frac{\lambda_{hi,t}}{\lambda_{ii,t}} \right)^{\eta-1}. \tag{53}$$

B Additional Results

B.1 Trade Costs and the Macroeconomy

Having estimated the impact of trade costs on inflation and the domestic sourcing share, we now turn to the transmission of trade costs to other macroeconomic variables. We amend our regression specification such that, given $y_{i,t}$, we estimate:

$$\log y_{i,t+h} - \log y_{i,t-1} = \alpha_i + \beta_h^j \tau_{i,t} + A_h Z_{i,t} + \varepsilon_{i,t+h} \qquad \text{for } h \geq 0 \tag{54}$$

where $y_{i,t}$ is our chosen real macroeconomic quantity, and $C_{i,t}$ is a vector of controls including lagged unemployment, GDP year-on-year growth, CPI inflation rate, and $y_{i,t-1}$, or a lag of the macroeconomic variable of interest.

Figure 9 plots the response of four macroeconomic aggregates: real GDP, real exports, real imports, and the real exchange rate. The top panels trace out the responses of these four variables to an increase in final trade costs. The bottom panels trace out the responses to intermediate trade costs. We scale the response of all the macroeconomic aggregates to a 1 p.p. increase in the corresponding sourcing share.

[FIGURE 4 AROUND HERE]

Our main result is that higher trade costs that increase the domestic sourcing share by 1 percentage point generate a persistent contraction in economic activity, a decline in real exports, a decline in real imports, and an appreciation of the real exchange rate. The real GDP response is weak on impact, but it progressively increases over time, bottoming out at around -1% after five years. The economic recovery is slow, with the level of real GDP recovering its losses only after 10 years. The response of GDP with respect to final and intermediate trade costs is broadly similar.

Turning to the response of trade variables, an increase in trade costs leads to a contraction in real exports and real imports. The muted short-run response of trade variables is consistent with a low-trade elasticity due to fixed costs in exporting and importing decisions (Alessandria and Choi, 2021). However, real exports decline by about -3% to -4%, while real imports decline slightly less, implying a deterioration of the real trade balance Once again, the effects of higher trade costs on trade flows are persistent, with imports and exports taking nearly a decade to recover. The reduction in trade flows and the increase in the domestic sourcing shares translates into an appreciation of the real exchange rate of about -1.5% to -2.5% by year five. The appreciation induced by higher trade costs reverts slowly.

B.2 Robustness

The Trade Elasticity

To compute our measure of trade costs we made an assumption about the value of the trade elasticity. Despite its central importance, there is a wide range of estimates for the value of η in the literature, with long-run estimates ranging from $\eta \approx 3$ to $\eta \approx 9$, see Boehm et al. (2023). We explore how the trade elasticity affects our main result. We first recompute the Head-Ries indices in Equation 7 using four different values of the trade elasticity $\eta - 1 = \{2, 4, 6, 8\}$. We then re-estimate our local projection in Equation 8 to obtain the impact response of inflation ($h = 0$).

Table 2b shows the results. The top panel presents estimation results of the impact response of inflation to final trade costs. The bottom panels shows the impact responses of inflation to higher trade costs of intermediate inputs. Across all specifications we normalize the estimated response coefficient to obtain a 1 percentage point increase in the domestic sourcing shares.

Table 2: Inflation regressions on different elasticities ($\eta - 1$) of trade cost

(a) Final trade cost, scaled to 1% increase in final sourcing share

	YoY Inflation Rate			
	(1)	(2)	(3)	(4)
	$\eta - 1 = 2$	$\eta - 1 = 4$	$\eta - 1 = 6$	$\eta - 1 = 8$
τ_C	1.2651**	0.9439**	0.8487**	0.8038**
	(0.4426)	(0.3384)	(0.3044)	(0.2883)
Memo				
Implied $\Delta\tau_C$ *(p.p.)*	92.97	9.98	4.31	2.64
R-squared	0.4872	0.4808	0.4769	0.4749
Number of individuals	37	37	37	37
Number of observations	681	681	681	681

(b) Intermediate trade cost, scaled to 1% increase in intermediate sourcing share

	YoY Inflation Rate			
	(1)	(2)	(3)	(4)
	$\eta - 1 = 2$	$\eta - 1 = 4$	$\eta - 1 = 6$	$\eta - 1 = 8$
τ_M	0.8352**	0.7028**	0.6546**	0.6302**
	(0.3589)	(0.3019)	(0.2820)	(0.2720)
Memo				
Implied $\Delta\tau_M$ *(p.p.)*	73.84	9.11	4.07	2.52
R-squared	0.4682	0.4655	0.4636	0.4627
Number of individuals	37	37	37	37
Number of observations	681	681	681	681

$^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$

Note: country fixed effects and year error clustering are included. The magnitudes reflect the increase in Tau that correspond to a 1 p.p. increase in the corresponding domestic sourcing share. Controls not shown includes one lag of the inflation rate, lag of GDP growth, and lag of unemployment.

Our results are consistent across different specifications of the trade elasticity, with inflation increasing between 0.6 and 1.2 percentage points in response to higher trade costs. Note, however, that the trade elasticity matters to determine the size of the shock. In each panel, the memo line shows the associated increase in the Head-Ries index necessary to achieve a 1 percentage point increase in the domestic sourcing shares. We note that the required change in trade costs to induce a 1 percentage point increase in the sourcing share is decreasing in the value of the trade elasticity.

B.3 Sectoral Trade Costs

In our baseline results we investigated the effect of aggregate trade costs on inflation. We now briefly investigate if the inflation response is more sensitive to particular sectors in the economy. We use the granularity of the Input-Output tables to construct sector specific trade costs. In particular we map 16 non-service WIOD sectors for the 2000-2011 period and 23 non-service WIOD sectors for the 2012-2014 period, into four broad categories: (a) agricultural and mining, (b) low-tech manufacturing, (c) mid-tech manufacturing, and (d) high-tech manufacturing. We then run a local projection of the following form:

$$y_{i,t+h} = \alpha_i + \beta^{y}_{h,s}\tau^{j}_{i,s,t} + A_{h,s}Z_{i,t} + \varepsilon_{i,s,t+h} \qquad \text{for } h \geq 0,, \tag{55}$$

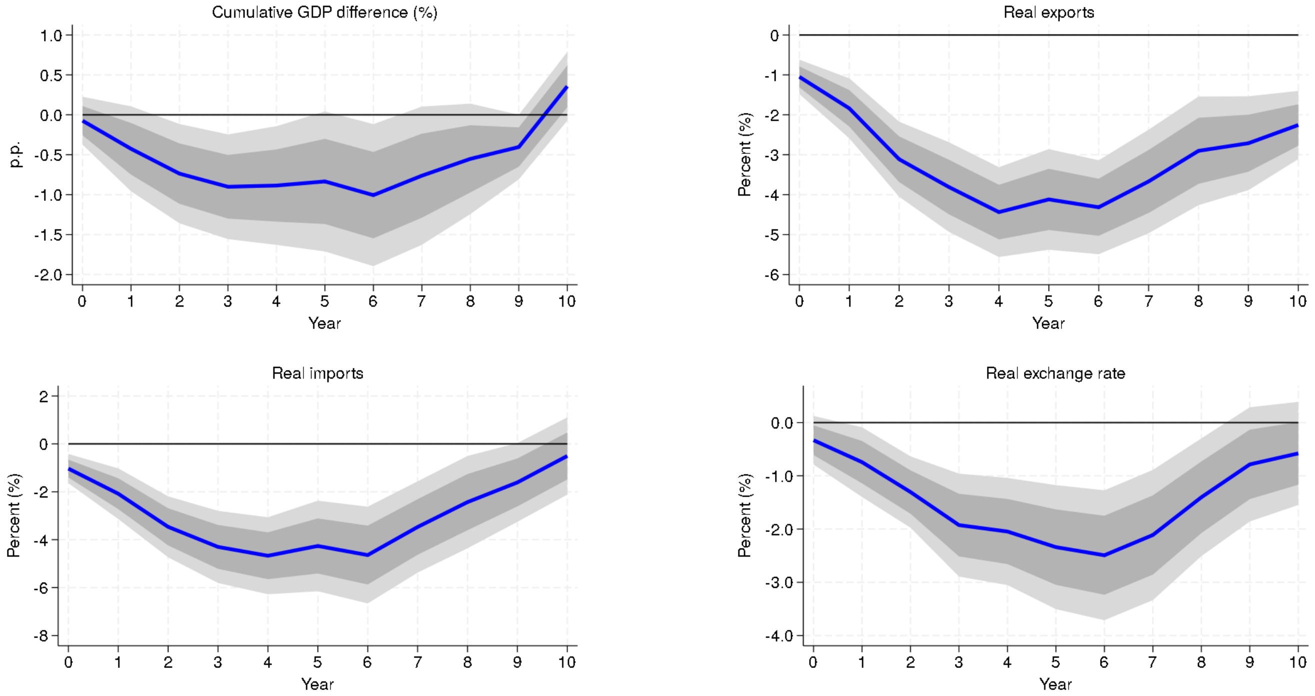
where the coefficient $\beta^{y}_{h,s}$ now traces the response of inflation to an increase in trade costs in sector $s = \{a, b, c, d\}$ for goods of type $j = \{C, M\}$, after h years following the shock. For comparison, we scale the aggregate inflation response such that the sectoral trade costs lead to an increase in sectoral domestic sourcing shares of 1 percentage point.

Figure 10 shows the inflation responses to sectoral trade costs. For illustration, we focus on final trade costs in each sector. The peak inflation response, typically observed one year after the shock, ranges from 0.5 to 3 percentage points. The magnitudes are consistent with the average effects of higher trade costs in the aggregate. Heterogeneity in inflation responses is consistent with the different importance and substitutability of domestic and foreign goods across different sectors. For example, inflation increase modestly in response to higher trade costs in low-tech manufacturing sectors. In contrast, inflation is more sensitive to increases in trade costs in the high-tech manufacturing sector.

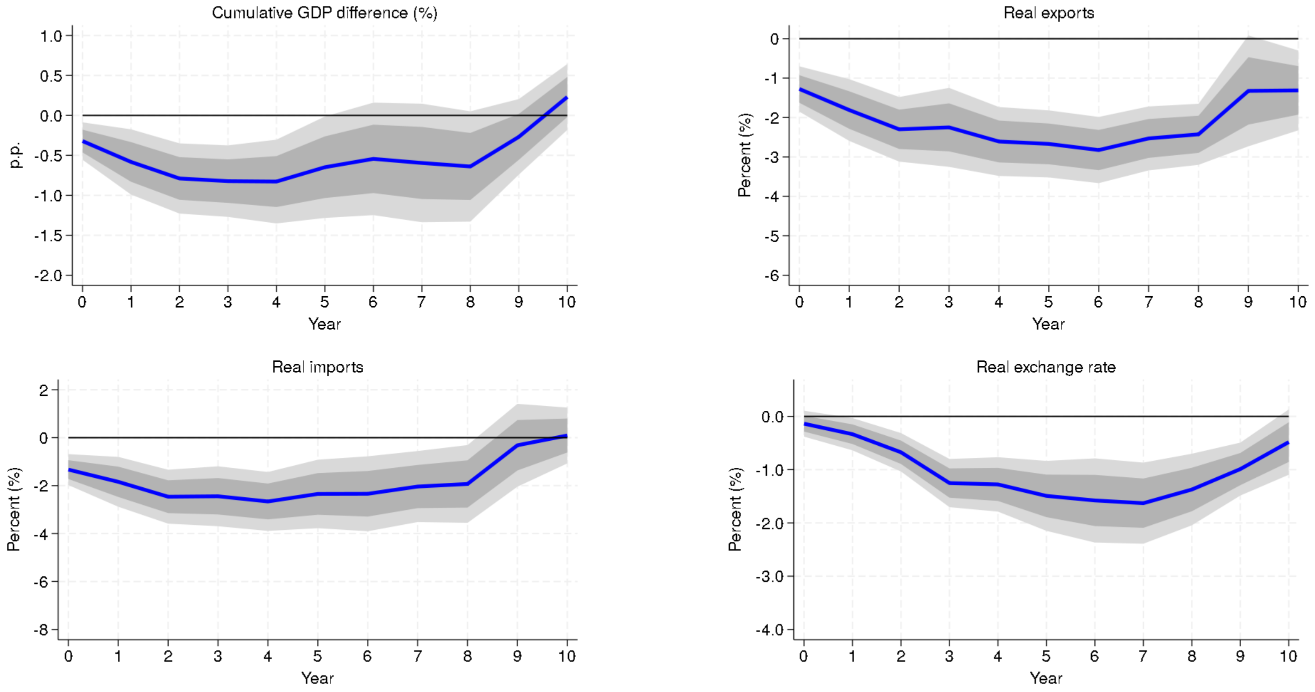
[FIGURE 5 AROUND HERE]

Figure 9: Macroeconomic Response to Higher Trade Costs

Response to Final Trade Costs

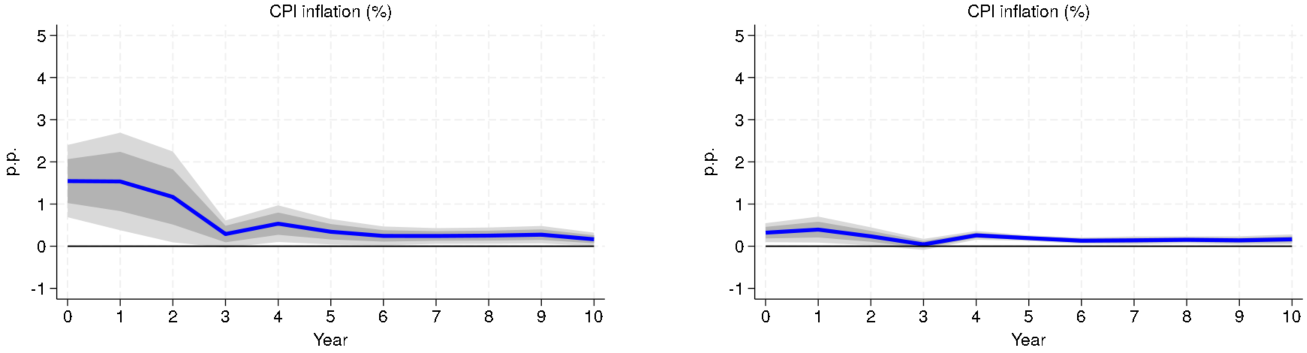


Response to Intermediate Trade Costs



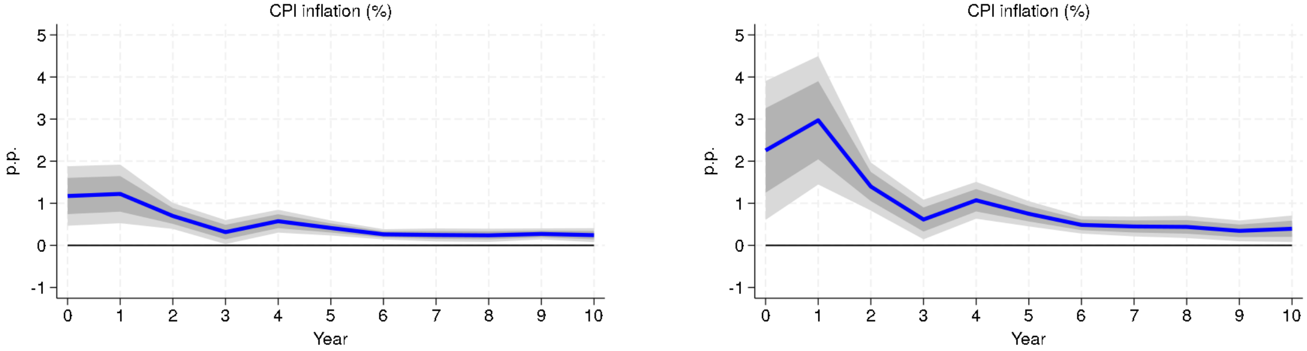
Note: country fixed effects and year error clustering are included. We multiply the trade cost by the same coefficient as in Figure 4 so as to correspond to a 1% increase in the sourcing share. This gives us the same numbers in Year 0 as we computed, namely 4.3% and 4% for final and intermediate trade costs, respectively.

Figure 10: Inflation Response to Sectoral Trade Costs (Final Goods)



(a) Agriculture and mining

(b) Low-tech manufacturing



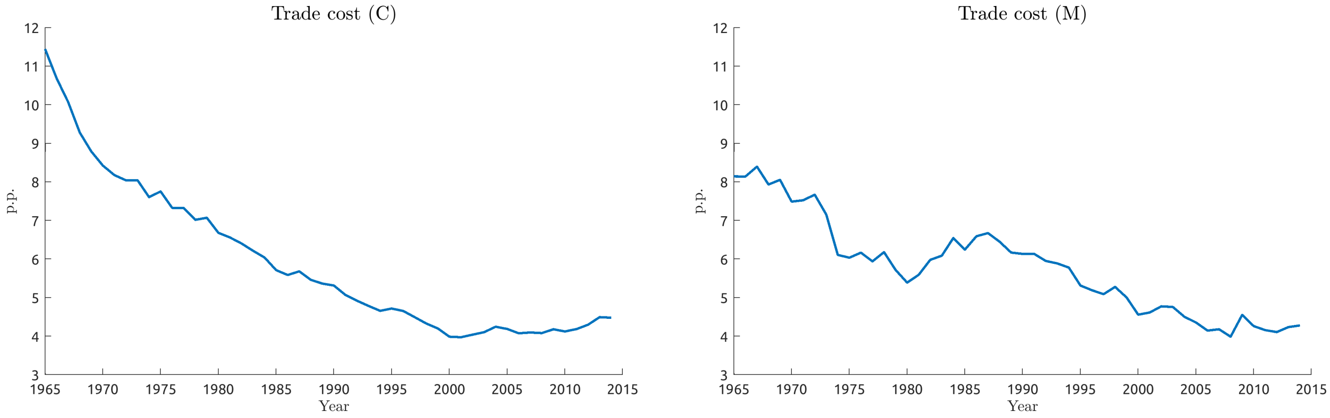
(c) Mid-tech manufacturing

(d) High-tech manufacturing

Note: country fixed effects and year error clustering are included. Controls are one lag of CPI inflation, Unemployment and GDP growth. The size of the trade cost shock is scaled to 1% for all, and the sourcing share is the corresponding sub-sector sourcing share.

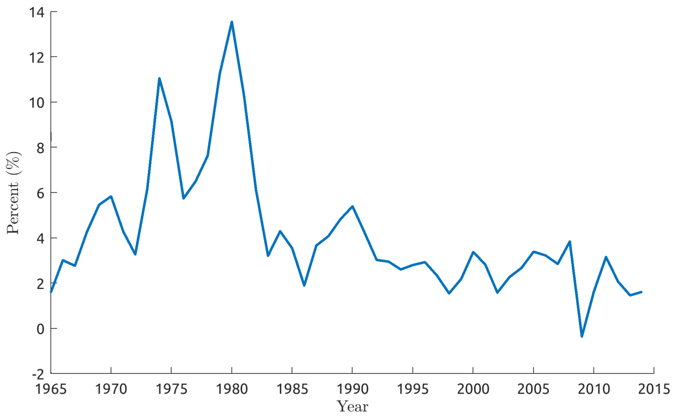
C Evolution of Trade Costs Around the World

Figure 11: **Evolution of United States trade costs**



Note: data comes from WIOD database. The 2011-2014 numbers have been taken from the WIOD 2016 database and stitched to the WIOD 2013 numbers. The 1965-1999 come from the historical WIOD database

Figure 12: **Evolution of United States inflation, 1965-2014**



Note: core PCE inflation from WDI database - World Development Indicators. Washington D.C. : The World Bank. We end our inflation data in 2014 to coincide with the end of the WIOD database in 2014.

D Additional Regression Results

Table 3: Inflation and sourcing share regressions on different elasticities (θ) of trade cost

(a) Final sourcing share and trade cost

	YoY Inflation Rate				Sourcing share			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	$\eta - 1 = 2$	$\eta - 1 = 4$	$\eta - 1 = 6$	$\eta - 1 = 8$	$\eta - 1 = 2$	$\eta - 1 = 4$	$\eta - 1 = 6$	$\eta - 1 = 8$
Tau	0.0138**	0.0946**	0.1967**	0.3050**	0.0109***	0.1002***	0.2318***	0.3795***
	(0.0048)	(0.0339)	(0.0706)	(0.1094)	(0.0022)	(0.0194)	(0.0454)	(0.0748)
CPI rate % (-1)	0.2561***	0.2673***	0.2735***	0.2767***				
	(0.0515)	(0.0545)	(0.0561)	(0.0570)				
Sourcing share (-1)					0.6462***	0.6009***	0.5920***	0.5886***
					(0.0559)	(0.0613)	(0.0628)	(0.0634)
GDP growth % (-1)	0.0118	0.0256	0.0319	0.0352	-0.0366	-0.0235	-0.0218	-0.0215
	(0.0896)	(0.0887)	(0.0883)	(0.0881)	(0.0385)	(0.0380)	(0.0376)	(0.0373)
Unemployment % (-1)	-0.1026	-0.0981	-0.0946	-0.0926	-0.0495	-0.0467	-0.0471	-0.0475
	(0.1027)	(0.0981)	(0.0970)	(0.0965)	(0.0668)	(0.0629)	(0.0615)	(0.0608)
R-squared	0.4872	0.4808	0.4769	0.4749	0.9835	0.9849	0.9853	0.9855
Num. ind.	37	37	37	37	37	37	37	37
Num. obs.	681	681	681	681	681	681	681	681

(b) Intermediate sourcing share and trade cost

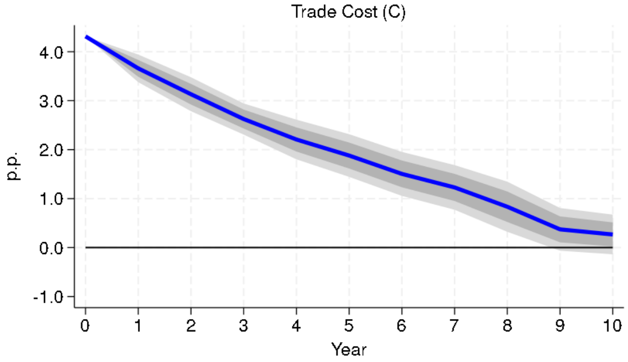
	YoY Inflation Rate				Sourcing share			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	$\eta - 1 = 2$	$\eta - 1 = 4$	$\eta - 1 = 6$	$\eta - 1 = 8$	$\eta - 1 = 2$	$\eta - 1 = 4$	$\eta - 1 = 6$	$\eta - 1 = 8$
Tau	0.0113**	0.0771**	0.1608**	0.2503**	0.0135***	0.1097***	0.2457***	0.3973***
	(0.0049)	(0.0331)	(0.0693)	(0.1081)	(0.0029)	(0.0216)	(0.0470)	(0.0750)
CPI rate % (-1)	0.2868***	0.2906***	0.2934***	0.2948***				
	(0.0595)	(0.0605)	(0.0613)	(0.0618)				
Sourcing share (-1)					0.6314***	0.6059***	0.6007***	0.5981***
					(0.0695)	(0.0699)	(0.0695)	(0.0693)
GDP growth % (-1)	0.1108	0.1172	0.1176	0.1176	0.0064	0.0203	0.0220	0.0226
	(0.0912)	(0.0920)	(0.0920)	(0.0920)	(0.0613)	(0.0575)	(0.0568)	(0.0564)
Unemployment % (-1)	-0.0998	-0.1040	-0.1015	-0.0999	-0.0899	-0.1001	-0.1015	-0.1020
	(0.1060)	(0.1054)	(0.1049)	(0.1046)	(0.1014)	(0.0974)	(0.0963)	(0.0958)
R-squared	0.4682	0.4655	0.4636	0.4627	0.9810	0.9819	0.9821	0.9821
Num. ind.	37	37	37	37	37	37	37	37
Num. obs.	681	681	681	681	681	681	681	681

$^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$

Note: country fixed effects and year error clustering are included. Both sourcing share and CPI inflation tables respond to a 1% increase in trade costs. We compare different theta values for the Head-Ries index, which is $\eta - 1 = 6$ for our analysis.

E Additional Local Projection Responses

Figure 13: **Local projection of trade cost on itself**

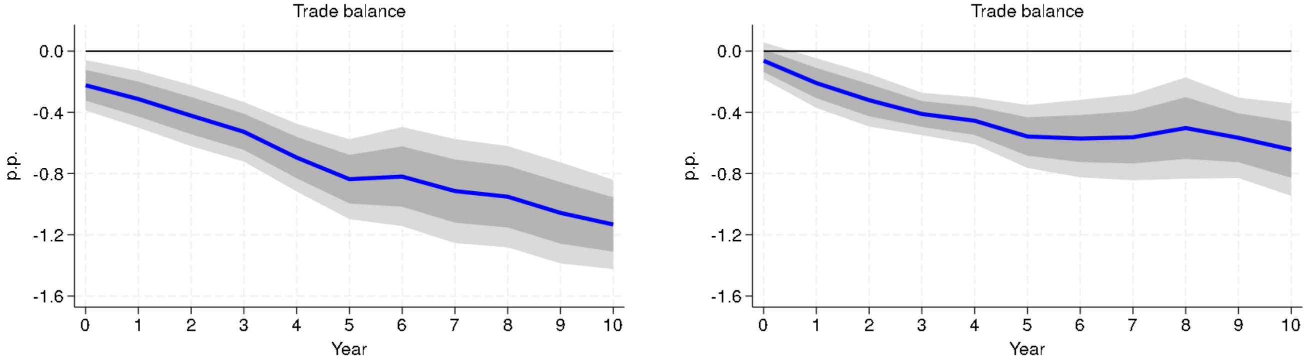


(a) Final trade cost

(b) Intermediate trade cost

Note: country fixed effects and year error clustering are included. We multiply the trade cost by the same coefficient as in Figure 4 so as to correspond to a 1 p.p. increase in the sourcing share.

Figure 14: **Local projection of trade cost on Trade Balance (% GDP)**



(a) Final trade cost

(b) Intermediate trade cost

Note: country fixed effects and year error clustering are included. We multiply the trade cost by the same coefficient as in Figure 4 so as to correspond to a 1 p.p. increase in the sourcing share.

F Post-Pandemic Inflation: Bayesian Estimation

F.1 Data Summary

- Gross Domestic Product (Y): we collect quarterly real GDP from the Bureau of Economic Analysis (BEA). We take the quarter-on-quarter log difference as our final measure.
- Personal consumption Expenditure (C): we collect real consumption from the BEA, taking the quarter-on-quarter log difference.
- PCE Inflation (π^C): we take the personal consumption expenditure price inflation index, which we then transform by taking the quarter-on-quarter log difference.
- Foreign GDP (C^*): we obtain the measure of foreign real GDP from the Dallas FED Globalization and Monetary Policy Institute. We take the quarter-on-quarter log difference.
- Imported foreign final consumption price inflation (π^F): we take the price of imported consumer goods ex auto price inflation to proxy the price index of imported final goods. We take the quarter-on-quarter log difference. Taken from the BEA.
- Real imported foreign intermediate consumption growth (M_F): we collect industrial supplies and materials, as well as petroleum and products, from the BEA in nominal terms. To back out industrial supplies and materials ex-petroleum and products in real terms, we first subtract the nominal series to obtain nominal industrial supplies and materials ex-Petroleum/products, then divide by the deflator of the price series of industrial supplies and materials ex-Petroleum/products. This then gives us the real series, and finally we take the quarter-on-quarter log difference.
- Real imported foreign final consumption growth (C_F): we obtain imported consumer goods ex auto in real terms from the BEA, which we then use to proxy for imported final goods quantity. We then transform to quarter-on-quarter log difference.
- Interest rate (r): we take the Wu-Xia shadow federal funds rate to measure the interest rate, to prevent from being stuck at the ZLB. The data is assembled by the Federal Reserve Bank of Atlanta.

F.2 Observation Equations

$\log(MFY_t)^o = \log(\frac{\bar{M_F}}{\bar{Y}}) + \hat{M}_{F,t} - \hat{Y}_t$

$\log(CFY_t)^o = \log(\frac{\bar{C_F}}{\bar{Y}}) + \hat{C}_{F,t} - \hat{Y}_t$

$\pi_t^o = \bar{\pi}_C + \hat{\pi}_{C,t}$

$\hat{y}_t^o = \hat{y}_t$

$\hat{c}_t^o = \hat{c}_t$

$R_t^o = \log(\bar{r}\bar{\pi}_C) + \hat{R}_t$

F.3 Estimated Parameters

Table 4: Estimated Parameters

	High Sourcing Share		**Low Sourcing Share**	
Shock Persistence	**Mean**	**[5 95]**	**Mean**	**[5 95]**
ρ_{p_F}	0.99	[0.98, 1]	0.98	[0.97, 0.99]
ρ_{C^*}	0.96	[0.93, 1]	0.98	[0.95, 1]
ρ_z	0.77	[0.73, 0.81]	0.83	[0.8, 0.87]
ρ_z^d	0.94	[0.91, 0.97]	0.91	[0.87, 0.95]
ρ_{p_H}	0.89	[0.86, 0.93]	0.95	[0.93, 0.96]
ρ_{τ_c}	0.97	[0.96, 0.99]	0.97	[0.96, 0.98]
ρ_{τ_m}	0.98	[0.96, 1]	0.99	[0.98, 1]
Standard Deviation	**Mean**	**[5 95]**	**Mean**	**[5 95]**
$100 \times \sigma_{p_F}$	1.52	[1.36, 1.68]	1.57	[1.4, 1.72]
$100 \times \sigma_{C^*}$	0.63	[0.56, 0.69]	0.63	[0.56, 0.7]
$100 \times \sigma_z$	1.91	[1.65, 2.14]	4.59	[3.9, 5.26]
$100 \times \sigma_z^d$	2.78	[1.87, 3.62]	2.38	[1.78, 2.95]
$100 \times \sigma_{p_H}$	3.94	[3.19, 4.69]	6.69	[5.43, 7.95]
$100 \times \sigma_{\tau_c}$	1.97	[1.76, 2.18]	1.97	[1.75, 2.17]
$100 \times \sigma_{\tau_m}$	2.92	[2.6, 3.23]	3.02	[2.69, 3.35]
$100 \times \sigma_r$	0.11	[0.1, 0.12]	0.11	[0.1, 0.12]