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 of final goods lead to large but short-lived increases in inflation, while increases in trade costs of intermediate goods generate small but relatively more persistent increases in inflation. 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.We estimate the model and explore the drivers of U.S. inflation in the aftermath of the COVID-19 pandemic and find that trade costs explain about one percentage point of additional inflation in 2022 and contributed to the bulk of inflationary pressures in 2023.

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1 Introduction

The world economy became significantly more integrated over the past half century. In terms of the value of goods and services traded across borders, countries are now markedly more interconnected than fifty years ago. 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] Moreover, emerging economies played a prominent role in this globalization process as they experienced high growth rates and became increasingly open to trade, thus increasing the number of countries actively trading with each other.[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 a densely and tightly interconnected world economy.

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]

[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). A recent exception is Di Giovanni et al. (2022).

[4] Some important exceptions to this dichotomy include the works by Comin and Johnson (2020), Barattieri et al. (2021), and Di Giovanni et al. (2022).

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 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 with key differences in inflation dynamics depending on the type of trade shock considered—either for final or intermediate goods. 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

[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.

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]. Di Giovanni et al. (2022) focus on the case of the effects of COVID-19 on inflation. Our work is most closely related to Barattieri et al. (2021) who identify changes in protectionist measures in the data and study the consequences of changes in these measures on business cycles. We contribute to this literature by focusing on the effects on 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. Our focus on the transmission of trade cost shocks through the intermediate inputs channel is consistent with the evidence in Flaaen and Pierce (2019), who show that that through this channel, the 2018-19 U.S.-China trade war had significant effects on U.S. manufacturing prices and employment.

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.

[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.

2 Trade Costs Across Time and Space

2.1 Measuring Trade Costs: Static Armington Model 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 literature in international trade that estimates trade costs based on the structure of static trade models that deliver gravity equations (Head and Mayer, 2014). Relying on a structural framework rather than just on observable measures of trade costs will also allow us to compare trade costs across countries and over time.

We consider an Armington model of trade determining bilateral trade flows across countries at any given point in time and consistent with static gravity.[7] In section 4, we embed the exact structure of this static model into a dynamic stochastic general equilibrium model that we will use to analyze the mechanisms through which shocks to trade costs affect inflation. The equilibrium of the static bloc of the model delivers predictions for bilateral trade flows for different types of goods conditional on aggregate spending on such goods at a point in time.[8] We rely on the equilibrium conditions of the static bloc of the model to back out bilateral trade costs as functions of observable data.

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 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, $M_{i,t}$. This aggregation is done according to a constant elasticity of substitution (CES) aggregator given by

$$Q_{i,t} = \left(\sum_{h=1}^{N} (Q_{ih,t})^{\frac{\eta_Q - 1}{\eta_Q}} \right)^{\frac{\eta_Q}{\eta_Q - 1}}, \tag{1}$$

where $Q \in \{C, M\}$ and $\eta_Q > 1$. 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, where C and M stand for final consumption and intermediate goods, respectively.

[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.

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 of a good produced in h in terms of country i's currency is $P_{ih,t} \equiv \mathcal{E}_{ih,t} P_{h,t}$.

Trade across countries is subject to iceberg-type trade costs given by $\tau^Q_{ih,t} \geq 1$, implying that for one unit of good of type $Q \in \{C, M\}$ produced in h to be delivered to i, $\tau^Q_{ih,t}$ units have to be shipped at time t. That is, $\tau^Q_{ih,t} - 1$ units of the good disappear when this is shipped internationally from country h to country i.[9] We normalize domestic trade costs such that $\tau^Q_{ii,t} = 1$ for 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 type $Q \in \{C, M\}$ produced in country h is given by

$$P^Q_{ih,t} \equiv \tau^Q_{ih,t} P_{ih,t}. \tag{2}$$

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 delivers conditional demand functions for goods of type $Q \in \{C, M\}$ given by

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

where

$$P^Q_{i,t} \equiv \left(\sum_{h=1}^{N} \left(\tau^Q_{ih,t} P_{ih,t} \right)^{1-\eta_Q} \right)^{\frac{1}{1-\eta_Q}} \tag{4}$$

denotes the ideal price index for composite good Q. Let $\lambda^Q_{ih,t}$ 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

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

where the trade elasticity in this model is given by $\eta_Q - 1$. Note that (5) is a gravity-type equations implying that bilateral trade flows between countries can be expressed in terms of importer i

[9] In section 4, we introduce tariffs that differ from non-tariff barriers into the model.

characteristics, exporter h characteristics, and a measure of bilateral trade frictions inclusive of the bilateral nominal exchange rate, $\tau^{Q}_{ih,t}\mathcal{E}_{ih,t}$, summarizing all frictions that impede trade across any two countries. There exists an extensive literature that estimates bilateral trade costs relying on this type of equations (Head and Mayer, 2014). In what follows, we describe our approach to infer bilateral trade costs relying on (5) and using only data on bilateral trade flows.

Note from (5) that we can use a country's domestic sourcing share, $\lambda_{ii,t}$, to control for the price of the good produced in the exporting country denominated in local currency units. More specifically, given (5) for importer i and exporter h, we can express bilateral trade costs between these countries as a function of their bilateral trade share, the exporter's domestic sourcing share, and prices as follows:

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

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 $\eta_Q > 1$.[10]

Relative prices across countries are difficult to measure and time series for these prices are scarce. These issues imply that it is difficult to have reliable time series data for these prices. However, we can further use the equilibrium conditions of the model to recover a measure of bilateral trade frictions that only depends on data on bilateral trade flows. By switching the roles of the importing and exporting countries in (6) to control for relative price differences, we obtain a measure of trade frictions between individual country pairs given by

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

which defines what the literature refers to as the Head-Ries (HR) index for country pair (i, h) (Head and Ries, 2001; Eaton et al., 2016b). The HR index provides a measure of bilateral trade frictions in our model in period t by considering the geometric mean of bilateral trade cost $\tau^{j}_{ih,t}$ for a pair of countries. Note that $HR_{ii,t} = 1$, which is consistent with the notion that trade with oneself is costless, and that under the assumption of symmetric trade costs, the index becomes the actual bilateral trade cost. While this measure has multiple appealing features, it cannot account

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

for asymmetries in bilateral trade costs. However, for a given importer i, changes in these bilateral measures will reflect changes in import costs against all its trading partners, which we will use in section 2.5 to construct a measure of import costs at the country level.

Before turning to the description of the data that we use to construct HR indices, note that we require each country's "domestic" trade flows or domestic sourcing to construct bilateral trade frictions. This requirement represents an important challenge in terms of data availability. To be more precise, let $X_{ih,t}^{Q} \equiv P_{ih,t}^{Q} Q_{ih,t}$ for $Q \in \{C, M\}$ denote expenditure by country i on goods produced in h of type Q. Then, $X_{i,t}^{Q} \equiv \sum_{h=1}^{N} X_{ih,t}^{Q}$ defines total expenditure by country i on type Q goods, which is such that $X_{i,t}^{Q} = P_{i,t}^{Q} Q_{i,t}$. While data for $X_{ih,t}^{Q}$ for $h \neq i$ is readily available in multiple datasets for bilateral trade flows, data for $X_{ii,t}^{Q}$ is not. However, we can obtain $X_{ii,t}^{Q}$ if we have data for $X_{i,t}^{Q}$ consistent with trade flows. In the following section we describe the datasets that allow us to construct bilateral and domestic trade flows for a large number of countries and going back in time over three decades.

2.2 Data

We use data on world input-output tables. These data allow us (i) to compute international bilateral trade flows, (ii) to compute domestic sourcing flows that are consistent with international trade flows and production data, and (iii) to distinguish these flows between goods used for final uses and goods used as intermediates in production.

We consider multiple data sources for our analysis. Our primary and main data source are the Inter-Country Input-Output tables (ICIO) published by the OECD. The ICIO provides global input-output tables, that is, it maps flows of production and expenditure within countries and flows of international trade between countries, broken down by economic activity and by country, globally. The regular ICIO considers 76 countries and a rest of the world aggregate (ROW) for the years 1995 through 2020. In addition to the ICIO, we source data from the World Input-Output Database (WIOD) (Timmer et al., 2015), which provides world input-output tables for a set of countries and time period that differ from the ICIO. There are two data releases of the WIOD. The WIOD 2013 Release considers 41 countries and a ROW aggregate for the the period 1995-2011, and the WIOD 2016 release considers 43 countries and a ROW aggregate for the period 2000-2014.

We rely on the HR indices that we construct using the ICIO data to derive our main empirical results because of the longer time period covered by these data. However, we also use HR indices recovered from WIOD data for comparison and robustness purposes. To that end, we aggregate both

the ICIO and WIOD releases to 41 countries—40 countries and a ROW aggregate—and "stitch" together the two WIOD releases to obtain series for the period period 2000-2014. We consider trade flows for tradable sectors—basically, non-service sectors in the data—and differentiate between goods used as intermediate inputs, $Q = M$, and those used as final goods for consumption or investment, $Q = C$.[11]

For each country i, we obtain from our data the expenditure for final or intermediate goods, $Q \in \{C, M\}$, on goods produced by each of i's trading partners including itself, $X^Q_{ih,t}$ for $i = 1, \ldots, N$. We then use $X^Q_{ih,t}$ construct expenditure shares, $\lambda^Q_{ih,t}$, that we use to construct HR indices according to (7), conditional on a value of the trade elasticity parameterized by η_Q. For our baseline empirical exercises and calibration (see section 5), we will consider equal parameters across types of goods, $\eta \equiv \eta_C = \eta_M$, and a value of $\eta = 5$ which implies a trade elasticity equal to four. We consider this value as a reasonable choice given the estimates of Simonovska and Waugh (2014) and the more recent estimates by Boehm et al. (2023) for the long-run trade elasticity. We explore the robustness of our main results to different values of this parameter in Appendix C.2.

2.3 Trade Costs Across Time

How do global bilateral trade costs evolve over time? The first fact that we document deals with low frequency changes in median bilateral trade costs.

Fact T1: Bilateral trade costs declined significantly between 1995 and 2008, and stabilized thereafter, remaining pretty much unchanged until 2020.

Figure 1 plots the evolution of the distribution of bilateral trade costs. The solid lines in figure 1 plot the median HR index—which we call bilateral trade costs from now on—for final (blue line) and intermediate (red line) goods in the cross-section of countries for any given year. These costs are expressed as a percentage of the sales price of the good, divided by 100—in terms of our definition in (7), the figure shows $HR^Q_{ih,t} - 1$ for $Q \in \{C, M\}$. According to our ICIO estimates shown in panel (a), median bilateral trade costs across countries for both final and intermediate goods fell approximately 80 percentage points from 1995 to 2008. This is a significant decline given that these costs in 1995 were approximately 380 and 420 percent for final and intermediate goods, respectively.[12] The plot also shows that, since 2008, median trade costs have remained pretty much

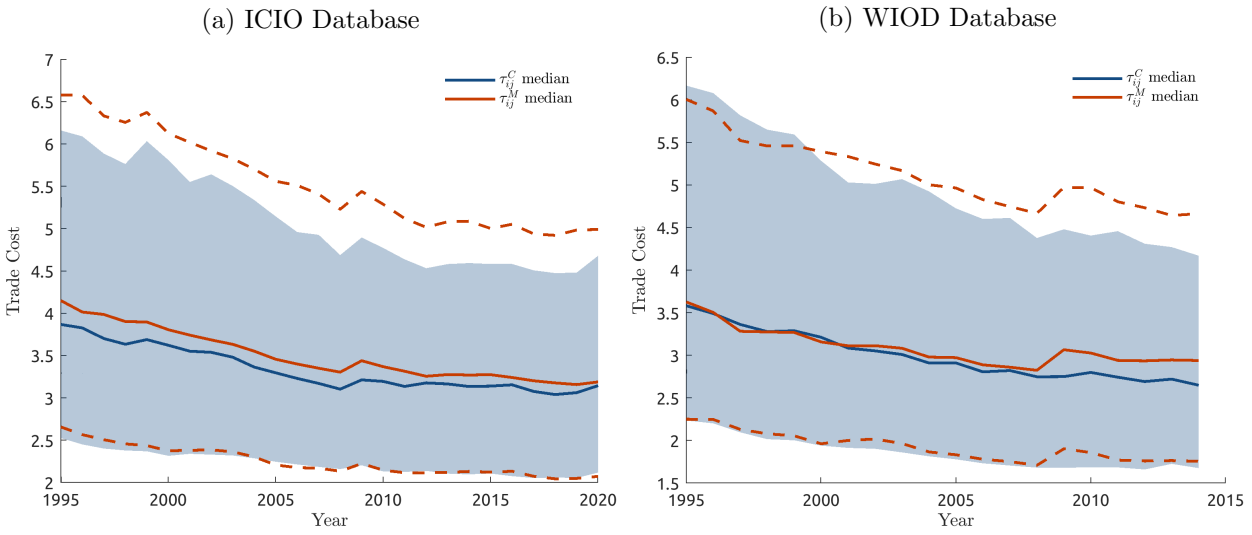
[11] See Appendix A for further details on data cleaning and manipulation.

[12] In terms of magnitudes, our estimates of bilateral trade costs are in line with previous literature showing that these

unchanged. From 2008 to 2020, median trade costs for final goods and intermediate inputs have hovered around values 310 and 350 percent, respectively. Hence, the long-run evolution of global trade costs is consistent with a process long period of globalization that has stalled since 2010.[13]

Fact T1 is not exclusive to data from the ICIO. Panel (b) of figure 1 considers the case of the evolution of the distribution of bilateral trade costs for WIOD data. These data show similar patters as those stated in Fact T1 for the case of ICIO data.

Figure 1: Evolution of global bilateral trade costs



Note: Trade costs are expressed as a percentage of the sales price of the good, divided by 100. That is, the figure shows the evolution of $HR_{ih,t}^{Q} - 1$ for $Q \in \{C, M\}$.

The second fact that we document is related to the long-run evolution of the dispersion in bilateral trade costs at a given point in time.

Fact T2: The dispersion in bilateral trade costs across country-pairs remained relatively stable from 1995 to 2020.

Figure 1 also plots the evolution of the dispersion of trade costs over time. The charts plot the 20-80 percentile bands for final consumption (boundaries of blued shaded region) and intermediate inputs (dashed red lines). Panel (a) shows that the dispersion in trade costs decreased minimally until 2010 and that it has remained completely stable since then. Hence, it seems that differences in costs across space have remained relatively stable.

are large (Anderson and van Wincoop, 2004). It is worth emphasizing that these magnitudes are not unreasonable given that our measure of trade costs includes all frictions that impede trade across any two country.

[13] Appendix B provides more details on the evolution of trade costs before 1995.

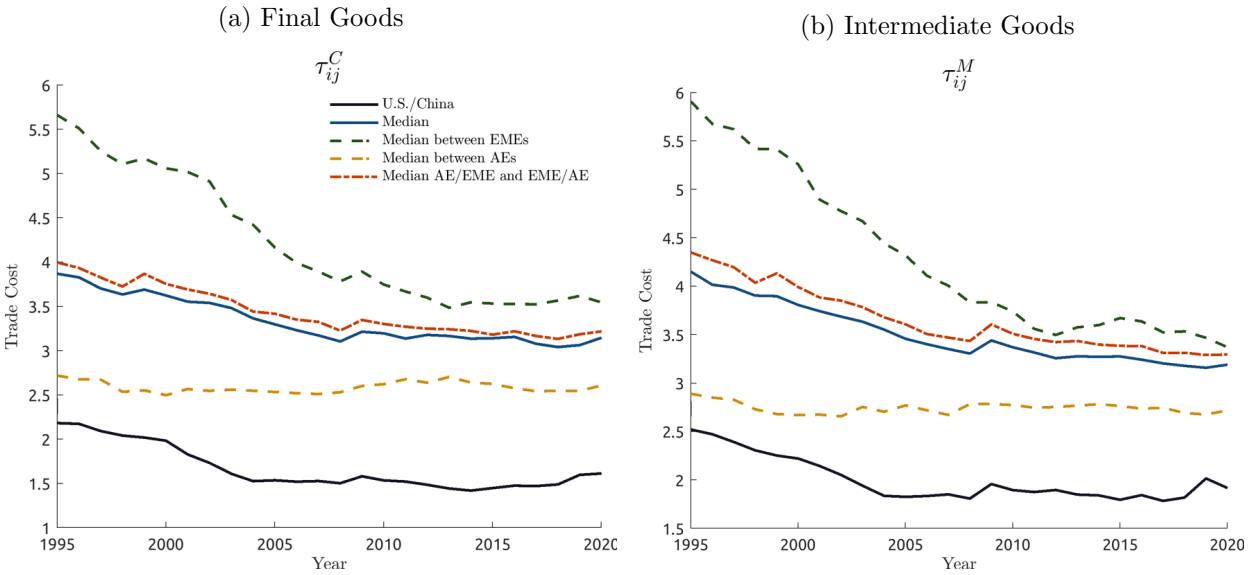
2.4 Trade Costs Across Space

How do global bilateral trade costs vary across space? Even though Fact T2 already provides insights into the variation of trade costs across space, we formalize and detail one fact in this section about the cross-sectional dispersion in bilateral trade costs.

Fact S1: There is substantial variation in trade costs across countries.

Figure 1 shows that variation in bilateral trade costs is substantial at any given point in time. Moreover, this variation remains sizable over the years considered. For instance, the ratio of 80th-percentile trade costs to those in the 20th percentile was about 2.5 for both final and intermediate goods in 1995. This ratio barely declined to 2.3 by 2019, before experiencing a small increase in 2020. Hence, there's substantial and persistent variation in trade costs across space.

Figure 2: Median Trade Costs for Selected Regions



Note: Trade costs are expressed as a percentage of the sales price of the good, divided by 100. That is, the figure shows the evolution of $HR_{ih,t}^{Q} - 1$ for $Q \in \{C, M\}$.

What types of country-pairs drive the differences in bilateral trade costs? Figure 2 plots the evolution of median bilateral trade costs conditional specific types of country-pairs. If we split our sample of countries into Advanced Economies (AE) and Emerging Market Economies (EME), then we can classify trade flows between any two counties as between AEs, between EMEs or between different types od countries (AE/EME of EME/AE). The figure shows that trade between EMEs and between countries of different types of countries (AE/EME or EME/AE) face the highest

costs. However, these costs also decline the most over the period 1995-2020. These trends are in line with the fact that trade between these types of countries has grown the most over the last 25 years (Reyes-Heroles et al., 2020). Interestingly, trade costs across AEs remained relatively stable, reflecting the fact that trade between these countries did not increase substantially over the period 1995-2020.

2.5 Import Costs and Inflation

To estimate the effects of changes in trade cost on inflation, we exploit variation in trade costs across time and space in section 2. The facts documented in this sections for bilateral trade costs provide partial support to our approach of using panel data local projections (Jordà, 2005) to estimate these effects. However, to follow this approach, we must first construct country-specific measures of trade costs that capture the variation arising from bilateral—or country-pair specific—trade frictions. Hence, we construct country specific import costs $\tau_{i,t}^{Q}$ for $Q \in \{C, M\}$ by aggregating bilateral trade costs using lagged import-weights. More specifically, our import costs are given by

$$\tau_{i,t}^{Q} = \sum_{h=1}^{N} \left(\frac{X_{ih,t-1}^{Q}}{\sum_{k \neq i} X_{ik,t-1}^{Q}} \right) HR_{ih,t}^{Q}, \tag{8}$$

for $Q \in \{C, M\}$. We choose to consider lagged import weights in order to the changes in import costs driven by contemporaneous changes in $HR_{ih,t}^{Q}$ rather than by changes in weights driven by changes in costs.

Figure 3 shows a scatter plot between our import costs and CPI inflation. More specifically, each dot in the figure corresponds to a country-year observation where we relate the trade costs in year t, $\tau_{i,t}^{Q}$, with the average CPI inflation observed in the subsequent four years, up to $t+4$.[14] We show inflation measured as the year-on-year change in the Consumer Price Index (CPI) for each country, which we collected from the World Development Indicators (WDI) database.[15] The left panel (right) shows the relation between trade costs in final (intermediate) goods and inflation.

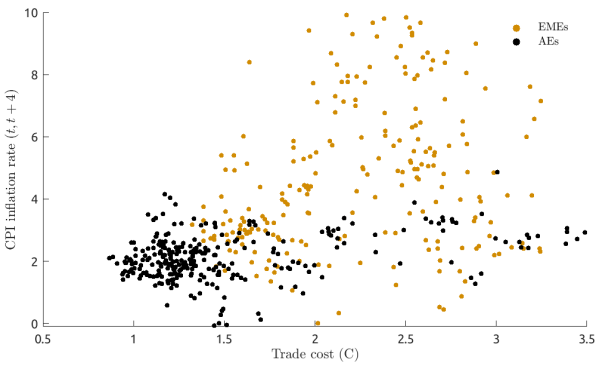
Visual inspection suggests that there is a positive correlation between higher import costs and future CPI inflation. The scatter plot also reveals substantial dispersion in the inflation rate, particularly for country-year observations where trade costs are above 100 percent. Uncovering the

[14] 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.

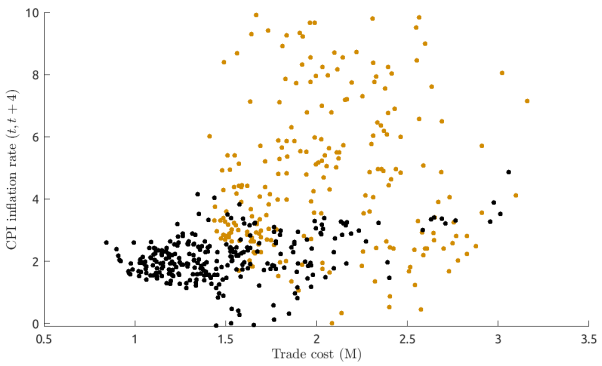
[15] Because the period of time we consider includes some high inflation episodes driven by factors unrelated to trade costs, such as currency crises or macroeconomic turmoil due to pro-market reforms in Eastern Europe, we restrict attention to country-year observations where the inflation is below 10 percent.

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.

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

To estimate the causal effects of changes in import costs on inflation, we rely on panel data local projections (Jordà, 2005) and estimate the following panel specification:

$$y_{i,t+h} = \alpha_i + \gamma_t + \beta_h^Q \tau_{i,t}^Q + A_h Z_{i,t} + \varepsilon_{i,t+h} \qquad \text{for } h \geq 0, \tag{9}$$

where $y_{i,t+h}$ is the dependent variable of interest for country i in period $t+h$. We will focus here on the case in which CPI inflation is the dependent variable and leave the analysis of other macroeconomic outcomes to Appendix C. Thus, we have that $y_{i,t} = \pi_{i,t}$.

Our coefficient of interest in equation (9) is β_h^Q, which captures the average effect of trade costs on CPI inflation h periods ahead. To isolate the effect of trade costs, $\tau_{i,t}^Q$, on inflation, 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 in (9). We also include a time-fixed effect γ_t to control for time-varying factors that influence all countries equally. The vector $Z_{i,t}$ to controls 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, the first lag of GDP growth, the first lag of the level of GDP, and the lag of the trade cost, $\tau^Q_{i,t-1}$. Note that including the lag of the trade cost implies that we are estimating the effects of innovations in these costs.

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.[16]

Given that our measure of import costs is expressed as percent of final sale price, the coefficient β^Q_h 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.

3.2 Inflationary Effects

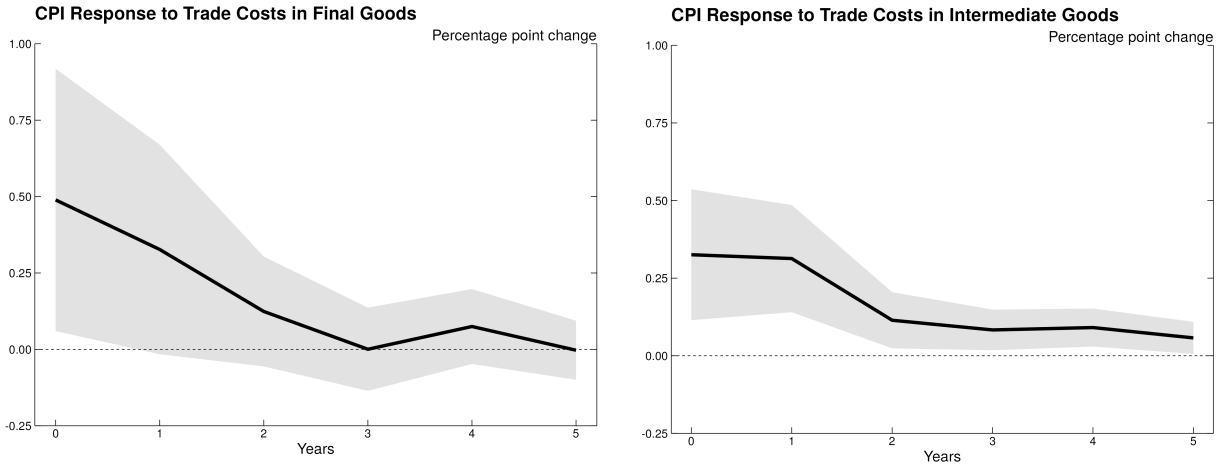
Our estimates for $h = 0, 1, ..., 5$ are presented in figure 4. According to our estimates, an increase in trade costs of either final (left panel) or intermediate (right panel) goods leads to a contemporaneous statistically significant rise of CPI inflation. According to our estimates, a 10 percentage point increase in a country's trade costs of final goods from all its trading partners leads to a 0.5 percentage point increase in CPI inflation within the first year. An equally sized increase in trade costs of intermediate goods leads to a 0.3 percentage point increase in CPI inflation. Hence, the magnitude of the immediate impact on CPI inflation varies depending on the type of trade cost that changes. The fact that the effect of an increase in import costs of final goods is almost twice as large as that of an increase in the costs for intermediate inputs is in line with the intuition that an increase in the costs to import final consumption goods affects the CPI directly. Meanwhile, higher import cost of intermediate inputs firs affect production costs, which in turn affect producers prices and, ultimately, consumer prices.

A novel result that we fins is that the persistence of the effects differs depending on the trade cost that changes. Higher costs for trade of final goods—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

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

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.

Given our main empirical results, we develop a dynamic model in section 4 to compare its predictions to our empirical estimates. We will show that our calibrated model does a good job in replicating the impulse response functions estimated in this section. Moreover, we show that by affecting firms' marginal costs, changes in trade costs of intermediate inputs lead to smaller, but more persistent responses in inflation, in line with our empirical results.

4 The Model

To better understand some mechanisms through which changes in trade costs affect inflation and macroeconomic outcomes, we now propose a dynamic model to explore these dynamic effects. We will conduct a series of experiments using the model to explore these mechanisms and their quantitative relevance. In addition, the model will allow us to carry a quantification of the relevance of trade costs shocks during the surge in inflation observed through 2021 and 2022 and its subsequent decline.

We build on the New Keynesian literature and extend a multi-country New Keynesian model with nominal price and wage rigidities to also feature trade in final consumption goods and intermediate inputs. Our New Keynesian bloc is similar to canonical open economy models (see

Corsetti et al. (2010) for a review). The trade bloc of our model—as described in in section 2.1—deviates from standard open economy New Keynesian models by allowing for trade in different types of goods. We will not only consider trade in final goods, but also trade in intermediates. A central aspect of this bloc of the model is that it delivers gravity-type bilateral trade equations which are in line with the how we measure trade costs in section 2.

We embed the static trade model described in section 2.1 into a dynamic framework. Time is discrete and indexed by $t = 1, 2, \ldots$. To recap, we consider a world comprised of N countries indexed by $i, h \in \mathcal{I} = \{1, \ldots, N\}$. We assume that each of these countries has population ξ_i, for $i = 1, ..., N$, and we normalize world population to unity in every period. We assume country 1 to be the United States. In addition to trading final consumption goods and intermediate inputs—as described in section 2.1—countries also engage in trade in financial assets under incomplete international financial markets. More precisely, countries can only trade a risk-free international bond denominated in (real) dollars, country 1's currency, across borders. Aside from the fact that country 1's currency is the one used in international financial markets, countries are otherwise symmetric. We proceed now to describe the structure of a generic country i.

4.1 Households

There is a continuum of households indexed by ℓ in each country. Within a country, households engage in monopolistic competition when supplying differentiated labor services to the production sector as in Erceg et al. (2000). That is, goods-producing firms regard each household's labor as an imperfect substitute for the labor services of other households. Hence, the objective function of household ℓ in country i is given by

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left[U_i(C_{i,t}) - V_i(L_{i,t}^{\ell}) \right], \tag{10}$$

where $C_{i,t}$ is as in (1) for $Q = C$.[17] 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 (10), $L_{i,t}^{\ell}$ denotes labor services (hours) provided by household ℓ in country i.

[17] 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 $C_{i,t}$.

Household ℓ in country i seeks to maximize (10) subject to the budget constraint

$$\sum_{h=1}^{N} \tau_{ih,t}^{C} P_{ih,t} C_{ih,t} + B_{ii,t} + \frac{B_{i1,t}}{\mathcal{E}_{1i,t}} \leq W_{i,t}^{\ell} L_{i,t}^{\ell} + R_{i,t-1} B_{ii,t-1} + R_{1,t-1} \Psi_{i,t-1} \frac{B_{i1,t-1}}{\mathcal{E}_{1i,t}} + T_{i,t} \tag{11}$$

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 denominated in U.S. dollars, $\mathcal{E}_{ih,t}$ denotes country i's nominal exchange rate against country h—as defined in section 2.1—and $T_{i,t}$ are transfers to households in country i.[18] We allow for risk premia to vary across countries by means of the term $\Psi_{1,t-1}$ in (11). These risk premium terms are such that $\Psi_{1,t} = 1$ and $\Psi_{i,t} \geq 1$ for $i \neq 1$. More specifically, we assume that for $i \neq 1$, $\Psi_{i,t}$ is given by

$$\Psi_{i,t} \equiv (1 - \psi \frac{b_{i1,t}}{\mathcal{Q}_{1i,t} Y_{i,t}}) \varepsilon_{i,t}^{\psi}, \tag{12}$$

where $b_{i1,t} \equiv \frac{B_{i1,t}}{P_{1,t}^{C}}$ denotes country i's borrowing in units of country 1's good, $Y_{i,t}$ denotes total tradable output in country i, $\varepsilon_{i,t}^{\psi}$ is an exogenous shock to the risk premium of country i, and $\mathcal{Q}_{ih,t}$ denotes the real exchange rate between country i and country h defined as

$$\mathcal{Q}_{ih,t} \equiv \frac{\mathcal{E}_{ih,t} P_{h,t}^{C}}{P_{i,t}^{C}}, \tag{13}$$

where $P_{i,t}^{C}$ is as defined in (4).

Note that in (11), we express prices paid for final consumption goods i, $P_{ih,t}^{C}$, explicitly in terms of the trade costs for final consumption goods, $\tau_{ih,t}^{C}$—as defined in section 2.1—and the bilateral prices that exclude the costs of shipping goods across borders, $P_{ih,t}$. We do so to emphasize how changes in these trade costs directly affect the prices paid by final consumers and, therefore, have a direct impact on their behavior and welfare. We now impose additional structure on these trade costs and assume that they are comprised of exogenous iceberg trade costs, $d_{ih,t}^{C} \geq 1$, and exogenous add-valorem tariffs, $\kappa_{ih,t}^{C} \geq 0$, such that total trade costs are given by $\tau_{ih,t}^{C} = d_{ih,t}^{C}(1 + \kappa_{ih,t}^{C})$.

Note that, conditional on $C_{i,t}$, equation (3) for $Q = C$ determines demand for consumption goods across country sources, where $P_{i,t}^{C}$ is given by (4) for $Q = C$. Hence, conditional on aggregate expenditure, all bilateral trade flows are fully determined by equation (5). Aggregate expenditure, in turn, is determined by the household's intertemporal optimality condition with respect to bonds

[18] Transfers tp households include those from firms and the government. The specific transfers are provided in section 4.4.

denominated in domestic currency. This condition is characterized by the Euler equation

$$U_i'(C_{i,t}) = \beta R_{i,t} \mathbb{E}_t \left[\frac{U_i'(C_{i,t+1})}{\pi_{i,t+1}} \right], \tag{14}$$

where $\pi_{i,t} \equiv \frac{P_{i,t}^C}{P_{i,t-1}^C}$ denotes CPI inflation.

For countries that trade bonds denominated in a currency other than their domestic currency, that is, for countries other than country 1, household's optimal portfolio choice is characterized by an uncovered interest parity (UIP) condition, which in real terms is given by

$$R_{i,t} \mathbb{E}_t \left[\frac{U_i'(C_{i,t+1})/U_i'(C_{i,t})}{\pi_{i,t+1}} \right] = R_{1,t} \Psi_{i,t} \mathbb{E}_t \left[\frac{U_i'(C_{i,t+1})/U_i'(C_{i,t})}{\pi_{1,t+1} \frac{\mathcal{Q}_{1i,t+1}}{\mathcal{Q}_{1i,t}}} \right]. \tag{15}$$

Hence, given our assumption about $\Psi_{i,t}$ in (12), we have that the uncovered interest rate parity condition between countries i and 1 will not hold if $\frac{b_{i1,t}}{\mathcal{Q}_{1i,t} Y_{i,t}}$ deviates from $\frac{1}{\psi}$.

4.1.1 Wage Setting

Following Erceg et al. (2000), we assume that there is an 'employment agency/union' in each country that combines households' labor services (hours) into an aggregate homogeneous labor input supplied to final producers which we denote by $L_{i,t}$. The agency combines labor services across households according to

$$L_{i,t} = \left(\int_0^1 {L_{i,t}^{\ell}}^{\frac{\epsilon_w - 1}{\epsilon_w}} d\ell \right)^{\frac{\epsilon_w}{\epsilon_w - 1}}, \tag{16}$$

where $\epsilon_w > 1$. Given a profile of wages across household types, $\{W_{i,t}^{\ell}\}_{\ell}$, the agency seeks to minimize its hiring costs by demanding labor services of type ℓ household according to

$$L_{i,t}^{\ell} = \left(\frac{W_{i,t}^{\ell}}{W_{i,t}} \right)^{-\epsilon_w} L_{i,t}, \tag{17}$$

where

$$W_{i,t} = \left(\int_0^1 {W_{i,t}^{\ell}}^{1-\epsilon_w} d\ell \right)^{\frac{1}{1-\epsilon_w}}, \tag{18}$$

and $W_{i,t}$ can be interpreted as the aggregate wage index in country i.

Households' in each country compete in a monopolistic fashion in the labor market and therefore can set wages to maximize their utility. However, we assume that in any given period t, household ℓ can only reset its nominal wage, $W_{i,t}^{\ell}$, with probability $1-\theta_w$, and that with probability θ_w, household ℓ's nominal wages has to be the same as in the previous period. Consider a household that can reset its nominal wage in period t. This household will choose its optimal reset nominal wage, $\overline{W}_{i,t}$, to maximize

$$\mathbb{E}_t \sum_{k=0}^{\infty} \beta^k \theta_w^k \left(U_i(C_{i,t}) - V_i(L_{i,t+k|t}^{\ell}) \right), \tag{19}$$

where

$$L_{i,t+k|t}^{\ell} = \left(\frac{\overline{W}_{i,t}}{W_{i,t+k}} \right)^{-\epsilon_w} L_{i,t+k} \tag{20}$$

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

The optimal reset nominal wage has to be such that the following first order condition holds:

$$\mathbb{E}_t \sum_{k=0}^{\infty} \beta^k \theta_w^k L_{i,t+k|t}^{\ell} U_i'(C_{i,t+k}) \left(\frac{\overline{W}_{i,t}}{P_{i,t+k}^{C}} - \frac{\epsilon_w}{\epsilon_w - 1} \frac{V_i'(L_{i,t+k|t}^{\ell})}{U_i'(C_{i,t+k})} \right) = 0. \tag{21}$$

Note that in the case in which workers can adjust wages in every period, $\theta_w^k = 0$, then we obtain the usual optimally condition that equates the real wage, $\overline{W}_{i,t}/P_{i,t}^{C}$, to the marginal rate of substitution, $V_i'(L_{i,t+k|t}^{\ell})/U_i'(C_{i,t+k})$, adjusted by the monopolistic distortion associated with a positive markup, $\epsilon_w/(\epsilon_w - 1)$.

Since a measure θ_w of firms keep their price unchanged and $1-\theta$ reset it optimally, the aggregate wage index, $W_{i,t}$, is such that $W_{i,t}^{1-\epsilon_w} = \theta_w (W_{i,t-1})^{1-\epsilon_w} + (1-\theta_w)(\overline{W}_{i,t})^{1-\epsilon_w}$.

4.2 Firms

There are two types of firms in each country. For the first type, a unit continuum of firms indexed by $v \in [0,1]$ produce differentiated goods that cannot be traded across borders. In country i, these goods are produced using the homogeneous labor supplied in country i and a bundle of intermediate inputs. The second class of firms consists of perfectly competitive identical retail firms that produce a final homogeneous good that can be traded internationally subject to trade costs. These firms produce tradable goods by aggregating the differentiated goods produced by domestic firms. We

first describe the technology and problem faced by the first type of firms and then proceed to describe these issues for the second type.

4.2.1 Differentiated Firms: Nontradables

Firm $v \in [0,1]$ in country i produces nontradable goods according to the production function

$$Y_{i,t}^v = A_{i,t}\left[(1-\nu)^{\frac{1}{\varepsilon_y}} L_{i,t}^{v\ \frac{\varepsilon_y-1}{\varepsilon_y}} + \nu^{\frac{1}{\varepsilon_y}} M_{i,t}^{v\ \frac{\varepsilon_y-1}{\varepsilon_y}}\right]^{\frac{\varepsilon_y}{\varepsilon_y-1}}, \tag{22}$$

where $A_{i,t}$ denotes exogenous productivity that does not vary across firms, $L_{i,t}^v$ is labor input, and $M_{i,t}^v$ is the amount of an intermediate input bundle used in production.[19] The intermediate input, in turn, consists of an aggregate of goods produced in all countries according to CES aggregator specified in (1) for $Q = M$. Note that, as long as $\eta_M < \infty$, intermediate inputs are not perfectly substitutable across countries.

Given prices of country-specific tradable goods in global markets, $\{P_{i,t}\}_{i=1}^N$, retail firms in country i will seek to minimize the total cost of intermediate inputs,

$$\sum_{h=1}^{N} \tau_{ih,t}^M P_{ih,t} M_{ih,t}, \tag{23}$$

subject to (1) for $Q = M$, and for a given level of $M_{i,t}$. As for the case of the trade costs faced by households, we assume that the trade costs faced by firms are comprised of exogenous iceberg trade costs, $d_{ih,t}^M \geq 1$, and exogenous add-valorem tariffs, $\kappa_{ih,t}^M \geq 0$, such that total trade costs are $\tau_{ih,t}^M = d_{ih,t}^M(1+\kappa_{ih,t}^M)$. The solution to the minimization problem yields demands for goods from different countries, $M_{ih,t}$, according to (3) with an ideal price index for the intermediate input bundle, $P_{i,t}^M$, as specified in (4) for $Q = M$.

Differentiated firms choose the amount of labor and the intermediate input bundle to minimize total production costs given by

$$W_{i,t} L_{i,t} + P_{i,t}^M M_{i,t}, \tag{24}$$

subject to (22). Given nominal wages and the price of the intermediate input bundle in country i,

[19] We will restrict attention to a first-order approximation of the model and ignore second-order price dispersion terms. Hence, in this section we can 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).

$P^M_{i,t}$, the solution to the cost minimization problem delivers the marginal cost faced by retail firms, which is the same across firms and given by

$$MC_{i,t} = \frac{1}{A_{i,t}} \left[(1-\nu) {W_{i,t}}^{1-\varepsilon_y} + \nu (P^M_{i,t})^{1-\varepsilon_y} \right]^{\frac{1}{1-\varepsilon_y}}. \tag{25}$$

Note that changes in trade costs of intermediate inputs affect the nominal marginal cost of the firms directly through their effects on the price of the intermediate input bundle, $P^M_{i,t}$. Therefore, an increase in trade costs leading to a higher $P^M_{i,t}$ will increase firms marginal and decrease production efficiency. Before analyzing the price setting behavior by firms producing differentiated goods, we describe the technology and problem of the representative retailer producing the homogeneous tradable good.

4.2.2 Retail Firms: Tradables

To produce tradable goods, the representative retail firm in country i aggregates differentiated goods available in i according to

$$Y_{i,t} = \left(\int_0^1 {Y^v_{i,t}}^{\frac{\epsilon-1}{\epsilon}} dv \right)^{\frac{\epsilon}{\epsilon-1}}, \tag{26}$$

where $\epsilon > 0$. The output of the homogeneous good in country i can then be used for final consumption or as an intermediate input in the production of differentiated goods, either domestically or abroad.

Given the prices of different varieties, final good producers maximize profits subject to (26). The solution to this maximization problem delivers the demand for variety v in country i:

$$Y^v_{i,t} = \left(\frac{P^v_{i,t}}{P_{i,t}} \right)^{-\epsilon} Y_{i,t}, \tag{27}$$

where

$$P_{i,t} = \left[\int_0^1 {P^v_{i,t}}^{1-\epsilon} dv \right]^{\frac{1}{1-\epsilon}} \tag{28}$$

defines the nominal price of a unit of the homogeneous good produced in country i in terms of its own currency, and $P^v_{i,t}$ denotes the nominal price charged by firm v in country i, also in terms of local currency units. As stated in section 2.1, excluding trade costs, 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,

$$P_{ih,t} = \mathcal{E}_{ih,t} P_{h,t}. \tag{29}$$

Given the conditional demands for differentiated varieties in (27), we now turn to how retails firms set prices.

4.2.3 Price Setting by Differentiated Firms

Differentiated firms in country i set prices to sell their goods to retailers.[20] However, in line with our assumption of staggered wage adjustments, we assume that firm v can only reset its price in period t with probability $1-\theta$, and with probability θ it must keep its price unchanged relative to last year's.

Let $\overline{P}_{i,t}$ denote the optimal price for a firm that is able to reset it price in period t. Such a firm in country i will set this price to maximize

$$\mathbb{E}_t \sum_{k=0}^{\infty} \beta^k \theta^k \frac{U'_{i,t}(C_{i,t})}{P^C_{i,t+k}} \left(\overline{P}_{i,t} - MC_{i,t+k}\right) \left(\frac{\overline{P}_{i,t}}{P_{i,t+k}}\right)^{-\epsilon} Y_{i,t+k}, \tag{30}$$

where the marginal cost is as specified in (25). The optimal price set by those firms able to adjust prices must be such that the following optimality condition holds:

$$\mathbb{E}_t \sum_{k=0}^{\infty} \beta^k \theta^k \frac{U'_{i,t}(C_{i,t})}{P^C_{i,t+j}} P^{\epsilon}_{i,t+k} Y_{i,t+k} \left[\overline{P}_{i,t} - \frac{\epsilon}{\epsilon - 1} MC_{i,t+k}\right] = 0. \tag{31}$$

Note that under flexible prices ($\theta = 0$), this condition reduces to the usual pricing condition setting prices equal to a markup over marginal cost.

Since a measure θ of firms keep their price unchanged and $1-\theta$ reset prices optimally, from (28) we obtain that $P_{i,t}$ satisfies the law of motion $P^{1-\epsilon}_{i,t} = \theta P^{1-\epsilon}_{i,t-1} + (1-\theta)\overline{P}^{1-\epsilon}_{i,t}$.

[20] Note that in this model, firms engaging in international trade are perfectly competitive. Therefore, firms do not set prices in international markets. However, our assumptions are equivalent to allowing for price setting in international markets under producer currency pricing (PCP). That is, firms set prices in the currency of the country in which they produce and let their prices in the foreign currency adjust with the exchange rate.

4.3 Monetary policy

We assume that central banks in all countries follow conventional Taylor-type monetary policy rules. More specifically, the central bank in country i sets the nominal interest rate according to the inertial policy rule given by

$$R_{i,t} = (R_{i,t-1})^{\phi_r} \left(\frac{1}{\beta} (\pi_{i,t})^{\phi_\pi} \left(\frac{GDP_{i,t}}{GDP_{i,0}} \right)^{\phi_y} \varepsilon^r_{i,t} \right)^{1-\phi_r}, \tag{32}$$

where $GDP_{i,t}$ denotes real value added in country i.[21] In (32), $\phi^r > 0$ is a parameter that determines the inertia in monetary policy, $\phi^\pi > 0$ and $\phi^y > 0$ parameterize the elasticities of the policy rate with respect to changes in inflation and GDP deviations, respectively, and $\varepsilon^r_{i,t}$ is an exogenous shock to the monetary policy rule.

4.4 Market clearing and balance of payments

Tradable goods produced in country i are sold either domestically or abroad to country i's trading partners. Domestic or foreign buyers of these goods then consume them or use them as intermediate inputs. Hence, the market clearing conditions for these goods are given by

$$\xi_i Y_{i,t} = \sum_{h=1}^{N} \xi_h (d^C_{hi,t} C_{hi,t} + d^M_{hi,t} M_{hi,t}) \tag{33}$$

for $i = 1, ...N$, where the population terms ξ_i reflect the fact that all variables are expressed in per-capita terms. Note that (33) accounts for the goods that are lost when traded across countries because of the iceberg-type trade costs $d^Q_{hi,t} \geq 1$ for $Q \in \{C, M\}$.

We can derive the balance of payments condition for every country i other than country 1 ($i \neq 1$) that determines the evolution of these countries' holdings of the dollar-denominated international bond. To do so, we aggregate domestic budget constraints and obtain

$$\sum_{h=1}^{N} \tau^C_{ih,t} P_{ih,t} C_{ih,t} + \frac{B_{i1,t}}{\mathcal{E}_{1i,t}} = W_{i,t} L_{i,t} + R_{1,t-1} \Psi_{i,t-1} \frac{B_{i1,t-1}}{\mathcal{E}_{1i,t}} + T_{i,t}, \tag{34}$$

where transfers to households in country i include tariff revenues that are rebated lump-sum to

[21] Real value added in country i is given by $GDP_{i,t} = Y_{i,t} - \frac{P^M_{i,t}}{P_{i,t}} M_{i,t}$.

households,

$$\mathcal{K}_{i,t} = \sum_{h=1}^{N} \left(\kappa_{ih,t}^{C} \frac{\tau_{ih,t}^{C} P_{ih,t} C_{ih,t}}{1 + \kappa_{ih,t}^{C}} + \kappa_{ih,t}^{M} \frac{\tau_{ih,t}^{M} P_{ih,t} M_{ih,t}}{1 + \kappa_{ih,t}^{M}} \right), \tag{35}$$

and firms profits, $\Pi_{i,t}$, such that $T_{i,t} = \mathcal{K}_{i,t} + \Pi_{i,t}$. Given that profits are given by $\Pi_{i,t} = P_{i,t} Y_{i,t} - W_{i,t} L_{i,t} - \sum_{h=1}^{N} \tau_{ih,t}^{M} P_{ih,t} M_{ih,t}$, (34) can be rewritten as

$$\sum_{h=1}^{N} d_{ih,t}^{C} P_{ih,t} C_{ih,t} + \frac{B_{i1,t}}{\mathcal{E}_{1i,t}} = P_{i,t} Y_{i,t} - \sum_{h=1}^{N} d_{ih,t}^{M} P_{ih,t} M_{ih,t} + R_{1,t-1} \Psi_{i,t-1} \frac{B_{i1,t-1}}{\mathcal{E}_{1i,t}}, \tag{36}$$

which does not depend on tariffs because we have imposed that all tariff revenues are rebated lump-sum to households, which is equivalent to the government running a balanced budget. Hence, we obtain that the evolution of holdings of U.S. bonds for country i—prescribed by the balance-of-payments condition—is given by

$$B_{i1,t} - B_{i1,t-1} = \mathcal{E}_{1i,t} \left(EX_{i,t} - IM_{i,t} \right) + \left(R_{1,t-1} \Psi_{i,t-1} - 1 \right) B_{i1,t-1}, \tag{37}$$

where $EX_{i,t} = P_{i,t} Y_{i,t} - P_{i,t} C_{ii,t} - P_{ii,t} M_{ii,t}$ and $IM_{i,t} = \sum_{h \neq i} d_{ih,t}^{C} P_{ih,t} C_{ih,t} + \sum_{h \neq i} d_{ih,t}^{M} P_{ih,t} M_{ih,t}$, denote exports and imports. Condition (37) simply states that country i's current account is equal to its trade balance plus its net foreign investment income.

5 Calibration

To illustrate how changes in trade costs affect inflation dynamics in our model, we calibrate it and then use it conduct a series of numerical experiments in section 6. We consider five countries, $N = 5$, with countries 1 through 5 representing the United States, China, the advanced non-U.S. economies, the Asian emerging market economies, and the rest of emerging market economies, respectively. The population parameters, ξ_i, are set to replicate the weights of these five regions in world GDP.

For households' preferences, we allow for habit formation in consumption. Thus, we consider a more general case than in the model presented in section 4, and replace $U_i(C_{i,t})$ with

$$U_i(C_{i,t}, C_{i,t-1}) = \frac{(C_{i,t} - h C_{i,t-1})^{1-\sigma} - 1}{1 - \sigma},$$

where $h \geq 0$ modulates the degree of habit formation and $\sigma > 0$ is the inverse of the intertemporal elasticity of substitution (IES). For the disutility of labor, we choose th functional form

$$V_i(L_{i,t}^{\ell}) = \frac{{L_{i,t}^{\ell}}^{1+\varphi}}{1+\varphi},$$

where $\varphi > 0$ is the inverse of the labor supply elasticity.

For our numerical experiments, we consider a log-linear approximation of the model around its steady state under balanced trade. Hence, we assume that trade costs can be expressed as $\tau_{ih,t}^{Q} = \left(\omega_{ih}^{Q}\right)^{\frac{1}{1-\eta_Q}} \varepsilon_{ih,t}^{Q}$, where ω_{ih}^{Q} are time-invariant parameters such that $\sum_{h=1}^{N} \omega_{ih}^{Q} = 1$ for all i, and $\varepsilon_{ih,t}^{Q}$ are stationary shocks to trade costs for $Q \in \{C, M\}$. Note that, by equation (5), this assumption implies that ω_{ih}^{Q} parameterizes the trade shares in a steady state of the model in which all relative prices are unity.[22] Given our assumption that trade is balanced in steady state, we can only calibrate half of the openness parameters for final consumption goods, ω_{ih}^{C}, and intermediate inputs, ω_{ih}^{M}, with the rest being determined by the restriction that trade must be balanced.[23]

We proceed to choose the parameters of the model by relying on previous literature or by using certain moments in the data. Table 1 lists the parameter values for our calibration. Starting with our choice for values of preference parameters, these are standard and similar to those in existing literature. For instance, our values for the discount factor, β, the inverse of the IES, σ, habit formation, h, and the inverse of the labor supply elasticity, φ, are all standard in the literature on open economy macro models (Bodenstein et al., 2023). For the trade elasticity for trade of final goods, we follow Comin and Johnson (2020) and choose η_C equal to 3. This value is lower than the value we used to construct bilateral trade costs in section 2. However, choosing a lower value is consistent with calibrating a the model at a quarterly frequency, while our estimates in our empirical exercises are for annual data.

For the case of technological parameters, our choices are also standard and similar to those in the literature. In terms of the New Keynesian bloc of our model, the values for the elasticities of substitution across retailers and labor varieties (ϵ, ϵ_w), and for rigidities of prices and wages

[22] In terms of the equilibrium conditions of the model, this assumption is equivalent to assuming that equation (1) is given by

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

and $\tau_{ih,t}^{Q} = \varepsilon_{ih,t}^{Q}$ for $Q \in \{C, M\}$.

[23] It can be shown that ω's can be chose recursively such that a steady state of the model with balanced trade and unity prices exists.

$(\theta,\ \theta_w)$, our values are standard (Bodenstein et al., 2023). We also allow for wage indexation to past inflation parameterized by ι_w. To calibrate the technologies of differentiated firms, we follow Comin and Johnson (2020) to choose the value of the steady-state share of intermediates in production, ν, the elasticity of substitution across labor and intermediate inputs, ϵ_y, and the trade elasticity for trade in intermediate inputs, η_M. We assume that labor and intermediate inputs are complementary ($\epsilon_y < 1$), and the trade elasticity for intermediates is equal to that of final goods.

For the policy rule, we assume in our baseline calibration that the policy rate does not responds to output deviations. In addition, our baseline calibration does not consider deviations in the UIP conditions.

For the parameters determining the trade shares, we set four of these parameters for the U.S., three for China, and so on, and let the rest be determined by the trade balance condition in steady state. We choose the values of these parameters based on data from the WIOD. These values are shown at the bottom of table 1.

6 Model Experiments

We next perform a series of experiments aimed at illustrating the model's predictions about 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 considering a 10 percentage point increase in trade costs against all trading partners, mimicking the experiment in the empirical analysis of section 3. Consistent with that empirical analysis, we assume here a symmetric increase in the costs that foreigner pay for U.S. imports, that is, we set $\tau^Q_{ih,t} = \tau^Q_{hi,t}$ 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

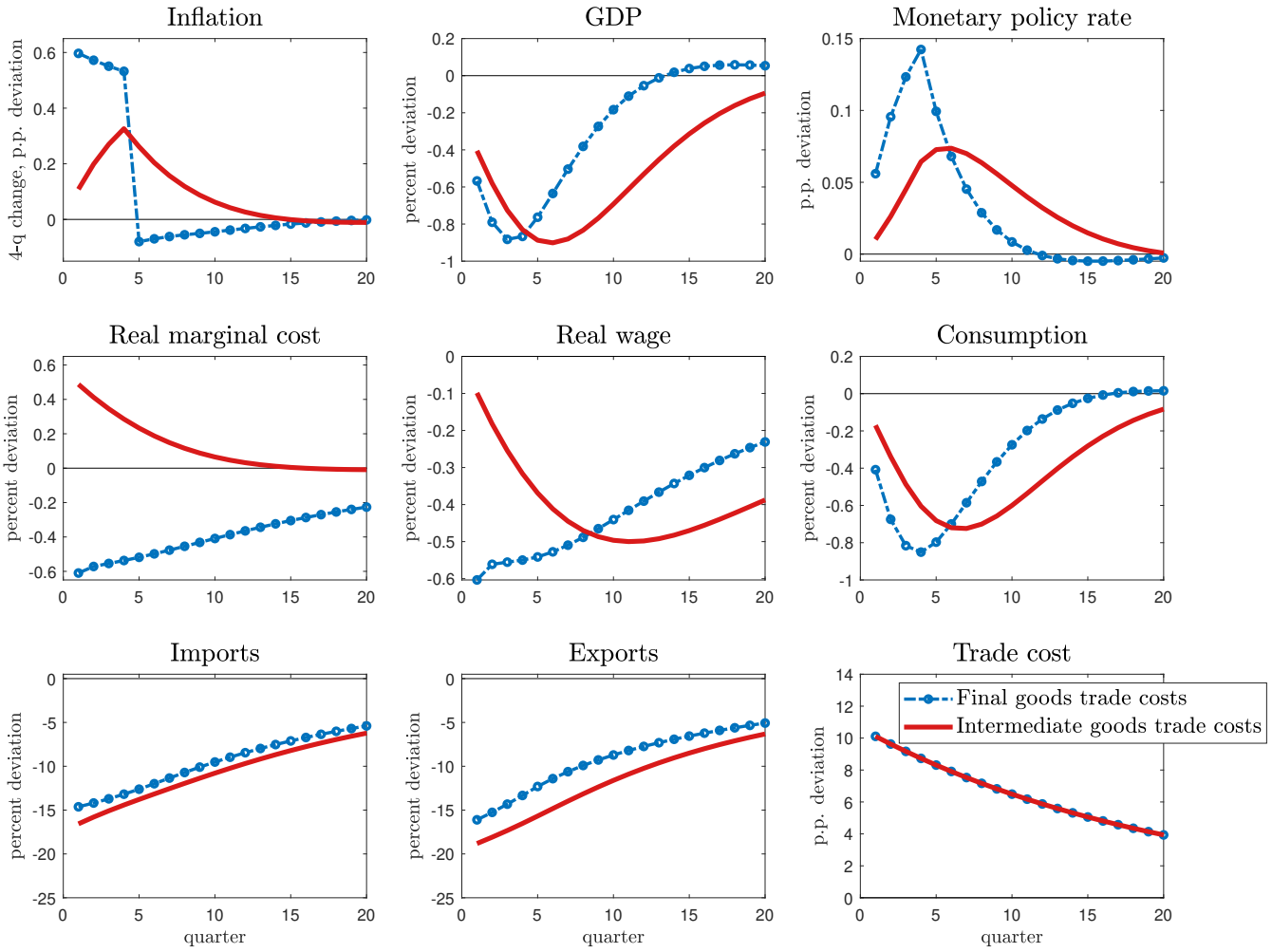
Table 1: Calibrated Parameters

Parameter	Description	Value
β	Discount factor	0.99
σ	Inverse IES	0.5
h	Habit	0.75
η_C	Elasticity of substitution for final consumption	3
φ	Inverse labor supply elasticity	2
ϵ	Elasticity of substitution across retailers	6
ϵ_w	Elasticity of substitution across labor varieties	6
θ	Price rigidity	0.80
θ_w	Wage rigidity	0.80
ι_w	Wage indexation to past inflation	0.05
ν	Share of intermediates in production	0.4
ε_y	Elasticity of substitution labor-intermediates	0.5
η_m	Elasticity of substitution for intermediate inputs	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]
$[\omega_{11}^C, \omega_{12}^C, \omega_{13}^C, \omega_{14}^C]$	Consumption trade weights, country 1	[.94,.012,.004,.021]
$[\omega_{11}^M, \omega_{12}^M, \omega_{13}^M, \omega_{14}^M]$	Intermediates trade weights, country 1	[.88,.025,.007,.04]
$[\omega_{22}^C, \omega_{23}^C, \omega_{24}^C]$	Consumption trade weights, country 2	[.95,.009,.02]
$[\omega_{22}^M, \omega_{23}^M, \omega_{24}^M]$	Intermediates trade weights, country 2	[.94,.01,.014]
$[\omega_{33}^C, \omega_{34}^C]$	Consumption trade weights, country 3	[.94,.014]
$[\omega_{33}^M, \omega_{34}^M]$	Intermediates trade weights, country 3	[.81,.045]
ω_{44}^C	Consumption trade weights, country 4	.94
ω_{44}^M	Intermediates trade weights, country 4	.89

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.

The more persistent inflation response reflects the fact that an increase in import costs raises the marginal cost of all domestic firms. As such, the effects are akin to an exogenous fall in aggregate

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).

total factor productivity. Even though firms are able to substitute away from more expensive foreign inputs into domestic inputs (including labor), these other inputs are imperfect substitutes and therefore inefficiencies arise. 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 driven by firms adjusting prices sluggishly. GDP falls in both cases, but the decline is much more persistent in the intermediate goods case, reflecting a drag from tighter monetary policy 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.

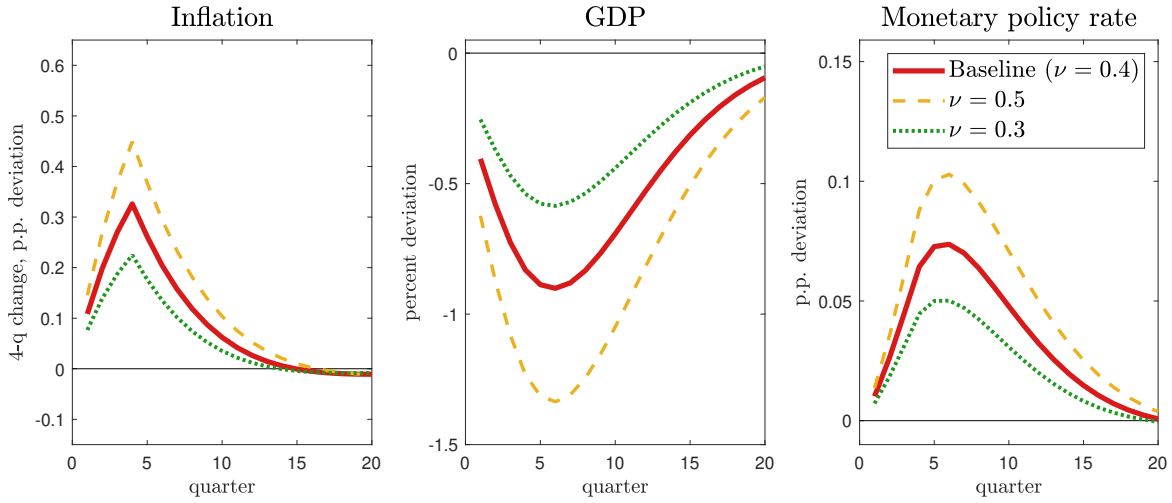
Hence, in line with our empirical results, increases in trade costs of intermediate inputs lead to smaller increases in inflation in the short run, but persistent higher inflation than an increase in inflation caused by higher import costs of final consumption goods. This result has important policy implication as shocks leading to more persistent increase in inflation are more likely to feed into agents' inflation expectations in models with risks associated to unanchored inflation expectations.

6.2 The role of the share of intermediates and the substitution between labor and intermediate inputs

Given the role that increases in trade costs of intermediates play in shaping firms' marginal costs and, therefore, inflation dynamics, we explore in this section the role of two key technological parameters shaping these effects. First, we consider how the share of intermediates in firms' production, governed by the parameter ν, affect the repose of inflation to shocks. We are particularly interested in this parameter because it determines the relevance of intermediate inputs in production. For instance, if intermediates were not used in production—as in most of the existing literature on open economy New Keynesian models—then firms' marginal costs would not be affected by changes in intermediate trade costs. Second, we consider how the value of the elasticity of substitution between intermediate inputs and labor—governed by the parameter ε_y—affects inflation dynamics. This parameter determines how easy it is to substitute away from intermediate inputs given an increase in the costs of this bundle.

Figure 7 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. Hence, the more dependent an economy is on intermediate inputs, the greater the inflationary risks posed by increases in intermediate trade costs. Similarly, figure 7 shows that lower elasticities of substitution between intermediates and labor are also associated with amplified GDP and inflation effects of trade shocks. However, the range of effects spanned by different values of the elasticity parameter is smaller. Taken together, the results indicate that economies with both higher ν—which could be interpreted as greater prevalence of supply chains—and with lower substitutability between intermediate inputs and labor, would feature worsened monetary policy trade-offs when hit by disruptions affecting intermediate goods trade. This issue

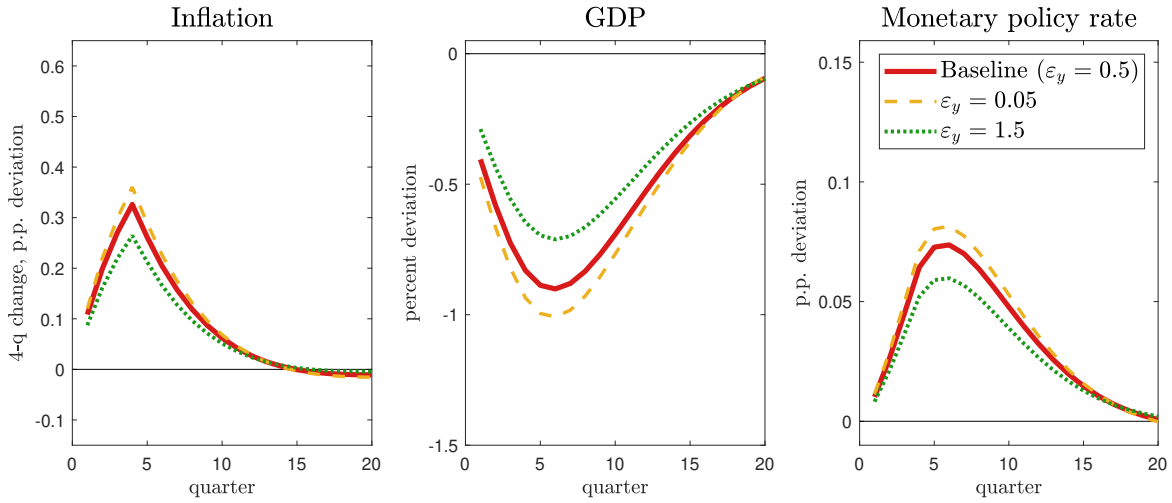
Figure 6: Effects on the U.S. of an increase in intermediates trade costs, role of ν



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).

represents an additional key concern for policy makers in charge of monetary policy decisions.

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).

6.3 U.S.-China trade tensions

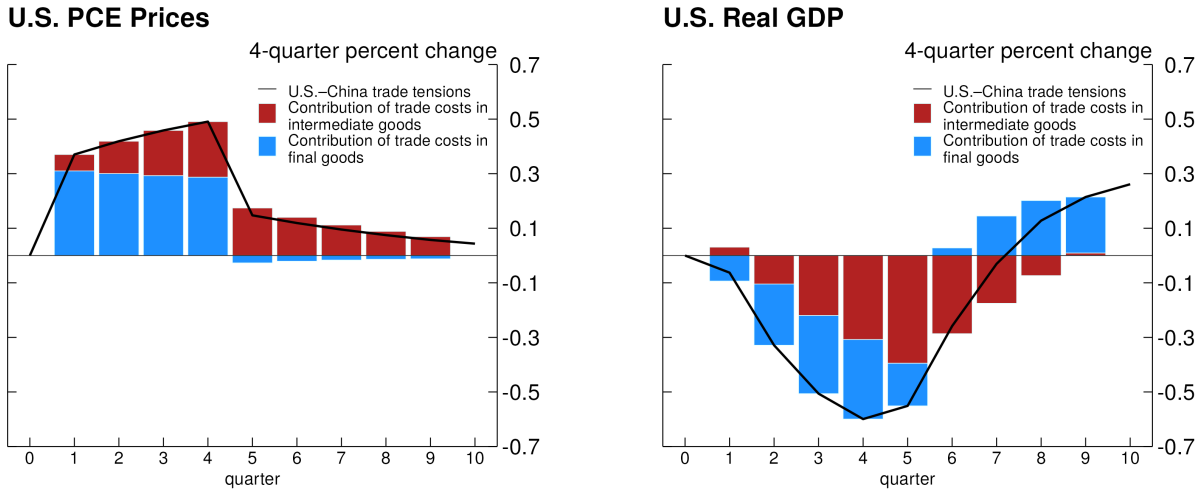
We can also use our model to estimate the effects on the U.S. economy of an increase in trade tensions between the U.S. and China such as that observed in 2018-19. Thus, we construct a scenario in which trade costs between the U.S. and China increase for both final and intermediate goods. Specifically, 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 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.[24] 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.

[24] 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.

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 (RoW) aggregate.

7.1 Data

Relative to our analysis in Section 2, we assemble a dataset that includes novel quarterly data on the evolution of U.S. domestic sourcing shares in final goods and intermediate inputs. Constructing sourcing shares at a quarterly frequency is a challenge because measures of gross output at such frequency are generally not available. To overcome this challenge we follow a procedure similar to Eaton et al. (2016b). We construct quarterly gross output interpolating annual figures from the BEA's input-output tables using industrial production as a reference series and making sure

our quarterly interpolated values aggregate to the annual figures. We combine our gross output estimates with quarterly trade flows of the U.S. with the rest of the world to obtain our measures of domestic sourcing shares. Additional details are provided in Appendix F.2.

Figure 9: U.S. Quarterly Domestic Sourcing Shares

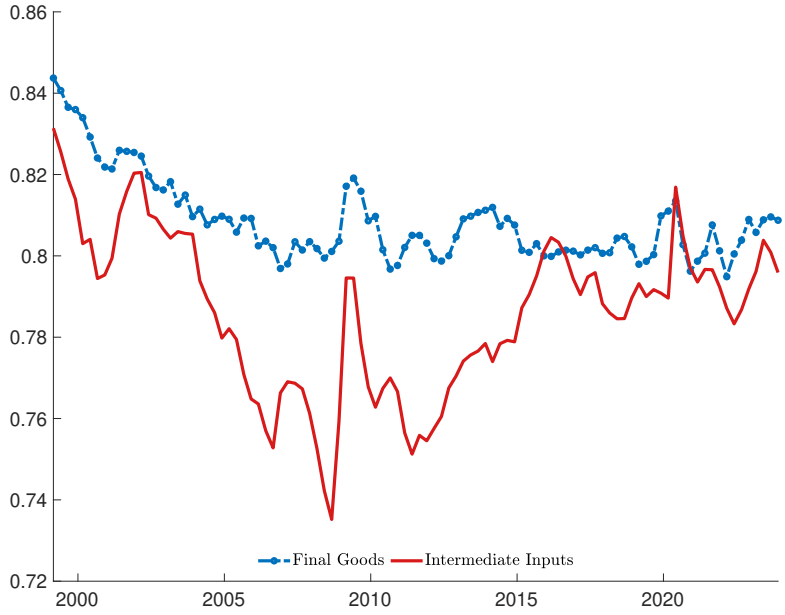


Figure 9 shows the evolution of our quarterly measure of the domestic sourcing shares. The blue line is the domestic sourcing share in final goods, and the the red line is the sourcing share in intermediate inputs. U.S. domestic sourcing shares declined through 2008:Q4. Thereafter the sourcing share for final goods moved sideways around 81 percent, whereas the domestic sourcing share in intermediate inputs trended upwards. The pattern is consistent with the facts documented in Comin and Johnson (2020) with annual data for the U.S., but we are able to capture higher frequency movements such as the large spike in sourcing shares at the onset of the Covid-19 lockdowns.

In addition to the new series on domestic sourcing shares, we estimate the model using standard macroeconomic variables. For both blocs we collect quarterly real GDP growth and CPI inflation, and a measure of nominal interest rates. For the U.S. We use the Wu-Xia shadow federal funds rate to account for the tightness of monetary policy during the period of zero interest rates. For the countries in the rest of the world we use a short-term nominal interest rate or policy rate when available. We measure the RoW aggregate as a trade-weighted average of the major U.S. trading partners as in Bodenstein et al. (2023). Additional details and data sources on the data are provided in the Appendix.

7.2 Calibration and Shock Inference

For structural parameters, we use the values reported in Table 1, assuming symmetric values in each country-bloc. In addition to trade cost shocks, we turn on three additional shocks in each country-bloc: technology $A_{i,t}$, domestic demand $D_{i,t}$, and monetary policy shocks, $\varepsilon^r_{i,t}$. The exogenous variables follow auto-regressive process of the form $x_{i,t} = \rho^x_i x_{i,t-1} + \epsilon^x_{i,t}$ for $x = \{A, D, \tau^C, \tau^M\}$ and where $\varepsilon^x_{i,t} \sim N(0, \sigma^x_i)$ for $x = \{A, D, \tau^C, \tau^M, r\}$.

Using Bayesian inference to estimate the parameters ρ^x_i and σ^x_i and recover the unobserved shocks. We proceed in two steps to avoid contaminating parameter estimates with large shocks due to Covid-19 COVID-19-related lockdowns. First, we restrict the estimation sample from 1999:Q1 to 2019:Q4. Conditional on the estimated shock process parameters, we extend our sample to 1999:Q1 to 2023:Q4 to recover the smoothed shocks $\epsilon^x_{i,t}$. The Appendix details our estimation procedure as well as the estimated parameters for the shock processes.

7.3 Trade Costs and Pandemic Inflation

Figure 10 shows the shock decomposition of U.S. CPI inflation implied by our estimated model. We focus on the period 2018:Q1-2023Q4. The contribution of shocks is grouped into four categories: (i) all trade cost shocks, (ii) supply factors that we capture in the TFP process, (iii) demand factors that combine U.S. aggregate demand and U.S. monetary policy, and (iv) all foreign factors shock.

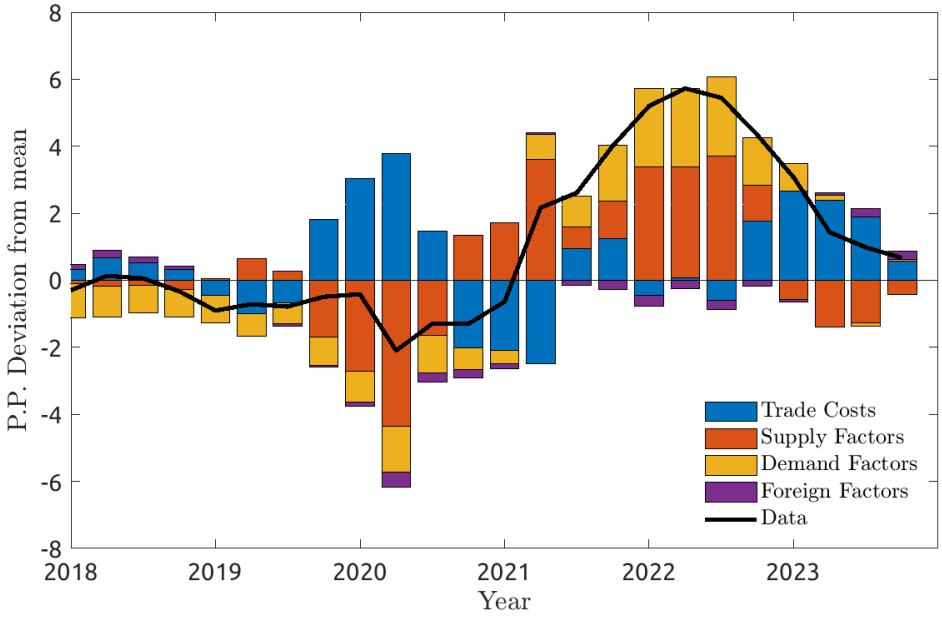
Our main finding is that an increase in trade costs can induce significant movements in inflation. For example, in the initial quarters of the pandemic, trade costs offset the demand contraction and the price reduction. This partly explains why the U.S. economy did not experience a more pronounced period of deflation, given the size of the economic shock.

Turning attention to the post-pandemic period in 2022 and 2023, we find that trade costs significantly contributed to sustaining inflation above the Federal Reserve's target. In particular, trade costs explained about one percentage point of additional inflation in 2022 and contributed to the bulk of inflationary pressures in 2023.

8 Conclusions

We construct a broad measure of trade costs from sectoral bilateral flow data consistent with the "gravity" framework. Empirically, we find that, on average, increases in trade costs are inflationary. A 10 percentage point increase in trade costs, for example, in the form of blanket tariffs with all

Figure 10: Decomposition of U.S. CPI Inflation (Y/Y annualized percents)



trading partners of a country, leads to a contemporaneous rise in CPI inflation of approximately 0.8 percentage points. Moreover, the inflationary effects are persistent, resulting in higher trade costs of intermediate goods.

We build a New Keynesian model with trade in final goods and intermediate inputs that replicates the empirical responses of macro variables to trade cost shocks and use it to analyze the inflationary effect of the rise in U.S.-China trade tensions. We also quantify the role of trade costs during post-pandemic inflation. Although non-trade-related factors affecting aggregate supply and aggregate demand conditions explain the buildup of inflation in the post-pandemic recovery, the effects of higher trade costs contributed to sustaining inflation above the Federal Reserve's target, particularly in late 2022 and 2023.

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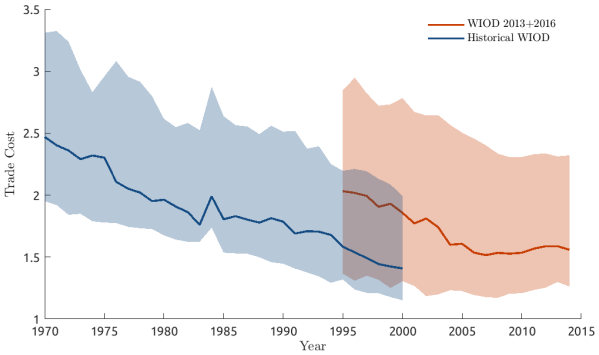
A Data

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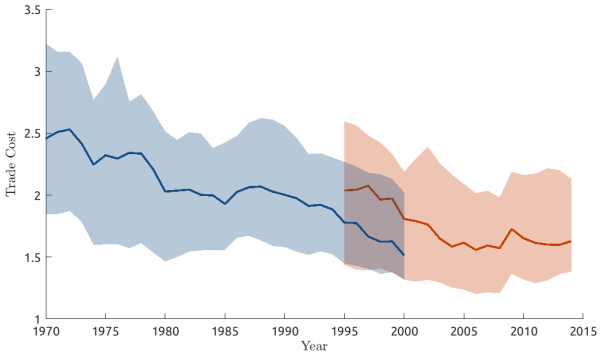
B Evolution of Trade Costs Around the World

Figure 11: Historical Evolution of Global Trade Costs

(a) Median Trade Cost: Final Goods (C)

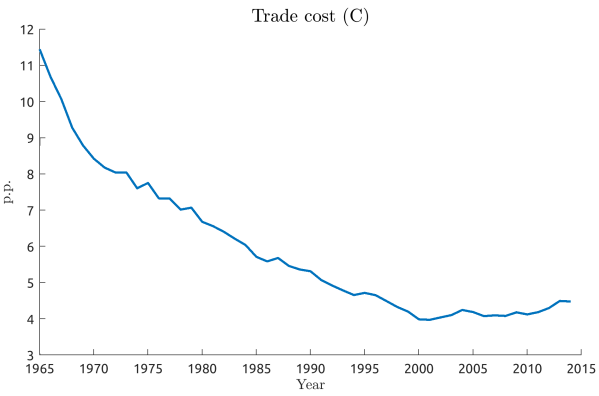


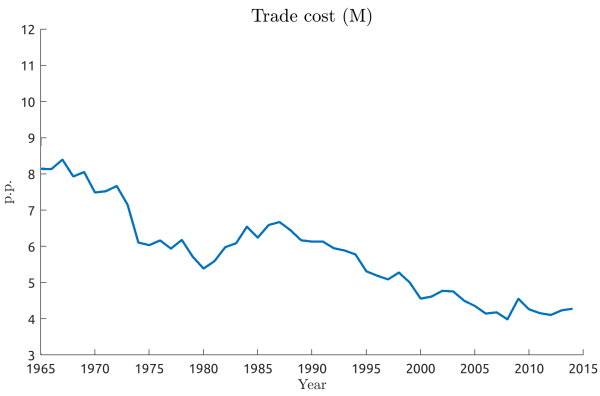
(b) Median Trade Cost: Intermediate Goods (M)



Note: Trade costs are expressed as a percentage of the sales price of the good, divided by 100. That is, the figure shows the evolution of $HR^{Q}_{ih,t} - 1$ for $Q \in \{C, M\}$. Shaded areas are bounded by the 20th and 80th percentiles.

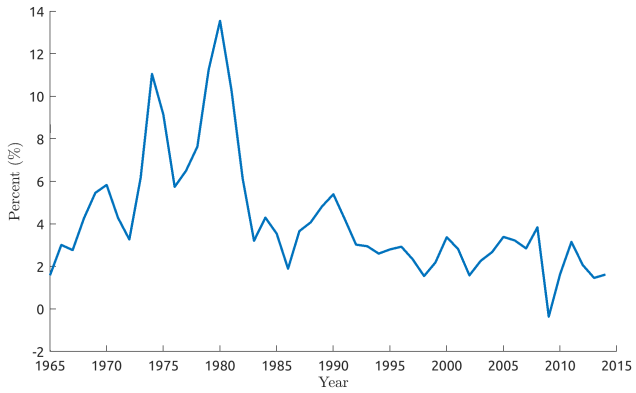
Figure 12: **Evolution of United States trade costs**





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 13: **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.

C Additional Empirical Results

C.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:

$$\log y_{i,t+h} - \log y_{i,t-1} = \alpha_i + \beta_h^j \tau_{i,t} + A_h Z_{i,t} + \varepsilon_{i,t+h} \qquad \text{for } h \geq 0 \tag{38}$$

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 14 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.

C.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 **??** 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.

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.

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.

C.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:

$$y_{i,t+h} = \alpha_i + \beta^y_{h,s}\tau^j_{i,s,t} + A_{h,s}Z_{i,t} + \varepsilon_{i,s,t+h} \qquad \text{for } h \geq 0,, \tag{39}$$

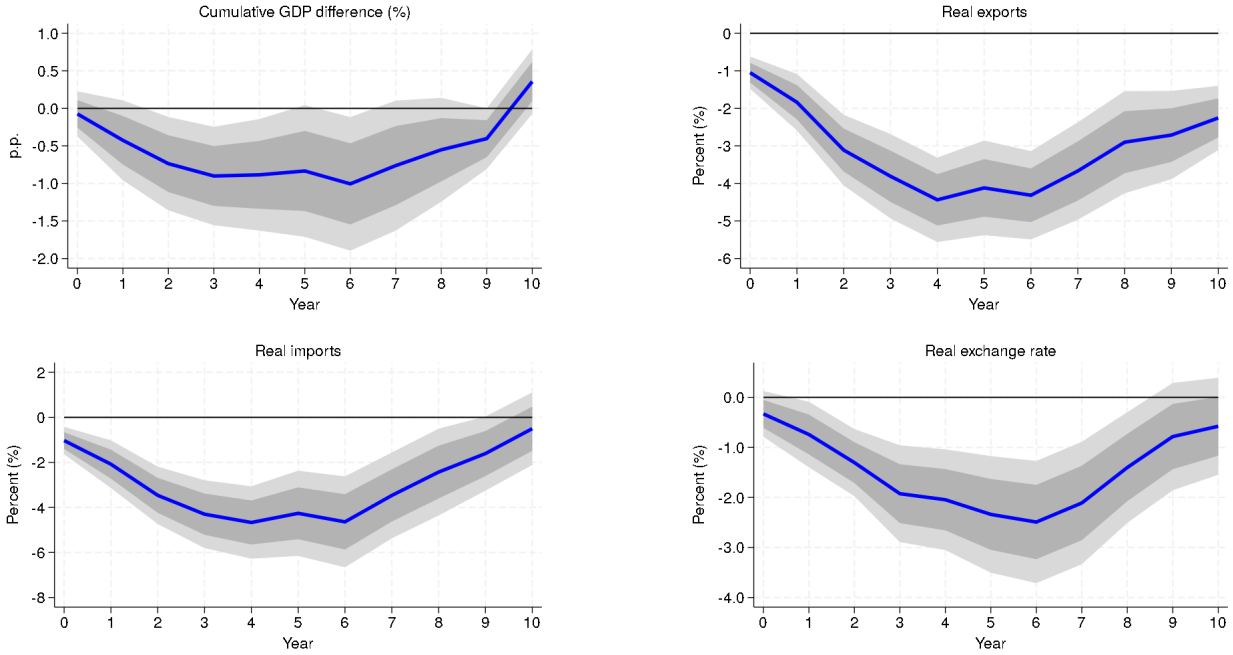
where the coefficient $\beta^y_{h,s}$ now traces the response of inflation to an increase in trade costs in sector $s = \{a, b, c, d\}$ for goods of type $j = \{C, M\}$, after h years following the shock. For comparison, we scale the aggregate inflation response such that the sectoral trade costs lead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

Figure 15 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.

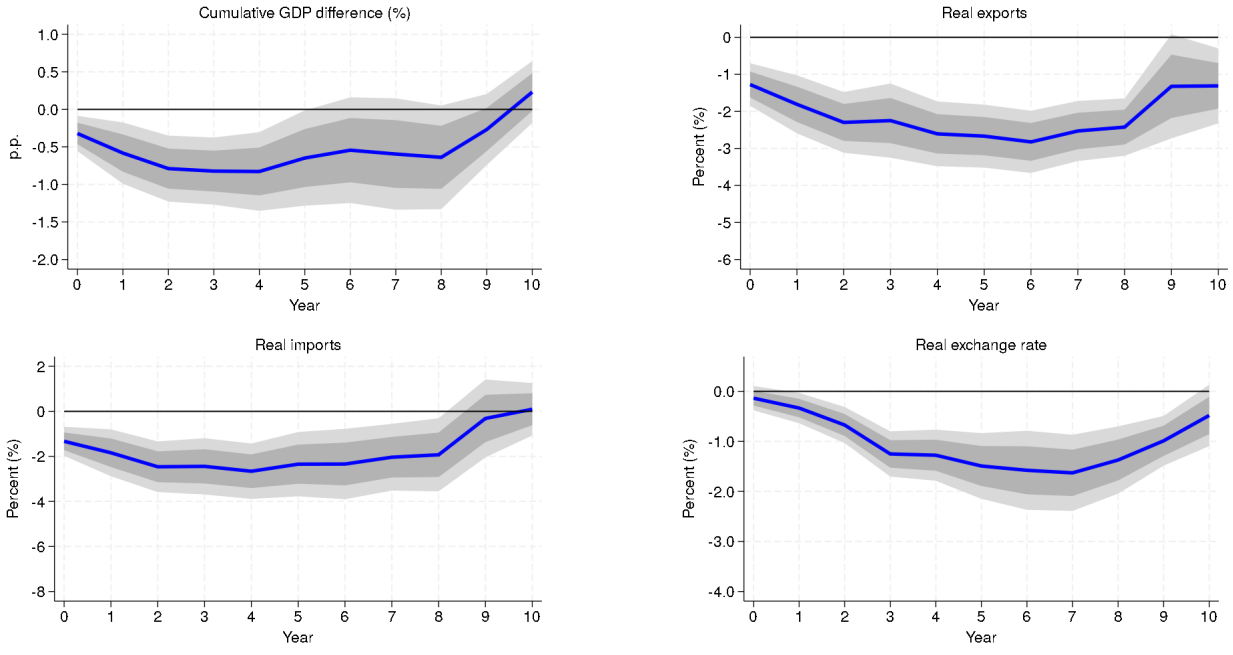
[FIGURE 5 AROUND HERE]

Figure 14: Macroeconomic Response to Higher Trade Costs

Response to Final Trade Costs



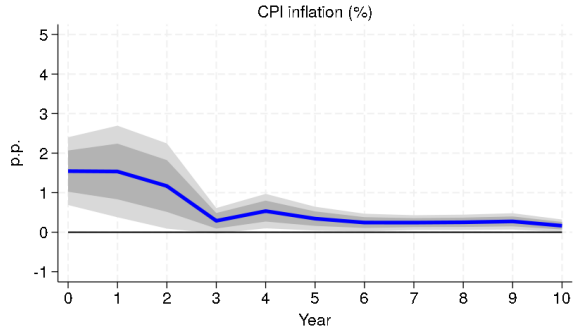
Response to Intermediate Trade Costs



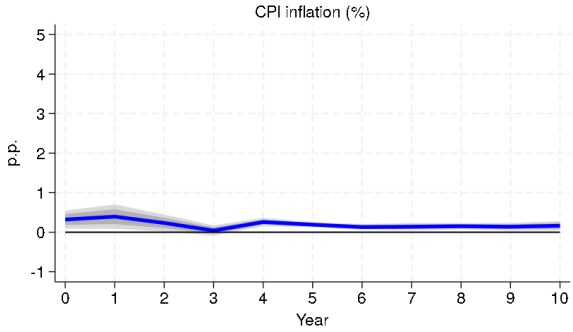
Note: country fixed effects and year error clustering are included. We multiply the trade cost by the same coefficient as in Figure 4 so as to correspond to a 1% increase in the sourcing share. This gives us the same numbers in Year 0 as we computed, namely 4.3% and 4% for final and intermediate trade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

Figure 15: Inflation Response to Sectoral Trade Costs (Final Goods)

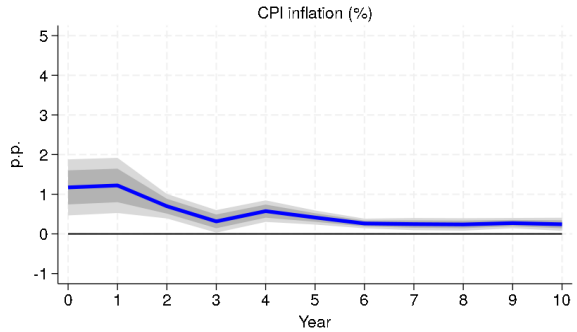
(a) Agriculture and mining



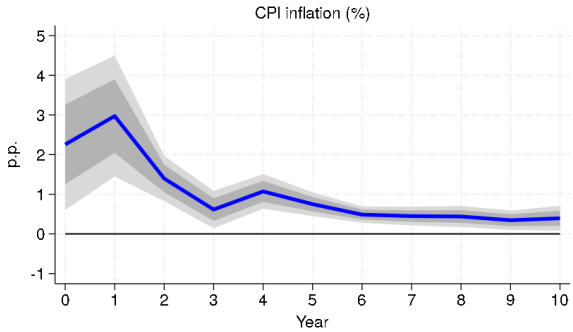
(b) Low-tech manufacturing



(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.

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

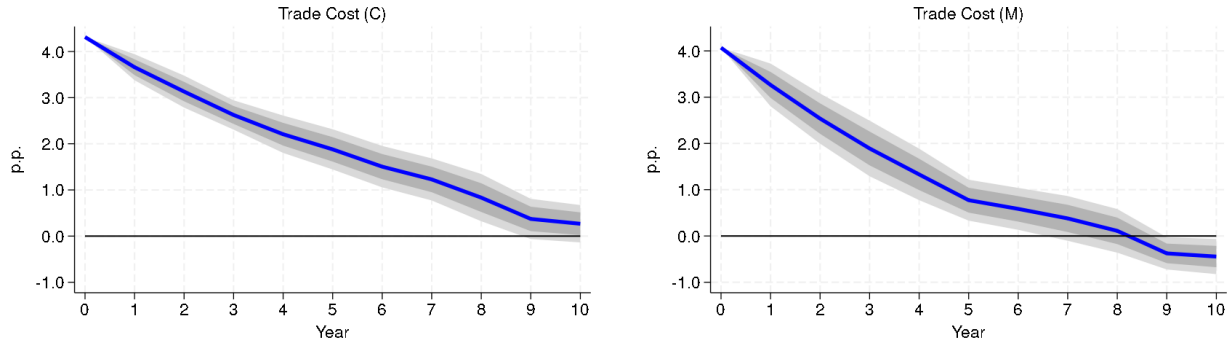
	YoY Inflation Rate				Sourcing share			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	$\eta-1=2$	$\eta-1=4$	$\eta-1=6$	$\eta-1=8$	$\eta-1=2$	$\eta-1=4$	$\eta-1=6$	$\eta-1=8$
Tau	0.0113**	0.0771**	0.1608**	0.2503**	0.0135***	0.1097***	0.2457***	0.3973***
	(0.0049)	(0.0331)	(0.0693)	(0.1081)	(0.0029)	(0.0216)	(0.0470)	(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

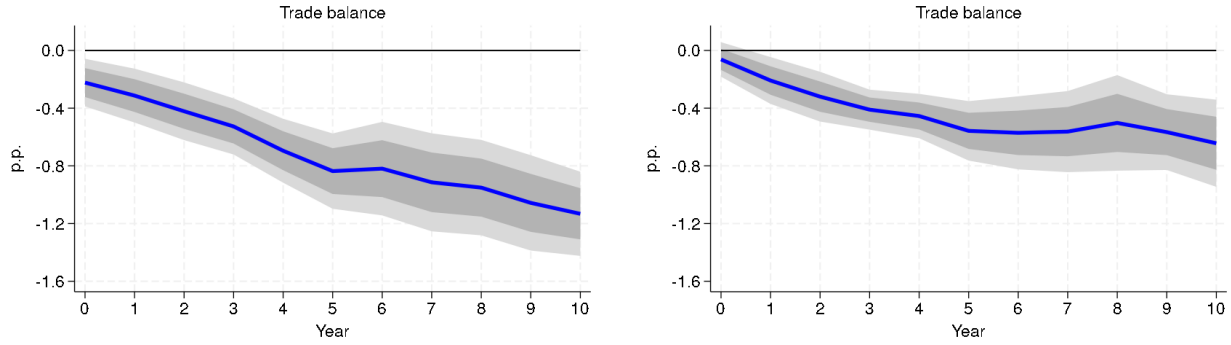
Figure 16: **Local projection of trade cost on itself**



(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 17: **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 Quarterly Domestic Sourcing Shares

From the BEA input-output tables, we can construct the annual intermediate and final domestic sourcing shares as follows. We first filter the sectors of the "Use of Commodities by Industries" tables by selecting only tradable sectors.[25] We then aggregate all rows, and the industry columns to compose the intermediate goods, while aggregating the final end-use columns (both denoted as E_j, or expenditure, where $j \in \{intermediate, final\}$). We also collect the nominal dollar export expenditure (which cannot be split into intermediates and final goods due to being a single series) from the same table, denoted as X. We then collect imports for intermediates and final goods using the "Use of imported commodities by industry" tables in a similar aggregation process to our earlier tables (denoted as M_j where $j \in \{intermediate, final\}$). We use the import series to construct the domestic sourcing share, as:

$$\lambda_j = 1 - \frac{M_j}{E_j}$$

Where j represents the final and intermediate sourcing share. Our data runs annually from 1997 to 2023.

We then use the BEA International Trade in Goods, to interpolate our annual sourcing share series. We first collect total intermediate and final exports from this table, which we use to derive intermediate and final "shares". We then multiply our previously collected nominal exports series, X, into intermediate and final exports using these shares (resulting in X_j, where $X = X_{final} + X_{intermediate}$). We then obtain annual intermediate and final output using the expenditure series as:

$$O_j = E_j - M_j + X_j \tag{40}$$

Where once again $j \in \{intermediate, final\}$.

Therefore, we have annual output, imports, exports and expenditure split by intermediate and final goods. We then use quarterly industrial production from FRED (manufacturing and consumer final goods IP) to interpolate our new annual output series for intermediate and final goods respectively (we use PPI to deflate the series before interpolation, and reflate after interpolation). Then, we use the quarterly exports and imports by intermediate and final goods

[25] Tradable sectors are defined as sectors 1-5 and 8-26, in accordance with NICS classifications.

(from our International Trade in Goods database) to interpolate our annual numbers X_j and M_j. All quantities are nominal, so no deflation is necessary.

Thus, we obtain quarterly $O_j^Q, E_j^Q, M_j^Q, X_j^Q$ (by reversing equation (40) to obtain E_j^Q), which enables us to obtain quarterly domestic sourcing share as $\lambda_j^Q = 1 - \frac{M_j^Q}{E_j^Q}$. We also compose "Annualized Domestic Sourcing Share" λ_j^{QAnn}, still a quarterly series, by taking 4-quarter rolling sums of M_j^Q, E_j^Q and recomputing λ_j as previously. We now have quarterly domestic sourcing share ready for our Bayesian estimation exercise.

F.3 Observation Equations To be updated

- $\log(MFY_t)^o = \log(\frac{\bar{M_F}}{\bar{Y}}) + \hat{M}_{F,t} - \hat{Y}_t$
- $\log(CFY_t)^o = \log(\frac{\bar{C_F}}{\bar{Y}}) + \hat{C}_{F,t} - \hat{Y}_t$
- $\pi_t^o = \bar{\pi}_C + \hat{\pi}_{C,t}$
- $\hat{y}_t^o = \hat{y}_t$
- $\hat{c}_t^o = \hat{c}_t$
- $R_t^o = \log(\bar{r}\bar{\pi}_C) + \hat{R}_t$

F.4 Estimated Parameters To be updated

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]