Regional Effects of Exchange Rate Fluctuations *†

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Abstract

We exploit differences across U.S. states' exposure to trade to study the effects of changes in the exchange rate on economic activity. Across states, trade-weighted exchange rate depreciations are associated with increased state exports, reduced state unemployment and higher state hours worked. The effects are particularly strong during periods of economic slack. A multi-region model with inter-state trade and labor flows, calibrated to match state-level trade data and migration flows replicates the empirical relationship between exchange rates and unemployment. The high degree of interstate trade plays an important role in transmitting shocks across states in the first year, whereas interstate migration shapes cross-sectional patterns in later years. We use the model to study the regional effects of tariffs in the United States. The model suggests that a 25 percent Chinese import tariff on U.S. goods would be felt throughout the United States, even in states with small direct linkages to China, raising unemployment rates by 0.2 to 0.7 percentage points in the short run.

Keywords: regional shocks, exchange rates, transmission across space, multi-country DSGE model

JEL Codes: F22, F41, F45

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1 Introduction

This paper is motivated by three facts. First, there are large differences in the volume of trade across states. State-level export shares range from as much as 20 percent to less than 1 percent of state GDP. Second, export destinations also vary considerably across states. For example, exports to Canada are systematically greater in Northern Midwest states while exports to Mexico are more highly concentrated in the Southwest. Third, changes in real exchange rates are frequent, large and persistent. Exchange rates of destination countries often exhibit changes as large as 20 percent over relatively short periods of time. These basic observations suggest that exchange rate fluctuations should have systematically different effects on each states' economic activity. To the extent that states are linked through trade and factor markets, exchange rate shocks will be transmitted across state borders.

We assemble a state-level dataset to examine the relationship between state-specific trade-weighted real exchange rates, state-level trade in goods, unemployment and output for the years 1999-2018. We find that variations in state-level exchange rates are systematically related to changes in the labor market. On average, a one percent exchange rate depreciation is associated with a decrease in state unemployment of roughly 0.4 percentage points and an increase in state GDP of one to two percent. This increase in economic activity goes along with an expansion of exports and a steady inflow of workers from other states. The strength of these effects at the state level depends on the extent of trade exposure to a particular foreign market. Following Ramey and Zubairy (2018), we also estimate state-dependent effects and show that the responses to exchange rate movements are greater when local labor market conditions are slack.

We then construct a multi-region model of the United States that is consistent with these empirical facts. The framework builds on the multi-country DSGE model in House, Proebsting and Tesar (2018) (HPT) that captures trade and migration flows between regions. We adapt the HPT model to the 50 U.S. states plus the District of Columbia. The model allows for trade in assets and goods and for migration between U.S. states. We follow the literature on small open economies, and add a large region that is unaffected by state-level economic developments (see e.g Galí, 2008; Kehoe and Ruhl, 2009). We refer to this region as the "rest of the world" or RoW. The model is calibrated to match broad features of the interstate trade statistics (Commodity Flow Statistics), labor migration data and international trade flows at the state and country level. We feed in the observed paths of exchange rates for each state into our model and show that it reproduces the effects of exchange rate fluctuations on economic activity observed in the data.

The model illustrates the transmission mechanism at play: A real exchange rate depreciation alters the terms of trade, making the local good cheaper for consumers and boosting demand. Local firms respond to the higher demand by hiring more labor and expanding output. Local consumption and investment rise along with the increase in employment, further stimulating the economy. Search frictions in the labor market prevent an immediate adjustment of labor across locations. There are two channels of transmission to those states that are not directly affected by the change in the exchange rate. First, the increase in labor demand in the affected state triggers migration from other states. Second, because states trade with each other, there is an indirect transmission of the exchange rate shock to demand for goods from other states. Our counterfactuals suggest that both channels contribute to explaining cross-sectional patterns in the data, with interstate trade shaping the response in the first year after the shock and migration playing a more important role in subsequent years.

We then ask how the last thirty years of trade globalization and the recent trade war have left states more or less exposed to exchange rates. Since 1989, U.S. states have steadily increased their exports (as a share of GDP), both in traditional export markets like Canada and the euro and to emerging economies like China and Mexico. Our counterfactual suggests that despite the increase in exports, states' unemployment rates are not necessarily more sensitive to foreign exchange rate fluctuations. This is because the rise in exports was accompanied by an overall increase in trade both with other states and with other nations. As each state trades more, temporary changes in demand at the state level can be offset with changes in imports with other trading partners. Thus, enhanced trade allows states to reduce fluctuations in production arising from changes in exchange rates.

Tariffs between the United States and China have increased substantially in recent years. We use our model to evaluate the effects of an increase in Chinese tariffs of 25 percent across all goods imported from the United States. In response to such a tariff, and abstracting from higher U.S. tariffs on Chinese goods, unemployment rates are predicted to increase by 0.2 to 0.7 percentage points across U.S. states within four quarters. Whereas exports to China are mostly concentrated in a handfull of states in the upper Northwest, the tariff increase will be felt throughout the United States because integrated goods and factor markets transmit the shocks even to states that export little to China.

Our work relates to several strands of literature on the impact of trade shocks on economic activity. Autor, Dorn and Hanson (2016) study the impact of the "China shock" on employment and wages in those parts of the United States specializing in sectors that compete with Chinese imports. Caliendo, Dvorkin and Parro (2019) develop a dynamic trade model with spatially distinct labor markets to capture the general equilibrium effects of the China trade shock on the U.S. economy. Our paper differs from their approach by focusing on the effects of trade shocks at the business cycle frequency. Consequently, we consider a dynamic model that includes investment, imperfect risk sharing and nominal rigidities, features that are likely to be important in the short run.

Our paper also relates to a long-standing literature in international finance that estimates the effect of exchange rates on economic activity (see e.g. Campa and Goldberg, 1995; Ekholm, Moxnes and Ulltveit-Moe, 2012). We add to this literature by emphasizing that the response to exchange rate movements and the transmission of shocks depend on interstate trade, input-output linkages and capital and labor market integration. Finally, our paper speaks to a growing literature in macroeconomics that has emphasized regional variation to macroeconomic shocks in monetary unions. While HPT focuses on European countries, Beraja, Hurst and Ospina (2019); Nakamura and Steinsson (2014); Dupor et al. (2018) have studied the consequences of regional fluctuations for both regional and aggregate business cycles in the United States.

2 Empirical Analysis

2.1 Trade Exposure Across U.S. States

We begin by examining the differences in regional exposure to trade across U.S. States and over time. Export data by state and country of destination are the Origin of Movement (OM) series compiled by the Foreign Trade Division of the U.S. Census Bureau. While the series provide the most accurate available information on state export patterns, they have two shortcomings: First, they only cover trade in manufactured and agricultural goods and therefore exclude trade in services. At the federal level, exports of services comprise roughly one third of all trade over our sample period. Second, the OM series attribute exports to the state where the goods began their final journey to the port of exit from the United States. This can either be the location of the factory where the export item was produced or the location of a warehouse or distributor. Comparing the OM series with the U.S. Census data set on “Exports From Manufacturing Establishments” (which does not contain destinations), Cassey (2009) concludes that, despite these flaws, the OM series are generally of high enough quality to use as origin of production data, and the quality of the data has improved over time.[1]

Table 1 lists each state, the state's size as measured by the share of its GDP relative to total U.S. GDP, the state's export share relative to state GDP, the primary destination for the states exports of goods and the corresponding export share. The median export share has increased slighlty over the last 20 years, from about 5 to 7 percent, indicating that the U.S. economy has become somewhat more open to trade. More importantly, the table shows that there is considerable variation in export shares across states. The lowest export share is close to zero (Hawaii) while the highest is nearly 18 percent of state GDP (Louisiana). There are also considerable state-level fluctuations in export shares over time (not shown).

The primary destination of a state's exports varies considerably across states and over time. Figure 1 shows heat maps of state exports to Canada, Mexico, the euro area, and Japan (the largest four export destinations for the United States) as a share of state GDP averaged over 1999 to 2018. The heat maps show that, in addition to the differences in overall trade exposure reported in Table 1, there is also substantial regional variation by export destination. While exports to Canada are concentrated in Northern States and the Midwest, exports to Mexico are concentrated in the Southwest.

2.2 Exchange Rate Exposure Across U.S. States

Each state exports to other U.S. states as well as several different foreign nations. We construct state-level effective exchange rates to reflect the fact that states have differing degrees of trade with other states and other countries. The effective exchange rates are trade-weighted combinations of individual exchange rates and thus vary across states depending on the volume and orientation of trade.

We calculate the log change in real effective exchange rates as the log change in nominal effective exchange rates deflated by the CPI:

$$\Delta \ln s^*_{i,t} = \Delta \ln S^*_{i,t} + \Delta \ln P^*_{i,t}, \tag{2.1}$$

[1] The Federal Reserve Bank of Dallas uses the same data sources to construct a trade-weighted value of the dollar by U.S. state, see Phillips et al. (2010).

where $\Delta \ln S^*_{i,t}$ is the log change in the nominal effective exchange rate, quoted in U.S. dollar per foreign currency, and $\Delta \ln P^*_{i,t}$ is the log change in the CPI in state n's effective export market relative to the log change in the U.S. CPI. The nominal effective exchange rate is a weighted average of foreign currency exchange rates, where the weights reflect the extent of trade with other countries as well as other states. Denoting country j's log exchange rate relative to the U.S. dollar in period t by $S^{US}_{j,t}$, we calculate the change in the effective exchange rate as

$$\Delta \ln S^*_{i,t} = -\sum_{j=1}^{J} \left(\frac{1}{4} \sum_{s=1}^{4} weight^j_{i,t-s} \right) \Delta \ln S^{US}_{j,t}, \tag{2.2}$$

where the weights correspond to the ratio of state n's exports to country j to state n's GDP. To allow for gradual drift in the trade shares, we average the weights over the four quarters prior to each period t. Export data is taken from the OM series and data on states' GDP is provided by the Bureau of Economic Analysis.[2] Data on U.S. dollar exchange rates are taken from the IMF International Financial Statistics. We calculate the values for $\Delta \ln P^*_{i,t}$ in a similar fashion. Specifically,

$$\Delta \ln P^*_{i,t} = \sum_{j=1}^{J} \left(\frac{1}{4} \sum_{s=1}^{4} weight^j_{i,t-s} \right) \Delta \left(\ln P_{j,t} - \ln P_{US,t} \right), \tag{2.3}$$

where $P_{j,t}$ is country j's CPI. Data on the CPI come from the IMF International Financial Statistics.

Figure 2 displays time series plots for bilateral real exchange rates (price of U.S. goods per price of foreign goods) for the ten most common export destinations for U.S. products. The plots show that there are often sudden large changes in the nominal exchange rates. Sudden changes on the order of 10 to 20 percent are not uncommon.

As described above, these individual nominal exchange rates are combined to produce state-specific effective exchange rates $\Delta \ln S^*_{i,t}$. Figure 3 displays year-to-year growth rates of these statet-specific real effective exchange rates. Year-to-year growth rates are calculated as the sum of the current and previous 3 quarters' growth rate, $\sum_{s=0}^{3} \Delta \ln s^*_{i,t-s}$. We then sort these growth rates and plot their mean across states together with the interquartile range, the interdecile range and the full range across states. The figure reveals common trends in real effective exchange rates across U.S. states, such as the initial depreciation and subsequent

[2] Quarterly state GDP data only starts in 2005:1. We evenly split annual state GDP across the four quarters for years prior to 2005.

appreciation of the U.S. dollar in the wake of the Great Recession. Across time, the average standard deviation of the growth rate is 0.37 percent. The reason this is so much smaller than the fluctuations in nominal exchange rates shown in Figure 2 is that the measure of the real effective exchange rate puts a substantial weight on the domestic market, where the exchange rate vis-a-vis other states is constant. As shown in Table 1, sales within the United States account for more than 90 percent of total state sales, tempering fluctuations in the real effective exchange rate.

Despite the common trends in effective exchange rates over time, the figure also shows some variation across states. The average cross-sectional standard deviation is 0.18 percent; that is, on average, states differ by 0.18 percentage points in the growth rates of their effective exchange rates. In comparison, the cross-sectional standard deviation of the annual change in the U.S. unemployment rate is about 1 percentage point.

2.3 Exchange Rates and Economic Performance

2.3.1 Baseline Results

We next ask whether fluctuations in effective exchange rates can account for the cross-sectional variation in economic performance observed across states. To study this relationship, we run the following regressions for each time horizon $h \geq 0$:

$$x_{i,t+h} - x_{i,t-1} = \alpha_t^h + \alpha_i^h + \beta_s^h \Delta \ln s_{i,t}^* + \beta_y^h \Delta \ln y_{i,t}^* + \left(\sum_{k=1,2} \gamma_k^h \Delta x_{i,t-k} \right) + \varepsilon_{i,t+h}, \tag{2.4}$$

where $x_{i,t}$ is a measure of economic performance (e.g. the unemployment rate or log GDP) in state n at time t. The main coefficient of interest is β_s^h that describes the response of the unemployment rate at horizon h to a log change in the real effective export exchange rate, $\Delta \ln s_{i,t}^*$, calculated according to (2.1). Our regression includes both state fixed effects and time fixed effects. We also control for demand changes in export markets through $\Delta y_{i,t}^*$, the log change in real GDP for state n's trade-weighted export market relative to the log change in U.S. real GDP and is similarly constructed to (2.3).[3,4]

Our approach addresses some important endogeneity concerns. First, to mitigate concerns of reverse causality, we lag the trade shares used to construct effective exchange rates by one period, so that the shares are pre-determined at the beginning of t. Second, our estimates might be subject to omitted variable bias. This is a justified concern because exchange rates are endogenous objects in general equilibrium. As observed in Figure 3, a large part of real exchange rate movements is common to all U.S. states, and this common component is likely to be correlated with economic activity and would therefore bias our estimates. We address this concern by adding time-fixed effects to isolate the state-specific component of exchange rate movements. Our identification therefore relies on differences in states' exposure to exchange rates, either through variations in the share of exports to GDP or through variations in the set of destination markets. While we think that this approach improves on regressions run on country-level data, it is possible to imagine situations that would pose a threat to identification. For example, it is conceivable that a bad maple syrup harvest leads to a depreciation of the Canadian dollar, but also slows down economic activity in U.S. states in the Northeast that have strong trade ties to Canada and are home to maple syrup producers themselves.[5] These possible concerns should be kept in mind when interpreting our empirical results.

We run regression (2.4) for the real effective state exchange rate ($\ln s^*_{i,t}$), as well as various measures of economic performance: the state unemployment rate ($ur_{i,t}$), state real per capita GDP ($y_{i,t}$), nominal exports, ($ex_{i,t}$), hours worked in the state ($l_{i,t}$, both total and in the manufacturing sector), and net immigration. Data on seasonally adjusted unemployment rates and hours worked are taken from the Bureau of Labor Statistics and data on state GDP are taken

[3]We assume that total demand for a state's exports is the sum of domestic (U.S.) demand and demand from foreign nations. Writing total demand for state n as $\omega_{i,US} \ln y_t^{US} + (1-\omega_{i,US}) \sum_{j \in \text{foreign}} \omega_{i,j} \ln y^*_{j,t}$ we then add and subtract $(1-\omega_{i,US}) \ln y_t^{US}$ to get total demand as

$$\ln y_t^{US} + (1-\omega_{i,US}) \sum_{j \in \text{foreign}} \omega_{i,j} \left[\ln y^*_{j,t} - \ln y_t^{US}\right]$$

Taking the first difference gives the variable $\Delta \ln y^*_{i,t}$.above.

[4]We use seasonally adjusted data for real GDP from the IMF International Financial Statistics. For some countries, only unadjusted data is available and we seasonally adjust the data ourselves using the X-13 ARIMA SEATS software used by the U.S. Census. Data on the CPI and real GDP is not available for all export markets and we implicitly set inflation and changes in real GDP for missing observations equal to their U.S. values. This only concerns on average 13 percent of a state's exports for real GDP and 3 percent of a state's exports for the CPI.

[5]We thank our discussant, George Alessandria, for this example.

from the Bureau of Economic Analysis. Data on exports are the OM series. We draw data on each state's foreign imports from the State of Destination series of foreign trade, published by the U.S. census. Both exports and imports are expressed as a percent of $t-1$ state GDP. Finally, data on annual net immigration by state are provided by the Internal Revenue Service and is partly based on tax returns (see Molloy, Smith and Wozniak, 2011, for a discussion of the dataset). We apply the Chow and Lin (1971) method to temporally disaggregate this dataset using quarterly unemployment rate data as high-frequency indicators.[6]

Our key empirical findings are shown in Figure 4. The figure illustrates the impulse responses to a shock to a state's real effective exchange rate. The upper left panel (panel (a)) displays the real exchange rate's reaction to its own innovation. Following a one percent depreciation, the real exchange rate shows essentially no tendency to return to its original value. That is, the real effective exchange rate is approximately a random walk over the horizons we consider.

Panel (b) shows that a real exchange rate depreciation is associated with an increase in exports by about 1 - 2 percent. The rise in exports is the standard supply response to an improvement in the terms of trade. Panels (c) - (e) show the estimated response of the state unemployment rate, state GDP and hours worked to a one-percent change depreciation of the real exchange rate. State unemployment falls by roughly 0.4 percentage points. The point estimates suggest that state GDP rises by about 0.5-1.5 percent while hours worked rise by perhaps 1 - 2 percent. The figure also reports estimates for hours worked in manufacturing. The manufacturing series appears to be substantially more responsive with hours rising by perhaps as much as 4 percent.

As shown in Figure 3, a 1 percent change in the state-level effective exchange rate is not uncommon over the time period we study. Taken together with the results from panels (c) - (e), this suggests that exposure to international trade and exchange rate fluctuations could contribute significantly to unemployment differentials and GDP growth rate differentials across states.

Panel (f) shows the response of cumulative net migration to exchange rate fluctuations. While the estimates are noisy, the point estimates suggest that a 1 percent real exchange rate depreciation at the state level causes an increase in state population through net migration

[6]Certain variables are not available for the entire 1999:1 - 2018:4 time period. In particular, quarterly state GDP is published since 2005:1, hours worked since 2007:1 and imports since 2008:1. Please refer to the Online Appendix for more details on how we apply the Chow-Lin method.

by perhaps 0.3 percent after two years. This finding is consistent with results in HPT who show that cross-state migration in the United States responds to unemployment differentials. The sluggish, but steady inflow of migrants could also help rationalize the reversal of the unemployment response after about a year displayed in panel (c).

Finally, panel (b) shows that besides exports, imports also increase. This increase in imports might at first pass be somewhat puzzling because the exchange rate depreciation should, a priori, make imports more expensive. However, states do not always import from the same states they are exporting to, implying that the exchange rate they face for imports does not move one-for-one with the exchange rate for their exports. In addition, several papers have shown that pass-through into import prices is particularly low for the United States, even in the medium run (see e.g. Gopinath, Itskhoki and Rigobon, 2010). We return to this issue when comparing the model's response to the data.

The results in Figure 4 correspond to changes in a single state's effective exchange rate. This specification imposes a structure that weights bilateral exchange rates by each state's bilateral export shares. Another way of looking at the effects of changes in exchange rates is to examine each state's response to a single bilateral exchange rate. To estimate this effect, we regress state economic indicators on exchange rates country-by-country. Consider the following specification in which we regress state n's change in unemployment on country j's exchange rate, s_t^j:

$$\begin{aligned} ur_{i,t+h} - ur_{i,t-1} = \alpha_t^{h,j} + \alpha_i^{h,j} + \beta_{s,n}^{h,j} \Delta \ln s_t^j + \beta_{y,n}^{h,j} \Delta \ln y_t^j + \beta_s^{h,j} \Delta \ln s_{i,t}^{*,\neq j} \\ + \beta_y^{h,j} \Delta \ln y_{i,t}^{*,\neq j} + \gamma_1^{h,j} \Delta ur_{i,t-1} + \gamma_2^{h,j} \Delta ur_{i,t-2} + \varepsilon_{i,t+h}^j. \end{aligned} \tag{2.5}$$

In this case, we estimate a state-specific reaction $\beta_{s,n}^{h,j}$ to changes in the real exchange rate vis-a-vis country j while controlling for changes in the weighted exchange rate for all other export destinations (the terms $\beta_s^{h,j} \Delta \ln s_{i,t}^{*,\neq j}$).

For example, consider the estimated responses to changes in the Canadian dollar. The state-specific coefficients of interest are $\beta_{s,n}^{h,j}$ which give the estimated reaction of unemployment for each state n in response to changes in currency j (where j is the Canadian dollar). One would anticipate that $\beta_{s,n}^{h,j}$ would be greater for states that are more closely tied to Canada through trade. We run regression (2.5) for the five top destination markets separately: the Canadian dollar, the Chinese yuan, the Japanese yen, the euro and the Mexican peso.

Figure 5 plots the estimated coefficients averaged over a year ($\frac{1}{4} \sum_{h=0}^{3} \hat{\beta}_{s,n}^{h,j}$) against the states' trade exposure to destination j. Because we estimate (2.5) for the five main export destinations, each state appears five times in the graph. The estimated coefficient is on the vertical axis with OLS standard errors displayed as bars. In the figure, states with more trade exposure experience a greater decline in unemployment when the U.S. dollar depreciates against a destination market's currency. The slope coefficient (-0.32) quantifies this relationship, implying that an increase in trade exposure by 1 percentage point raises a state's unemployment response to a U.S. dollar appreciation by 0.3 percentage points. This number is in line with the estimate displayed in panel (c) of Figure 4. We will compare this coefficient to the corresponding coefficient in the structural model.

2.3.2 Response Over the Business Cycle

It is possible that the responses of macroeconomic variables to changes in the real exchange rate depend on the degree of slack in the economy. To test for this effect, we re-estimate equation (2.4) allowing for different responses to depend on the business cycle. Specifically, we consider the regression specification:

$$\begin{aligned} x_{i,t+h} - x_{i,t+h} = {} & \mathbb{I}_{i,t}\left[\beta^h_{\text{slack},s}\Delta\ln s^*_{i,t} + \Gamma^h_{\text{slack},Z}\mathbf{Z}_{i,t}\right] \\ & + (1-\mathbb{I}_{i,t})\left[\beta^h_{\text{no slack},s}\Delta\ln s^*_{i,t} + \Gamma^h_{\text{no slack},Z}\mathbf{Z}_{i,t}\right] + \varepsilon_{i,t+h} \end{aligned} \tag{2.6}$$

Here $\mathbb{I}_{i,t}$ indicates periods of slack and $\mathbf{Z}_{i,t}$ is a vector of controls. As in the earlier specification (2.4), the controlls $\mathbf{Z}_{i,t}$ include state and time fixed effects, demand changes in export markets and two lags of the left-hand side variable. We follow Ramey and Zubairy (2018) and Owyang, Ramey and Zubairy (2013) and say that a state's economy has slack if its unemployment rate exceeds 6.5 percent.

The impulse responses in Figure 6 show that exports, unemployment, GDP and hours worked are more responsive during periods of relatively high slack compared to periods when the labor market is tight.[7] Exports rise by about 3 percent and stay up high during high unemployment states, whereas they never exceed 2 percent and quickly revert back to zero during periods of low slack. Similarly, unemployment falls by 0.9 percentage points during periods of slack, whereas it barely falls when labor markets are tight. As emphasized by Ramey and Zubairy (2018), different responses across the business cycle could be caused by differences in the shock process itself. This is not the case here: independent of the state of

[7] We thank Linda Goldberg for suggesting this extension.

the business cycle, the real exchange rate displays random-walk behavior in reaction to its own innovation.

3 A Model of U.S. State Exchange Rate Fluctuations

We apply the multi-region model in HPT to analyze the impact of changes in exchange rates across U.S. states. The goal of the model is to generate responses of unemployment and output to exchange rate shocks and to assess the model's performance relative to the facts we document in Section 2. The model includes many features that are now standard in modern DSGE frameworks as well as unemployment and cross-state labor migration. Because many of the model details are explained in our earlier work, we present only an overview of the model in this section and refer the reader to House, Proebsting and Tesar (2018, 2019) for a more detailed discussion.

We introduce labor mobility in a tractable way by making the "large" household assumption as in Merz (1995) to allow for complete risk-sharing across household members. We introduce unemployment into our model through a modified Diamond-Mortensen-Pissarides (DMP) search-and-matching framework (see Diamond, 1982; Mortensen, 1982; Pissarides, 1985).

3.1 Households

The model consists of the 50 U.S. states, the District of Columbia and a rest-of-the-world (RoW) aggregate (52 regions in total). Let i be an index of the regions. The number of households originating from state i is fixed at $\mathbb{N}^i$. Each state i has a representative household made up of a unit mass of individuals that can live and work in any state $j = 1, ..., \mathcal{N}$, with $\mathcal{N} = 51$ (they cannot live or work outside of the United States). Household members have to live and work in the same state. Let $n^i_{j,t}$ be the fraction of state i's household that *live* in state j at time t. Superscripts denote the state of origin while subscripts denote state of residence.

The total number of people living and working in state i is denoted by $\mathbb{N}_{i,t}$ and is given by

$$\mathbb{N}_{i,t} = \sum_j n^j_{i,t} \mathbb{N}^j. \tag{3.1}$$

For simplicity, we abstract from an intensive labor supply choice and instead assume that each person supplies a fixed amount of labor l_i wherever they choose to work. Household members from state i living in state j consume state j's final good. State-specific final goods cannot be traded.

In addition to receiving utility from consumption, household members receive a time-invariant utility gain or loss tied to their current residence (see the literature review in Redding and Rossi-Hansberg, 2017). We allow a state's amenity to differ between households from different states of origin. The utility gain from living in j for a person from state i is A_j^i. We normalize the home-state amenity to $A_i^i = 0$.

The representative household for each state maximizes the following discounted utility (expressed as of date 0):

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left\{ \sum_j n_{j,t}^i U(c_{j,t}^i) + \sum_{j \neq i} n_{j,t}^i \left(A_j^i - \frac{\ln(n_{j,t}^i)}{\gamma} \right) \right\}. \tag{3.2}$$

where $U(c_{j,t}^i) = \left(c_{j,t}^i\right)^{1-\frac{1}{\sigma}}$, and σ is the intertemporal elasticity of substitution. When household members migrate, they receive the state-specific amenity but average utility declines with the share of migrants $n_{j,t}^i$. The willingness to migrate is governed by the parameter $\gamma > 0$ that limits the extent to which migration responds to economic conditions.

Households receive labor income, capital income, profits and pay lump-sum taxes. Labor income is earned in the state of residence while capital and firms of state i are owned by the household members originating from state i. Household i's labor income at time t is $\sum_j W_{j,t}^h n_{j,t}^i l_j$. Each worker in state j is paid the same nominal wage $W_{j,t}^h$ irrespective of where they are from. We allow for country-specific variation in labor force participation rates so the per capita labor supply l_i differs for each state. We calibrate these parameters to match observed labor force participation rates.

Households have access to internationally traded non-contingent, one-period bonds that pay off a gross interest rate of $1 + i^*$ in foreign currency. Let S_t^* be the price of this foreign currency in U.S. dollars. Households then choose their members' locations $n_{j,t}^i$, consumption in each state $c_{j,t}^i$, investment $X_{i,t}$, the rate of capital utilization $u_{i,t}$, next period's capital stock,

$K_{i,t}$, and bond holdings B_t^i for all $t \geq 0$ to maximize (3.2) subject to the budget constraint

$$\mathbb{N}^i \left[\left(\sum_j P_{j,t} n_{j,t}^i c_{j,t}^i \right) + \left(\sum_{j \neq i} P_{j,t} n_{j,t}^i \frac{1}{1-\beta} \Phi \left(\frac{n_{j,t}^i}{n_{j,t-1}^i} \right) \right) \right] + \mathbb{N}_{i,t} P_{i,t} X_{i,t} + \mathbb{N}^i \frac{S_t^* B_t^i}{(1+i^*)}$$
$$= \mathbb{N}^i \sum_j n_{j,t}^i W_{j,t}^h l_j + \mathbb{N}_{i,t-1} K_{i,t-1} \left(R_{i,t}^k u_{i,t} - P_{i,t} a(u_{i,t}) \right) + \mathbb{N}_{i,t} \left(\Pi_{i,t} - T_{i,t} \right) + \mathbb{N}^i S_t^* B_{t-1}^i,$$

the capital accumulation constraint[8]

$$\mathbb{N}_{i,t} K_{i,t} = \mathbb{N}_{i,t-1} K_{i,t-1} (1-\delta) + \left[1 - \Lambda \left(\frac{\mathbb{N}_{i,t} X_{i,t}}{\mathbb{N}_{i,t-1} X_{i,t-1}} \right) \right] \mathbb{N}_{i,t} X_{i,t},$$

and the constraint $\sum_j n_{j,t}^i = 1$. The variables $X_{i,t}$, $K_{i,t}$ and $u_{i,t}$ denote investment, capital and capital utilization in state i; $R_{i,t}^k$ is the nominal rental price of capital; $\Lambda(\cdot)$ and $\Phi(\cdot)$ are adjustment cost functions for investment and migration respectively[9]; $\Pi_{i,t}$ are nominal profits and $T_{i,t}$ are nominal lump-sum taxes.

3.2 Firms

There are two groups of firms. Final-good firms produce a non-tradable good that is used for local consumption, investment and state government purchases. Final good firms purchase intermediate goods from other states and other countries to be used as inputs. Intermediate-good firms produce tradeable inputs for production of final goods.

Prices of the tradeable intermediate goods are sticky and governed by New Keynesian Phillips Curves:

$$\tilde{\pi}_{i,t} = \zeta \left(\widetilde{mc}_{i,t} - \tilde{p}_{i,t} \right) + \beta E_t \left[\tilde{\pi}_{i,t+1} \right],$$

where $\tilde{x}$ denotes the log change in the variable x relative to its non-stochastic steady state value, $\pi_{i,t}$ is inflation of the intermediate good, $\pi_{i,t} = \frac{p_{i,t}}{p_{i,t-1}}$, mc denotes the real marginal cost of production, and $\zeta = \frac{(1-\theta)(1-\theta\beta)}{\theta}$ where θ is the Calvo probability of price rigidity. The nominal marginal cost in state i is

$$MC_{i,t} = \frac{1}{Z_{i,t}} \left(W_{i,t}^f \right)^{1-\alpha} R_{i,t}^{\alpha} \left(\frac{1}{1-\alpha} \right)^{1-\alpha} \left(\frac{1}{\alpha} \right)^{\alpha}$$

[8] We assume adjustment costs in investment as in Christiano, Eichenbaum and Evans (2005), with $\Lambda(1) = \Lambda'(1) = 0$ and $\Lambda''(1) > 0$.

[9] The adjustment cost functions satisfy $\Lambda(1) = \Lambda'(1) = \Phi(1) = \Phi'(1) = 0$, while $\Phi''(1) > 0$ and $\Lambda''(1) > 0$.

where $W^f_{i,t}$ is the nominal wage paid by firms in state i, $R_{i,t}$ is the nominal rental price capital and $Z_{i,t}$ is a state-specific productivity shock. Real marginal cost is simply $mc_{i,t} = \frac{MC_{i,t}}{P_{i,t}}$. The real marginal cost in terms of the intermediate good is then $\frac{mc_{i,t}}{p_{i,t}}$.

3.2.1 Trade and Exchange Rates

The final goods are assembled from a (state-specific) CES aggregate of intermediate goods from all states and the RoW. Final-good firms are competitive and take the prices of the intermediate goods as given. Foreign imports to state i are denoted by $y^*_{i,t}$ and their U.S. dollar price is $p^*_{i,t}$. This import price in U.S. dollars is state-specific to reflect the fact that states differ in the set of countries they import from. We discuss how this price is determined below. Final-good producers maximize their profits

$$P_{i,t}Y_{i,t} - \sum_{j=1}^{\mathcal{N}} p_{j,t} y^j_{i,t} - p^*_{i,t} y^*_{i,t}$$

subject to the CES production function

$$Y_{i,t} = \left(\left[\sum_{j=1}^{\mathcal{N}} \left(\omega^j_i\right)^{\frac{1}{\psi_y}} \left(y^j_{i,t}\right)^{\frac{\psi_y - 1}{\psi_y}} \right] + \left(\omega^*_i\right)^{\frac{1}{\psi_y}} \left(y^*_{i,t}\right)^{\frac{\psi_y - 1}{\psi_y}} \right)^{\frac{\psi_y}{\psi_y - 1}} \tag{3.3}$$

Here, $y^j_{i,t}$ is the amount of state-j intermediate good used in production by state i at time t and ψ_y is the trade elasticity. The weights $\omega^j_{i,t}$ satisfy $\omega^*_i + \sum_j \omega^j_i = 1$. We calibrate ω^j_i to match average bilateral trade shares across states and calibrate ω^*_i to match the trade share of each states with the rest of the world.

The solution to this maximization problem yields state i's demand for domestic intermediate goods from state j:

$$y^j_{i,t} = Y_{i,t}\omega^j_i \left(\frac{p_{j,t}}{P_{i,t}} \right)^{-\psi_y}. \tag{3.4}$$

Similarly, the demand for foreign imports is given by

$$y^*_{i,t} = Y_{i,t}\omega^*_i \left(\frac{p^*_{i,t}}{P_{i,t}} \right)^{-\psi_y}. \tag{3.5}$$

Just as each state has a demand for the tradable intermediate good, foreign countries have demand functions for goods produced in the United States. Demand curves for the RoW are given by the isoelastic functions

$$y^i_{*,t} = \omega^i_* \left(\frac{p_{i,t}}{S^*_{i,t}}\right)^{-\psi_y}, \tag{3.6}$$

where $S^*_{i,t}$ is the nominal (effective) exchange rate that describes the price of a foreign currency bundle in U.S. dollars. The state subscript i reflects the fact that, because states have different trade shares and different trading partners, each state has a different effective exchange rate for their exports.

Shock process Exogenous fluctuations in exchange rates are the driving force in the model and influence local demand by shifting the foreign demand curves (3.6). In line with empirical evidence on exchange rate dynamics, we capture these exchange rate fluctuations by assuming that the trade-weighted exchange rates are random walks. Thus, for each state i,

$$lnS^*_{i,t} = lnS^*_{i,t-1} + \varepsilon_{i,t} \tag{3.7}$$

where $\varepsilon_{j,t}$ is a mean zero shock. The assumption that the exchange rate is a random walk together with international trade in nominal bonds implies that the interest rate set by the Federal Reserve has to be equal to the (constant) foreign interest rate. In effect, U.S. monetary policy does not react to state-specific exchange rate shocks.[10]

We assume that the U.S. dollar price of imports from RoW, $p^*_{i,t}$, is also influenced by movements in the nominal exchange rate, $S^*_{i,t}$.[11] The empirical literature suggests that the pass-through of exchange rate fluctuations into import prices for the United States is quite low, hovering between 0.2 upon impact and 0.3 after 2 years (see Gopinath, Itskhoki and Rigobon, 2010).[12] Consistent with this finding, we model the difference in state i's exchange

[10] To explicitly model monetary policy, we could add a bond denominated in U.S. dollars with its interest rate, i_t, set by the Federal Reserve. Such a setup would give rise to an uncovered interest rate parity between U.S. dollar bonds and international bonds:

$$(1+i_t)\mathbb{E}_t\left\{\frac{U_{1,i,t+1}}{P_{i,t+1}}\right\} = (1+i^*)\mathbb{E}_t\left\{\frac{S^*_{t+1}}{S^*_t}\frac{U_{1,i,t+1}}{P_{i,t+1}}\right\}.$$

Assuming that S^*_t follows a random walk and keeping the foreign interest rate fixed, this uncovered interest rate parity condition then requires the intereste rate set by the Federal Reserve to be kept constant.

[11] For simplicity, we assume the same exchange rate in both export and import markets. In the data, the two exchange rates are strongly correlated because states tend to engage in bilateral trade with countries.

[12] Gopinath (2015) relates these asymmetric pass-throughs to the dominance of the U.S. dollar as an invoicing currency.

rate and its U.S. dollar import price as a slowly adjusting AR(1) process:

$$\ln S_{i,t}^{*} - \ln p_{i,t}^{*} = \theta_1 \left(\ln S_{i,t-1}^{*} - \ln p_{i,t-1}^{*} \right) + (1-\theta_0)\varepsilon_{i,t}, \tag{3.8}$$

where $\varepsilon_{i,t}$ is the same shock as in (3.7).[13] A complete and immediate pass-through into import prices would require $\theta_0 = 1$ and $\theta_1 = 0$. To match the empirical evidence, we set $\theta_0 = 0.2$, i.e. upon impact, the pass-through into U.S. dollar import prices is 20 percent. Choosing $\theta_1 = 0.981$ ensures a pass-through of 30 percent at a horizon of 2 years, which then slowly grows towards 100 percent in the long run.

3.3 Labor Markets and Labor Reallocation

Workers move from one state to the next in response to changing labor market conditions. The incentive to move depends on the difference in local labor market conditions and the preferences to move included in the utility function (3.2). Workers in each state are matched to employers according to a DMP search framework. We model labor search by assuming that each entering worker provides work to employment agencies (EA) for the wage $w_{i,t}^{h} = \frac{W_{i,t}^{h}}{P_{i,t}}$ where the superscript indicates that this is the wage received by the household (i.e., by the worker). The employment agency then supplies available workers in a search market where workers are matched to vacancies. Vacancies are posted by human resource (HR) firms who in turn sell matched workers to the firms for a wage $w_{i,t}^{f} = \frac{W_{i,t}^{f}}{P_{i,t}}$. The wage paid by the HR firms to the EA firms is referred to as the "match wage" and is denoted $w_{i,t}$. Naturally, $w_{i,t}^{h} < w_{i,t} < w_{i,t}^{f}$.

The probability that a job hunter (an unmatched worker) finds a job is given by $f_{i,t}$. If the worker is matched, the employment agency receives

$$\mathcal{E}_{i,t} = w_{i,t} - w_{i,t}^{h} + (1-d)\beta \mathbb{E}_t \left\{ \Psi_{i,t+1} \mathcal{E}_{i,t+1} \right\},$$

where $d \in (0,1)$ is an exogenous job destruction rate and $\Psi_{i,t+1} = \frac{u_{1,i,t+1}^{i}}{u_{1,i,t}^{i}}$ is household i's stochastic discount factor. If the worker is not matched, the EA gets an unemployment benefit b_i less the wage $w_{i,t}^{h}$. Notice that the EA pays $w_{i,t}^{h}$ regardless of whether the worker

[13] Rewriting this equation, we obtain

$$\ln p_{i,t}^{*} = \theta_1 \ln p_{i,t-1}^{*} + \theta_0 \ln S_{i,t}^{*} + (1-\theta_0-\theta_1) \ln S_{i,t-1}^{*}.$$

is matched or not. The payoff to the EA from hiring a worker is $f_{i,t}\mathcal{E}_{i,t} + (1 - f_{i,t})(b_i - w^h_{i,t})$. Assuming that there is free entry for the EA firms, we must have $\mathcal{E}_{i,t} = \frac{1-f_{i,t}}{f_{i,t}}\left(w^h_{i,t} - b_i\right)$.

HR firms post vacancies $V_{i,t}$. Each vacancy requires a per-period cost $\varsigma > 0$. The job filling probability is denoted by $g_{i,t}$. Denote the value to the HR firm of filling a vacancy by $\mathcal{J}_{i,t}$. Then, the value of posting a vacancy to an HR firm is

$$\mathcal{V}_{i,t} = g_{i,t}\mathcal{J}_{i,t} + (1 - g_{i,t})\,\beta\mathbb{E}_t\left\{\Psi_{i,t+1}\mathcal{V}_{i,t+1}\right\} - \varsigma.$$

Since the HR firm gets $w^f_{i,t}$ for every matched worker but pays $w_{i,t}$ to the EA firm, the value of a filled vacancy is

$$\mathcal{J}_{i,t} = w^f_{i,t} - w_{i,t} + (1 - d)\,\beta\mathcal{J}_{i,t+1} + d\beta\mathbb{E}_t\left\{\Psi_{i,t+1}\mathcal{V}_{i,t+1}\right\}$$

We assume that HR firms face a quadratic cost to adjust the number of vacancies. This cost is given by a function $\Upsilon\left(\frac{V_{i,t+s}}{V_{i,t+s-1}}\right)$ with $\Upsilon(1) = \Upsilon'(1) = 0$ and $\Upsilon''(1) \geq 0$. The first-order condition for vacancies requires

$$\frac{\mathcal{V}_{i,t}}{\varsigma} = \Upsilon_{i,t} + \frac{V_{i,t}}{V_{i,t-1}}\Upsilon'_{i,t} - \beta\mathbb{E}_t\left\{\Psi_{i,t+1}\left(\frac{V_{i,t+1}}{V_{i,t}}\right)^2\Upsilon'_{i,t+1}\right\},$$

where $\Upsilon_{i,t} = \Upsilon\left(\frac{V_{i,t}}{V_{i,t-1}}\right)$.

The match wage, $w_{i,t}$, is determined through Nash bargaining and satisfies

$$\varrho\mathcal{J}_{i,t}(w_{i,t}) = (1 - \varrho)\left(\mathcal{E}_{i,t}(w_{i,t}) - (b_i - w^h_{i,t})\right).$$

The total number of job hunters $\mathbb{N}_{i,t}H_{i,t}$ is the sum of everyone who was unemployed in the previous period plus all the workers who lost their jobs plus any (net) new entrants into the labor force. Thus,

$$\mathbb{N}_{i,t}H_{i,t} = \mathbb{N}_{i,t-1}\left[l_i - L_{i,t-1}\right] + d\mathbb{N}_{i,t-1}L_{i,t-1} + l_i\left[\mathbb{N}_{i,t} - \mathbb{N}_{i,t-1}\right].$$

Matches per capita are given by the matching function

$$M_{i,t} = \bar{m}H^{\zeta}_{i,t}V^{1-\zeta}_{i,t}$$

where $\bar{m} > 0$. The job finding rate, $f_{i,t} = \frac{M_{i,t}}{H_{i,t}}$ and $g_{i,t} = \frac{M_{i,t}}{V_{i,t}}$. Total employment in state i evolves according to

$$\mathbb{N}_{i,t} L_{i,t} = (1-d)\mathbb{N}_{i,t-1} L_{i,t-1} + \mathbb{N}_{i,t} M_{i,t}.$$

and finally, the unemployment rate is

$$ur_{i,t} = l_i - L_{i,t}. \tag{3.9}$$

3.4 Aggregation

For each state i, aggregate production of the tradable intermediate goods is

$$\mathbb{N}_{i,t} Q_{i,t} = Z_{i,t} \left(\mathbb{N}_{i,t-1} u_{i,t} K_{i,t-1}\right)^{\alpha} \left(\mathbb{N}_{i,t} L_{i,t}\right)^{1-\alpha} = \left(\sum_{j=1}^{\mathcal{N}} \mathbb{N}_{j,t} y^i_{j,t}\right) + y^i_{*,t}.$$

which must equal the total demand for the states intermediate good by other trading partners. Real state-level GDP is also $\mathbb{N}_{i,t} Q_{i,t}$.

Final goods production (per capita) is $Y_{i,t}$ and is given by (3.3). The market clearing condition for the aggregate final good is

$$\mathbb{N}_{i,t} Y_{i,t} = \mathbb{N}_{i,t} C_{i,t} + \mathbb{N}_{i,t} X_{i,t} + \mathbb{N}_{i,t} G_{i,t} + a(u_{i,t})\mathbb{N}_{i,t-1} K_{i,t-1} + \varsigma \mathbb{N}_{i,t} V_{i,t},$$

where $\mathbb{N}_{i,t} C_{i,t} = \sum_{j=1}^{N} n^j_{i,t} c^j_{i,t} \mathbb{N}^j$ is aggregate consumption in state i. The labor market clearing condition is given by (3.9). Finally, the bond market clearing condition requires that the bond position of the RoW mirrors the aggregate bond position of the United States, $\sum_{i=1}^{\mathcal{N}} \mathbb{N}^i B^i_t$.

3.5 Steady State

We solve the model by log-linearizing the equilibrium conditions around a non-stochastic steady state with zero inflation. We adjust the productivity levels Z_i so that the real price of the intermediate good, and hence the real exchange rates, are 1 for all states. We set the amenity values A^i_j and the trade weights ω^i_j to match observered state location patterns (for the A^i_j parameters) and state trade patterns (for the ω^i_j parameters). Given the number of people living out of state (n^i_j) and data on state populations $\mathbb{N}_i$, we set the household size for each state $\mathbb{N}^j$ (i.e., the number of people originating from state j) from (3.1). See the section on calibration below for more detail on these parameter settings.

The state trade data implies net export shares (in goods) for each state. These shares are determined jointly by the trade weights, ω_i^j, and country size as measured by state domestic absorption, $\mathbb{N}_i Y_i$.[14] Given the net export shares and observed government purchases in state GDP, we can derive the shares of investment and consumption in state GDP.

The real wage paid by firms, w_i^f, equals the marginal product of labor and is therefore proportional to GDP per employed worker. We directly back out employment, L_i, from data on labor force participation, l_i, and the unemployment rate, ur_i for each state. Using the free entry conditions for both the EA and HR firms we can recover the household real wage w_i^h.

3.6 Calibration

The model is solved at a quarterly frequency and calibrated for the U.S. sample of 50 states plus the District of Columbia. The parameter values are displayed in Table 2 and for the most part match those reported in HPT. While most of these parameter values are conventional, HPT estimate a small set of parameters for which we have little guidance from the literature. This concerns the two parameters related to interstate migration, γ and Φ'', as well as the vacancy adjustment cost, Υ''. The migration parameters are estimated to match the observed relationship between unemployment and migration at the state level. HPT report that over 1977 - 2014, an increase of 100 unemployed workers in a state coincided with outmigration of 27 people from the state, with the number only slightly smaller in the latter part of the sample. Outmigration due to high unemployment happens gradually over time. Following an initial increase of 100 unemployed workers, the drop in a state's population reaches its peak of 130 people only after five years.

While many parameters pertaining to preferences, technology and government policy are assumed to be the same across states, our model captures states' variation in size and their exposure to trade and migration. Data on interstate trade is taken from the freight analysis framework that sources most of its data from the commodity flow survey. As with the data on states' exports, we capture only trade in goods, not services. The freight analysis framework also publishes numbers on trade within states, which we use to calculate the implied home bias in states' trade patterns. We use the data on state-to-state trade to construct the matrix of bilateral preference weights, ω_i^j. For a typical state, half the goods are imported from another

[14] Keep in mind, our state trade data captures only trade in goods. States that run persistent trade deficits will typically have large offsetting service trade surpluses.

state and 10 percent are imported from abroad.[15]

The U.S. 2000 Census provides state-level data on each resident's state of birth. We use these figures to calculate the number of households born in state j, $\mathbb{N}^j$, and to calculate the share of people from state j living in state i, n_i^j. For the typical state, the share of people living in a different state is 38 percent. Overall, the data indicates a high degree of economic integration in the United States, with states being tightly linked to each other through both trade and migration.

4 Regional Effects of Exchange Rate Fluctuations

In this section, we first evaluate the fit of the model by repeating the two empirical exercises for simulated data from the model. In the first exercise, we feed in the observed state-specific effective exchange rate innovations over the 1999 - 2018 period and record the simulated unemployment rates. We then run local projections of these simulated unemployment rates on the effective exchange rates, as in regression (2.4) and compare the estimated coefficients to those obtained from the actual data. In the second exercise, we use the model to compute state-specific responses to currency depreciations in the top destination markets for the United States and plot them against states' trade exposure to these markets. These results can then be compared to their empirical counterpart in Section **??**.

We then conduct a series of counterfactuals to evaluate the role of economic integration on the impact of state-specific exchange rate shocks. Specifically, we recompute first experiment described above, but adjust our model to (i) remove interstate trade in goods, (ii) remove migration, and (iii) remove trade in bonds. In addition to evaluating the model's reaction to random exchange rate movements, we use the model to simulate the response to a 25 percent tariff imposed by China on U.S. exports. Finally, we conclude this section by considering how the observed growth in U.S. trade over the past 30 years affects the model's predicted response to exchange rate changes.

[15] Alessandria and Choi (2019) emphasize the role of short- and long-run trade elasticities for explaining trade dynamics. We adopt a time-invariant trade elasticity of 1.5, but our model does produce different responses to exchange rate shocks in the short and long run due to the adjustment of labor, capital and intra-state trade. Additional analysis of the difference between shor- and long-run responses to trade shocks is left to future work.

4.1 Model and Data Comparison

Figure 7 compares the impulse response functions implied by the calibrated model with the estimated impulse responses from Figure 4. The shaded regions correspond to 90 percent confidence intervals. For the model responses, these shaded regions should be interpreted as the confidence intervals that an econometrician would compute if he or she were using data from the model simulations.

To construct the figure, we simulate the model by feeding in the exchange rate innovations observed in the data. This involves two steps: First, we calculate exchange rate innovations as residuals of regressing changes in exchange rates, $\Delta \ln s^*_{i,t}$, on a set of state fixed effects, α_i, and time fixed effects, α_t. This isolates the state- and time-specific component of the exchange rate movements. In a second step, we choose series of shocks $\varepsilon_{i,t}$ for each state i in (3.7) such that the state-specific real exchange rate changes in the model—based on the state-specific nominal exchange rate, $S^*_{i,t}$, deflated by the aggregate price level, P_t—match these innovations.[16] The model produces simulated time paths of the unemployment rate and GDP for each state from 1999-2018. We then estimate local projections as we did for the actual data in Figure 4.

The impulse responses of the unemployment rate to a 1 percent depreciation of the trade-weighted effective exchange rate in the model and the data have a similar shape, though the effects are more pronounced in the model. The model-implied unemployment rate drops on impact by roughly 0.75 percentage points (panel (a)) whereas the empirical drop is zero on impact and declines over time. For both the data and the model, the unemployment rate returns to steady state at roughly the same pace. State GDP (panel (b)) rises by roughly 1 percent in both the model and the data though the estimated change in production in the data has some tendency to revert towards its initial level over time while there is no such pattern in the model.[17] Both in the data and in the model, exports (panel (c)) and imports

[16]In the model, $S^*_{i,t}$, refers to the exchange rate for state i's exports. In the empirical section, the exchange rate as calculated in (2.1) refers to a state's total output (not only exports) because we use as weights the ratio of state i's exports to country j to state i's *GDP*. To create an empirical counterpart of the exchange rate used in the model, $S^*_{i,t}$, we recalculate the empirical exchange rates using as weights the ratio of state i's exports to country j to state i's *total exports*. Part of the variation in real effective exchange rates observed in the data is driven by changes in the foreign CPI and changes in the trade weights used to calculate the effective rates. Our model does not explicitly model these two features. Changes in $S^*_{i,t}$ therefore implicitly encompass changes in foreign CPI and possible changes in trade weights.

[17]Our solution algorithm relies on a log-linear approximation to the models' equilibrium conditions. This means that we cannot use the model to assess whether exchange rate depreciations are more expansionary during periods of economic slack. Using non-linear methods, Michaillat (2014) rationalizes larger government spending multipliers during economic downturns in a search-and-matching framework similar to ours. It is

(panel (d)) go up in response to an exchange rate depreciation. While the model matches the initial response quite well, it underestimates the rise in trade in the medium run, especially for imports. The positive response of imports in the model might seem surprising because imports become more expensive. However, our model assumes a low degree of pass through that is consistent with empirical estimates, and this mutes the rise in import prices. At the same time, higher export demand puts upward pressure on prices of domestically-produced intermediate goods, reducing consumers' incentives to switch away from imports. The positive export demand shock raises overall demand and hence the demand for imports through an income effect.[18] Finally, our model replicates reasonably well the increase in population (panel (e)). After 3 years, state population has grown by 0.17 percent in the model and 0.26 percent in the data.

Panel (b) of Figure 5 plots the model-implied coefficients ($\beta^{h,j}_{s,n}$) from regression (2.5). As in panel (a), we consider the relationship between the state-level reactions to bilateral exchange rates for the five largest trade destinations against the states corresponding export shares. Relative to the estimates from the data, the model produces tighter relationship between states' trade shares and their unemployment response. The cross-sectional relationship is also slightly stronger in the model relative to the data; the model coefficient is -0.38 compared to its counterpart in the data of -0.32.

4.2 Regional Shocks and Economic Integration

We now use the model to study the impact of increased trade exposure over time on economic outcomes across the United States. Many studies examine the impact of localized trade shocks on output and employment assuming that communities are isolated from one another and that labor is unable to reallocate in response to shocks. Our model allows us to disentangle the relative importance of labor market adjustment, financial risk sharing and intrastate trade in response to changes in state-specific exchange rates. To do this, we reestimate the local projections (2.4) for data from our model, but we sequentially shut off labor migration, interstate trade, and financial trade.

therefore conceivable that a non-linear solution method to our model would replicate the state-dependent response found in the data.

[18] Our model abstracts from re-exports, i.e. either direct exports of imported goods or the use of imported materials in the production of exported goods. We presume that adding re-exports to the model would generate a stronger comovement of exports and imports and help explain the positive response of imports to an exchange rate depreciation.

For each counterfactual, we feed in the observed state-specific effective exchange rates, record the simulated unemployment rates and run local projections as in (2.4). The results are reported in Figure 8.

When there is trade between states but no interstate migration (panel (a)), we see that the impact on unemployment is somewhat greater than the benchmark case, especially in the medium run (falling by 0.6 percentage points instead of 0.5 percentage points). Because workers cannot relocate to states experiencing the exchange rate appreciation of the foreign currency, more workers are drawn out of the local unemployment pool. By failing to account for labor mobility, models with trade shocks will overestimate the effect on local unemployment. Because population movements are somewhat sluggish in their response to changing economic conditions (as emphasized by HPT and captured in our model), this mechanism needs several quarters to attain its full effect.

In the second counterfactual, we allow for labor mobility but assume that there is no trade between states. The impulse response in panel (b) shows that a state-specific exchange rate depreciation produces a decline in unemployment of 2.3 percentage points. The depreciation of the exchange rate – effectively an increase in foreign import demand – induces an increase in state output, both to satisfy increased export demand and also to permit the increase in local consumption and investment spending. In this no-intrastate-trade counterfactual, all the extra demand must be met through local production, resulting in a sharp decline in local unemployment. The impulse response also shows that the impact effect in the no-intrastate-trade specification is rather short-lived and the unemployment response converges to the benchmark after 1 year.

In the last experiment we close cross-state asset markets, but allow for interstate trade and migration. We let states run bilateral current account imbalances, as long as their aggregate (across all other states and RoW) current account is balanced. In the benchmark model, households respond to an exchange rate depreciation by borrowing against future income to increase investment (and consumption). Financial markets therefore help states finance the economic expansion. In financial autarky, households must self-finance their investment. This dampens the response of the unemployment rate.

Taken together, these experiments suggest that financial markets, migration and, in particular, interstate trade play an important role in the allocation of resources in response to exchange rate changes. Whereas financial markets accentuate state-specific shocks, migration and trade help smooth out these shocks, with interstate trade being a key adjustment mechanism in the short run, but migration being more important in the medium run. Models that fail to account for interstate linkages and labor mobility will overstate the impact of trade shocks in both the short- and the long-run.

4.3 Chinese Import Tariffs on U.S. Exports

Our model emphasizes the effects of exchange rate shocks on output and employment through changing demand for exports. We next consider an experiment that captures changing trade policy in China. In response to the recent hike in U.S. tariffs on Chinese imports under President Donald Trump, China retaliated by raising tariffs on U.S. exports. Here we consider a scenario in which China imposes a 25 percent tariff on all U.S. exports. In our model, we interpret this as an unexpected, permanent change in the export demand function from (3.6) to

$$y^i_{*,t} = \omega^i_* \left(\frac{(1+\tau_{i,t})p_{i,t}}{S^*_{i,t}} \right)^{-\psi_y},$$

where the tariff state i faces in its export markets is set to

$$\tau_{i,t} = 0.25 \times \frac{exp^i_{CHN}}{exp^i}.$$

That is, we multiply the tariff of 0.25 by state i's share of exports going to China.[19] A few notes are in order: First, our experiment abstracts from possible indirect changes in Chinese demand caused by the tariff, such as a slowdown of Chinese economic activity, a rise in China's CPI or an endogenous change in the U.S. dollar - yuan exchange rate. These endogenous adjustments would either dampen or heighten the initial change of 25 percent in the tariff. Second, we do not model the impact of U.S. tariffs on U.S. import demand from China and therefore keep the U.S. dollar price of imports from China, $p^*_{i,t}$, constant. Finally, we assume that there is no monetary policy response to the Chinese import tariff. The precise monetary policy will typically affect the aggregate response of the U.S. economy, but it should play a minor role in shaping the regional, cross-state effects of the tariff. It is these regional effects that we focus on.

Panel (a) of Figure 9 shows exports to China as share of state's GDP, as of 2018. As can

[19] Looking at the modified version of (3.6), it is clear that from the perspective of a U.S. state, the imposition of a tariff $\tau_{i,t}$, is equivalent to a change in the exchange rate $S^*_{i,t}$ provided that there is no pass-through into import prices $p^*_{i,t}$ (i.e. setting $\theta_0 = 0$ and $\theta_1 = 1$ in equation (3.8).

be seen in the Figure, there is a large variation in export exposure across states: while many states export less than $^1/_2$ percent of their GDP to China, this number is substantially higher for some states, especially in the Northwest: the states with the greatest export shares to China are Alaska, South Carolina, Oregon, and—reaching about 5 percent of state GDP—Washington.

Panel (b) shows the model-implied change in unemployment by state resulting from the Chinese retaliation. Clearly, the states with the greatest direct export exposure suffer the largest increases in unemployment, with unemployment rates in Washington rising by 0.78 percentage points over the first four quarters. However, while the effects are concentrated in the upper Northwest, the effects are transmitted to other states through interstate trade and migration. This transmission substantially reduces the cross-state dispersion in unemployment to almost a tenth of the dispersion in export shares. The effects of Chinese import tariffs on U.S. exports are therefore felt throughout the United States, not just in states that directly export to China, but also in states with little direct ties to China.

4.4 Trade Growth and Exchange Rate Fluctuations

Finally, we consider the consequences of the steady expansion in trade and changing patterns of destination markets for the United States over the last 30 years. Since our state-level export data goes back only to 1999, we have to extrapolate bilateral export exposure back to 1989 using destination-specific export data at the national level. We proceed similarly for state-level imports. The Online Appendix provides more details on the assumptions underlying these extrapolations.

For each of the U.S. top 5 destination markets (Canada, Mexico, the euro area, Japan and China), we calculate the value of state-level exports towards that destination over state GDP, both for 1989 and 2018. On the x-axis of Figure 10, we plot the median value of this figure across U.S. states. Exports as a percent of state GDP have increased by 0.3 to 0.5 percentage points for all markets, except for Japan, where they slightly fell. Mexico and China have overtaken Japan, but Canada and the euro area clearly remain the U.S.' main trading partners.

In a second step, we examine how the economy reacts to an exogenous change in the various foreign currencies, both in the calibration matching trade shares in 1989 and in the calibration for 2018. The median unemployment response (across U.S. states) to a 10 percent real exchange rate appreciation of either one of the five foreign currencies is plotted against the y-axis.[20] We observe that despite the increase in exports, states' unemployment rates do not generally react more to foreign exchange rate fluctuations: While a 10 percent appreciation of the Chinese yuan or the Mexican peso lowers unemployment rates by 0.13 or 0.19 percentage points more in 2018 compared to 1989, a similar appreciation of the Canadian dollar or the euro cause unemployment to respond *less* today than 30 years ago, and this despite increasing export shares to Canada and the euro area. Graphically, although higher export shares shift observations to the right on the figure, a flatter least-squares line indicates a lower elasticity of the unemployment response to states' export exposure.

This weaker responsivess of unemployment is the result of two counteracting effects in the model: First, because states trade more with foreign countries, changes in foreign exchange rates will tend to have larger effects on economic activity. This effect dominates the change in the response to the Mexican peso, the Chinese yuan and the Japanese yen. Second, the expansion in trade offers states the ability to use trade with a broader set of countries to limit fluctuations in local production and employment. If a state satisfies its demand mostly through domestic production (as observed in 1989), then an increase in the demand for a states product would need to be met by either a reduction in the state's consumption or by an increase in the state's production or both. However, imports, both from other U.S. states and from other foreign countries have increased over the last 30 years with e.g. international imports more than doubling (from an average of 5 percent of states' GDP to an average of 11 percent). As a result, states can satisfy additional demand for its product while keeping consumption and production fixed by re-directing domestic consumption towards imports. This channel which our multi-country model captures tempers the degree to which exchange rate fluctuations cause economic volatility and dominates the change in the response to the Canadian dollar and the euro.

5 Conclusion

Our paper studies the impact of changes in real exchange rates on economic activity across U.S. states. Changes in exchange rates are relatively large, and there is considerable heterogeneity

[20]More precisely, consider the example of a 10 percent appreciation of the Canadian dollar at time t. We construct the state-specific exchange rate shock, $\varepsilon_{i,t}$, as $0.10 \times \frac{exp^i_{CAN}}{exp^i}$, where $\frac{exp^i_{CAN}}{exp^i}$ is the share of exports to Canada in state i's overall exports. These trade shares as well as the trade shares among U.S. states are calibrated to those in either 1989 or 2018. For each of the five currencies, we run separate experiments.

across states in terms of the volume and direction of trade. We find that an effective exchange rate depreciation of the U.S. dollar by 1 percent increases state-level exports by 1 - 2 percent and raises output by as much as $1/2$-1 percent. Within the first year unemployment falls by about 0.4 percentage points before reverting back, whereas population steadily increases by perhaps 0.3 percent over the first two years. The magnitude of such effects depends on the state's exposure to international trade, and are generally stronger when there is sufficient slack in local labor markets.

In a multi-state model calibrated to state-level trade, labor mobility and relative state size, we find that interstate trade plays a key role in transmitting local shocks across the United States in the short run, whereas state-to-state migration shapes economies' response in subsequent periods. In a counterfactual 25 percent depreciation of the Chinese yuan (an approximation of the impact of retaliatory tariffs by China on U.S. exports), unemployment rates are predicted to increase by 0.2 to 0.7 percentage points, with the impact being particularly strong in the upper Northwest. However, integrated goods and factor markets help transmit the shocks throughout the United States, even to states that export little to China.

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Table 1: SUMMARY STATISTICS

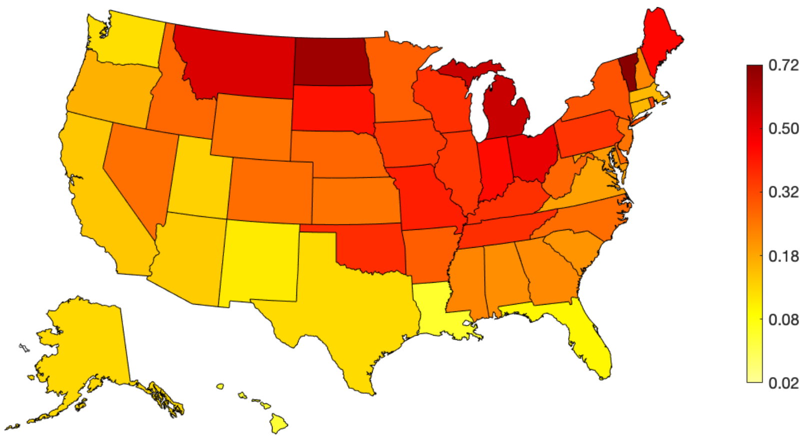
State	Size	Export share	Main destination	Exp share main	State	Size	Export share	Main destination	Exp share main
Alabama	1.2	8.1	Euro area	2.0	Montana	0.3	2.7	Canada	1.3
Alaska	0.3	8.5	Japan	2.5	Nebraska	0.6	5.2	Canada	1.3
Arizona	1.7	5.7	Mexico	1.8	Nevada	0.8	3.9	Switzerland	1.2
Arkansas	0.7	4.3	Canada	1.1	New Hampshire	0.4	4.6	Euro area	1.0
California	13.4	5.6	Mexico	0.9	New Jersey	3.4	4.8	Canada	1.0
Colorado	1.7	2.5	Canada	0.6	New Mexico	0.5	2.8	Mexico	0.6
Connecticut	1.6	5.3	Euro area	1.7	New York	8.0	4.0	Canada	0.9
Delaware	0.4	5.6	Canada	1.3	North Carolina	2.7	5.4	Canada	1.3
District of Columbia	0.7	1.2	U.A.E.	0.3	North Dakota	0.2	6.5	Canada	4.0
Florida	5.0	5.2	Euro area	0.5	Ohio	3.5	7.3	Canada	3.3
Georgia	2.9	5.7	Canada	1.1	Oklahoma	1.0	2.9	Canada	1.0
Hawaii	0.4	1.0	Japan	0.2	Oregon	1.1	8.8	Canada	1.3
Idaho	0.4	5.7	Canada	1.1	Pennsylvania	4.0	4.5	Canada	1.4
Illinois	4.5	6.4	Canada	2.0	Rhode Island	0.3	3.3	Canada	1.0
Indiana	1.9	8.6	Canada	3.5	South Carolina	1.1	10.7	Euro area	2.7
Iowa	1.0	6.6	Canada	2.2	South Dakota	0.2	3.0	Canada	1.2
Kansas	0.9	6.7	Canada	1.6	Tennessee	1.8	7.2	Canada	2.2
Kentucky	1.1	10.0	Canada	3.1	Texas	8.3	12.8	Mexico	4.9
Louisiana	1.5	17.8	Euro area	2.6	Utah	0.8	7.8	U. K.	1.8
Maine	0.3	5.0	Canada	2.1	Vermont	0.2	9.2	Canada	4.2
Maryland	2.0	2.4	Euro area	0.5	Virginia	2.7	3.8	Euro area	0.8
Massachusetts	2.7	5.4	Euro area	1.4	Washington	2.4	15.4	China	2.4
Michigan	2.8	10.0	Canada	5.2	West Virginia	0.4	7.9	Canada	2.0
Minnesota	1.8	5.7	Canada	1.5	Wisconsin	1.7	6.6	Canada	2.2
Mississippi	0.6	6.7	Canada	1.3	Wyoming	0.2	2.9	Canada	0.7
Missouri	1.7	4.3	Canada	1.6	Average		6.2		1.7

Notes: Table displays states' relative size (measured as a state's GDP in U.S. GDP), export share in state GDP, the main destination country of their exports and the corresponding export share of that destination in state GDP. The main destination country is identified as the country with the highest share of exports in total exports. All statistics are averages over 1999-2018.

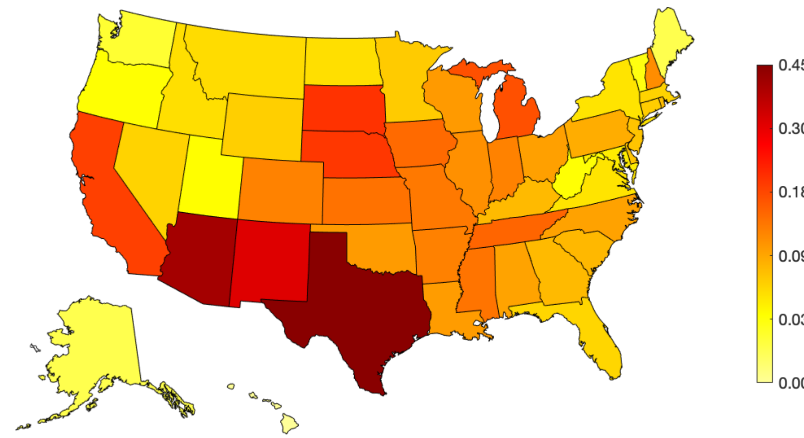
Table 2: CALIBRATION

Parameter		Value	Target / Source
Preferences			
Discount factor	β	0.995	2% real interest rate
Coefficient of relative risk aversion	$\frac{1}{\sigma}$	2	Standard value
Technology & Nominal Rigidities			
Curvate of production function	α	0.30	Labor income share of 0.63 (Karabarbounis and Neiman, 2013)
Depreciation rate	δ	0.021	Annual depreciation rate of 8 percent
Utilization cost	a''	0.286	Del Negro et al. (2013)
Investment adjustment cost	Λ''	0.05	House, Proebsting and Tesar (2018)
Elasticity of substitution bw. varieties	ψ_q	10	e.g. Basu and Fernald (1995), Basu and Kimball (1997)
Sticky price probability	θ_p	0.70	Price duration: 10 months (Nakamura and Steinsson, 2008)
Trade and State Size			
Trade demand elasticity	ψ_y	1.5	e.g. Heathcote and Perri (2002), Backus, Kehoe and Kydland (1994)
Trade preference weights	ω_i^j	x	Share of imports from j; Freight Analysis Framework (2002, 2007, 2012, 2016)
State's absorption	$\mathbb{N}_n Y_n$	x	Nominal GDP (BEA)
Migration			
Population	$\mathbb{N}_i$	x	Population, Census ('00)
Amenity value	A_i^j	x	Share of people from j living in i, Census ('00)
Migration propensity	γ	2.27	House, Proebsting and Tesar (2018)
Migration adjustment cost	Φ''	1.91	House, Proebsting and Tesar (2018)
Labor Markets			
Unemployment rate	ur	x	BLS ('00-'17)
Labor force	l	x	BLS ('00-'17)
Separation rate	d	0.10	Shimer (2005)
Matching elasticity to tightness	ζ	0.72	Shimer (2005)
Bargaining power of workers	ϱ	0.72	Same as matching elasticity
Unemployment benefits	b/w	0.44	Net replacement rate, Engen and Gruber (2001)
Vacancy cost	$\frac{\varsigma V_i}{Y_i}$	0.004	Shimer (2010)
Vacancy adjustment cost	Υ''	0.85	House, Proebsting and Tesar (2018)
Fiscal Policy			
Gov't purchases over final demand	$\frac{G_i}{Y_i}$	0.18	BEA ('00-'17)

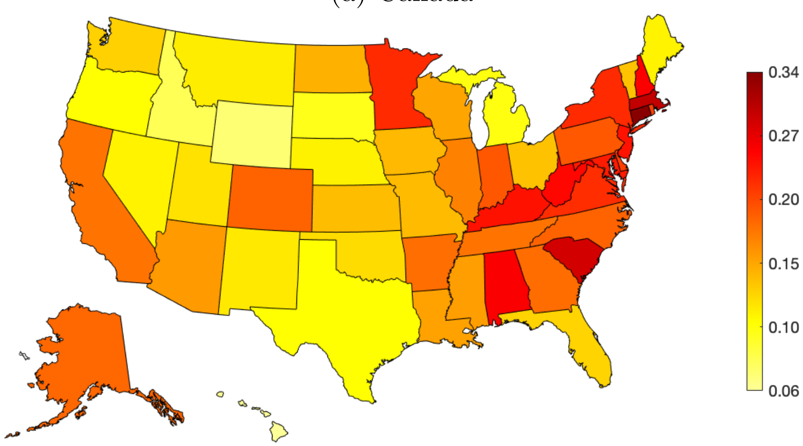
Notes: Values marked with x are state- or state-pair specific.



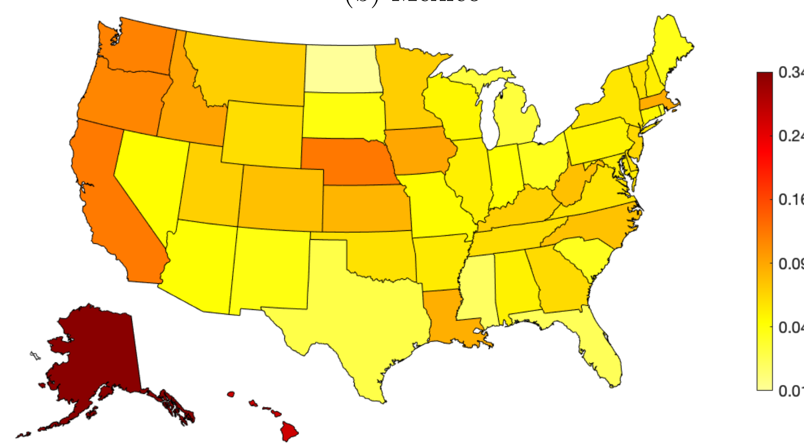
(a) Canada



(b) Mexico



(c) Euro Area



(d) Japan

Figure 1: Export Shares by Destination

Notes: Figures display a state's share of exports towards (a) Canada, (b) Mexico, (c) the euro area, and (d) Japan. Shares are averaged over 1999 - 2016.

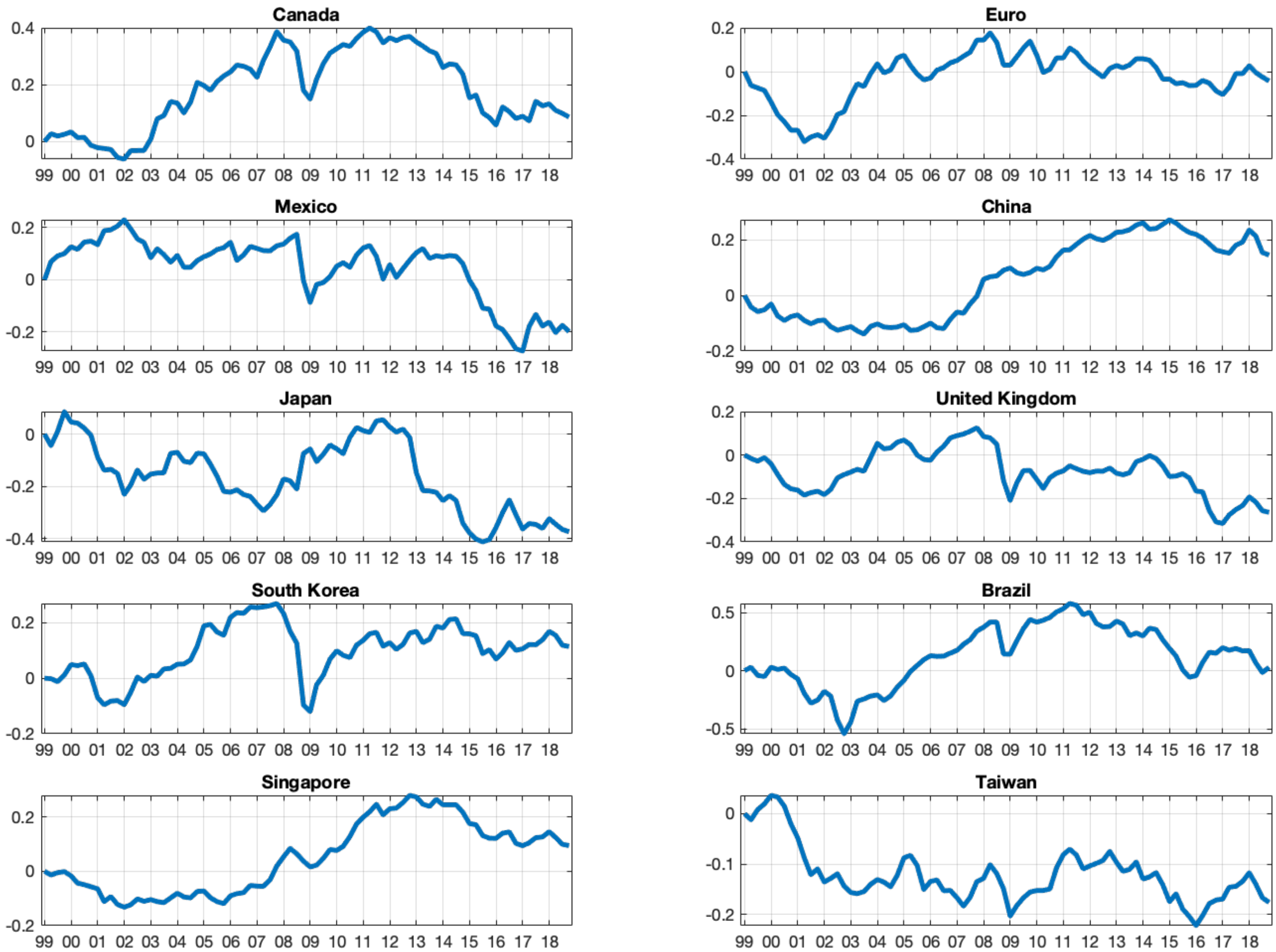


Figure 2: US Dollar Real Exchange Rate: Top Destinations

Notes: Figure displays the bilateral real exchange rate of the US Dollar relative to the 10 top destination markets. Exchange rates are quoted in US Dollar per foreign currency and deflated by the ratio of the consumer price indices.

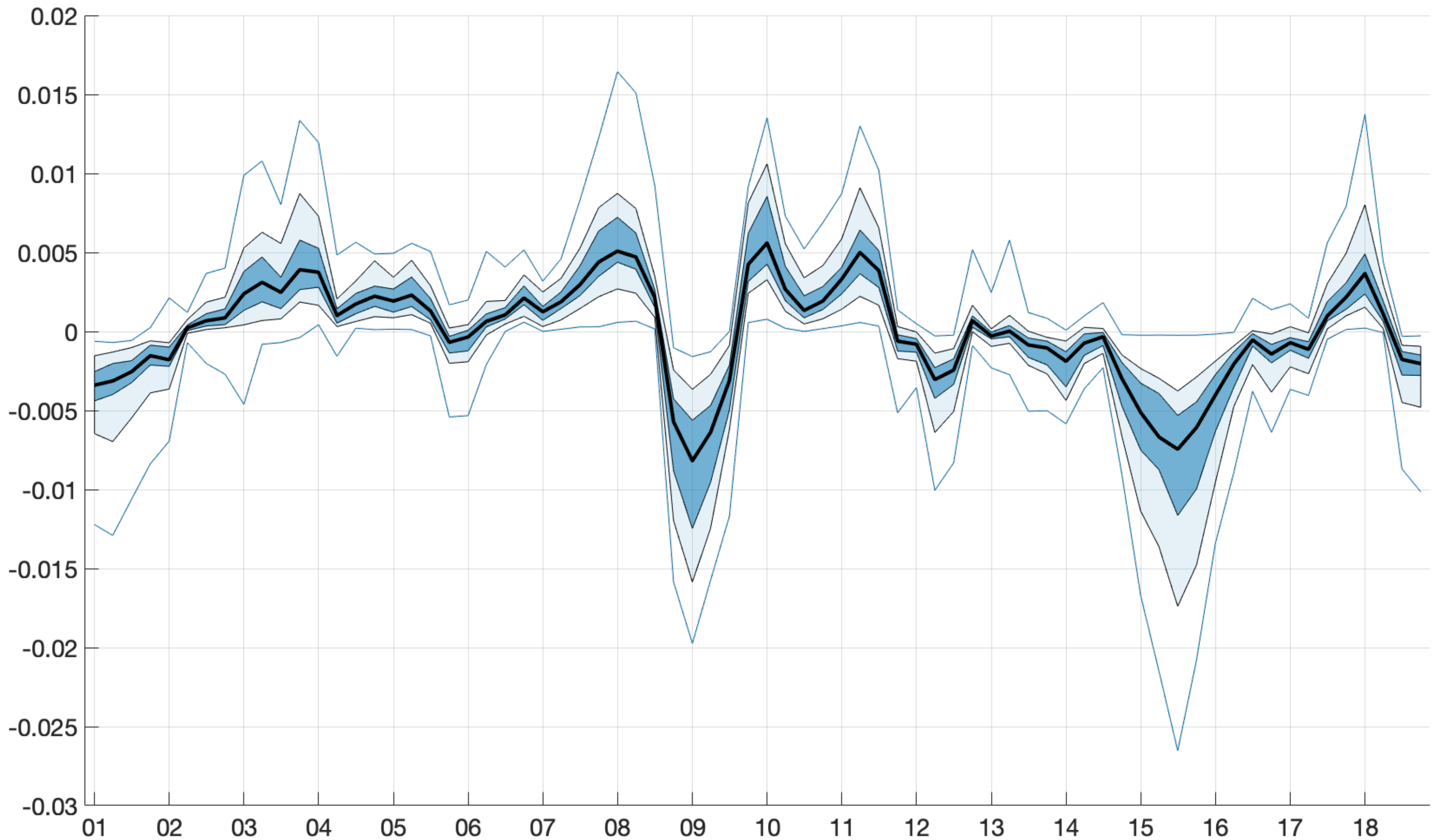
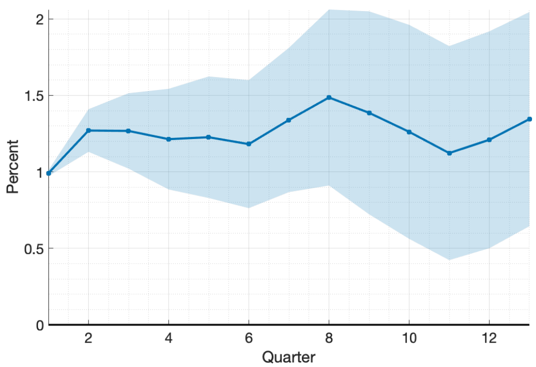
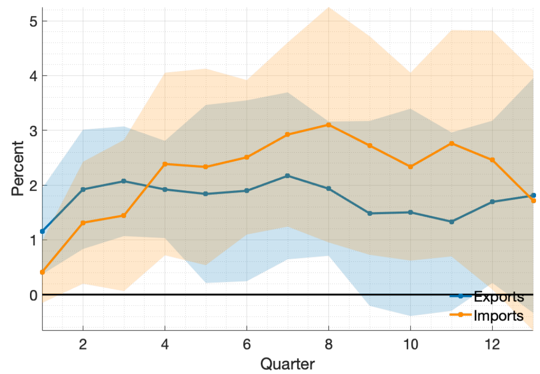


Figure 3: Growth Rates of the Real Effective Exchange Rate Across U.S. States

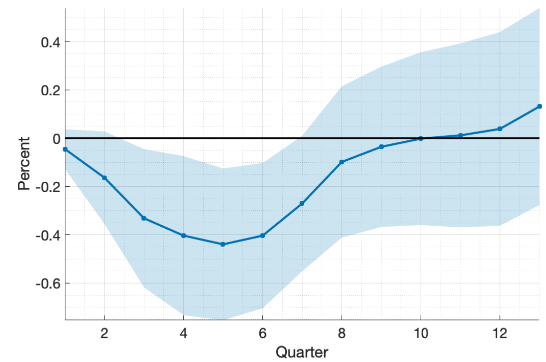
Notes: Figure displays year-to-year growth rates of the real effective exchange rate across states between 2001 and 2018. For any point in time t, the growth rate between $t-4$ and t is displayed. Effective exchange rates are calculated based on average export shares over the last four quarters. Export data starts in 1999q1, so that effective exchange rates can only be calculated starting in 2000q1 and annual growth rates start in 2001q1. The thick black line is the growth rate for the median state, the heavy-shaded area is the interquartile range, the light-shaded area is the interdecile range and the thin blue lines display the minimum and maximum growth rates observed across U.S. states.



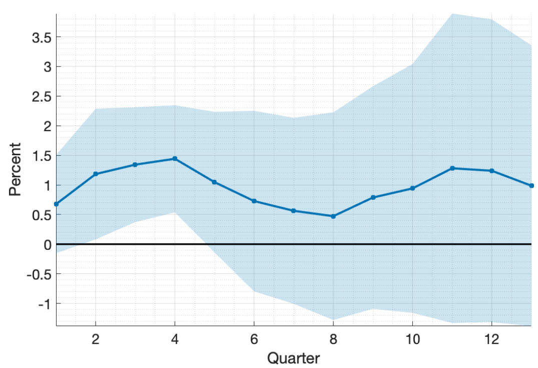
(a) Real Exchange Rate



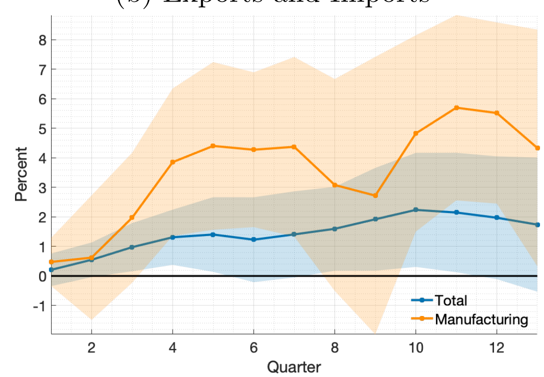
(b) Exports and Imports



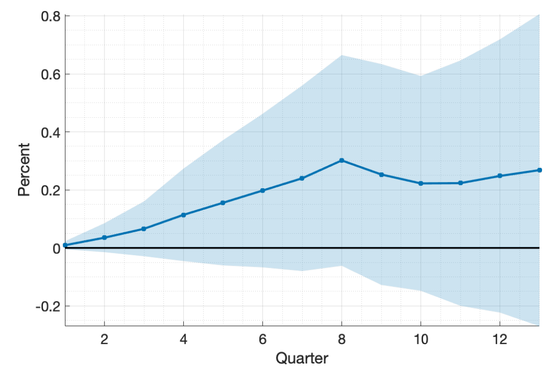
(c) Unemployment Rate



(d) State GDP



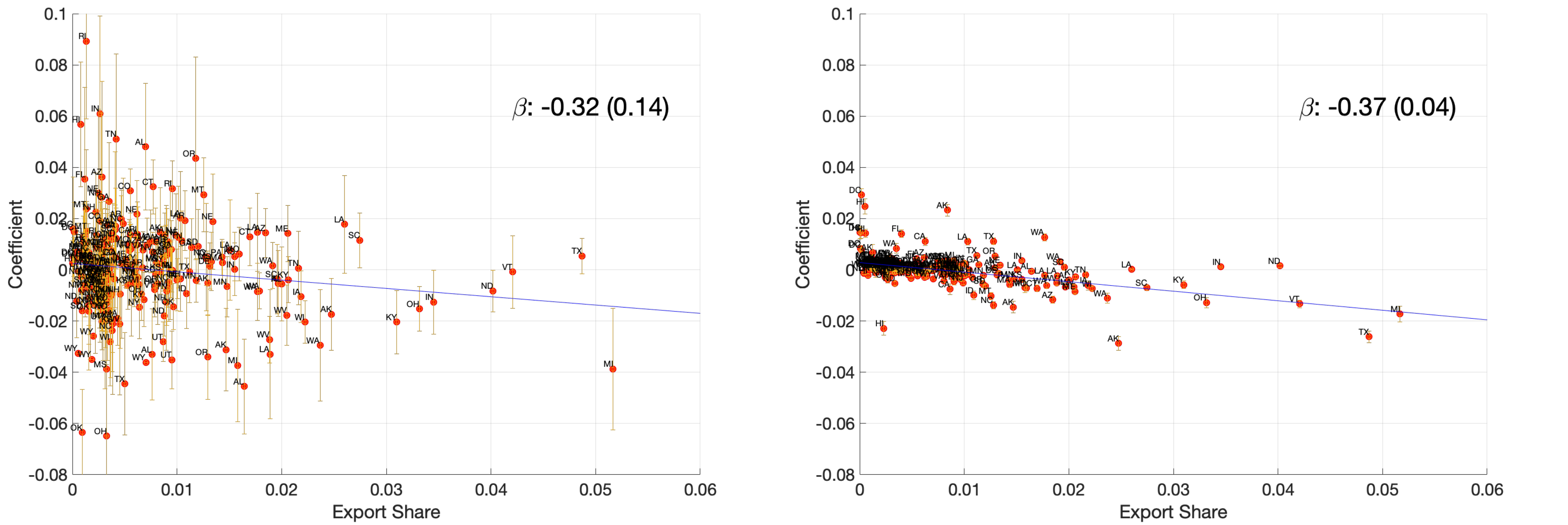
(e) Hours worked



(f) Net Immigration

Figure 4: Empirical Impulse Response to a Real Effective Exchange Rate Depreciation

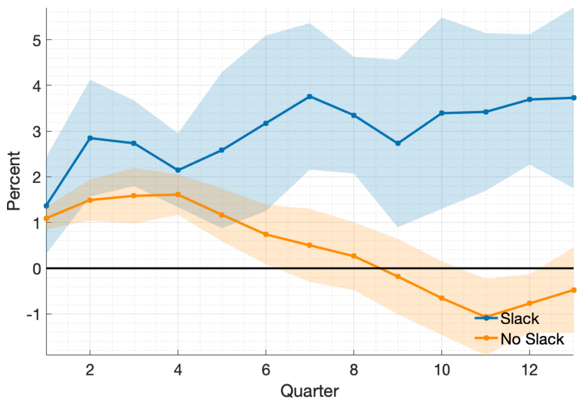
Notes: Figure displays the local projection of (a) the real effective exchange rate, (b) nominal exports and imports (expressed in percent of state's GDP), (c) the unemployment rate, (d) state GDP, (e) hours worked and (f) cumulative net immigration to a 1% depreciation of the real effective exchange rate based on regression (2.4). The definition of the (export) effective exchange rate covers the U.S. market, including the state itself. State GDP is real, total GDP at the state level. Bands are 90 percent confidence intervals.



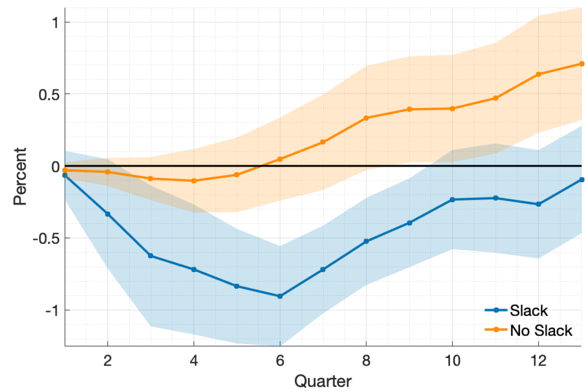
(a) Data (b) Model

Figure 5: Unemployment Rate Response to a Depreciation of the U.S. dollar and Export Shares

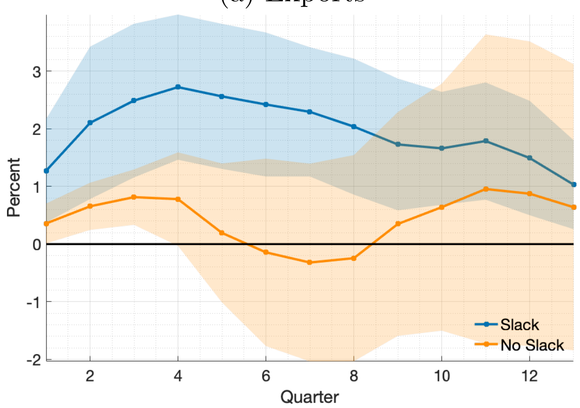
Notes: Panel (a) displays the estimated response of the unemployment averaged over the first four quarters for a depreciation of the U.S. dollar relative to one of the five top export markets as a function of a state's exports to that market (normalized by a state's GDP). Each dot represents an estimated regression coefficient, $\frac{1}{4}\sum_{h=0}^{3}\hat{\beta}_{s,n}^{h,j}$, and the vertical lines are standard deviations, $\frac{1}{4}\sum_{h=0}^{3}\left(\hat{\beta}_{s,n}^{h,j} \pm std\left(\hat{\beta}_{s,n}^{h,j}\right)\right)$. Panel (b) displays the coefficients from the simulated response in the model.



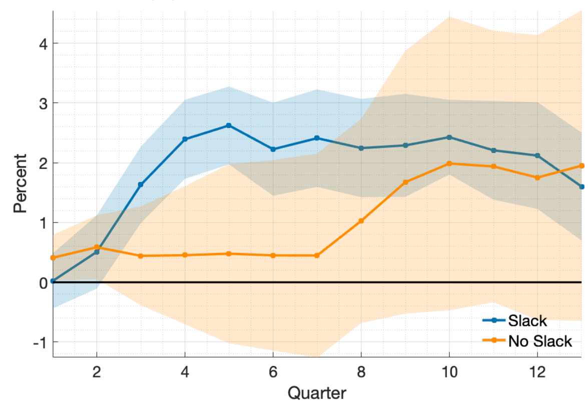
(a) Exports



(b) Unemployment Rate



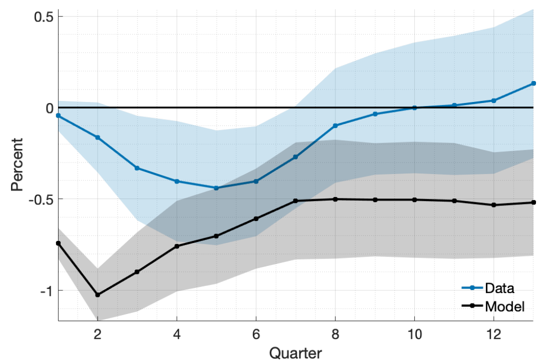
(c) State GDP



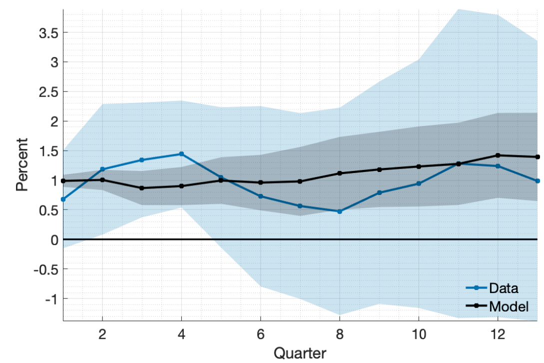
(d) Hours Worked

Figure 6: Response to an Exchange Rate Depreciation Over the Business Cycle

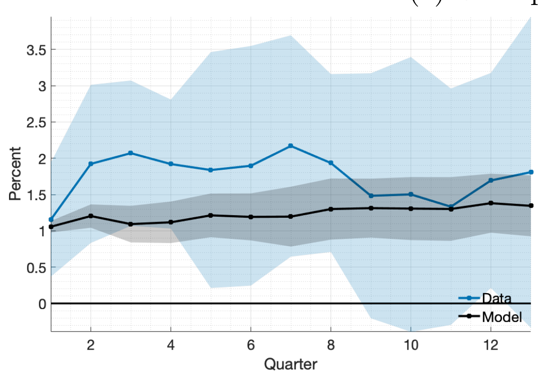
Notes: Figure displays the local projection of (a) nominal exports (expressed in percent of state's GDP), (b) the unemployment rate, (c) state GDP, (d) hours worked to a 1% depreciation of the real effective exchange rate based on regression (2.6). The definition of the (export) effective exchange rate covers the U.S. market, including the state itself. State GDP is real, total GDP at the state level. Bands are 1-standard error-deviation bounds. Slack is identified as time periods where a state's unemployment rate exceeds 6.5 percent.



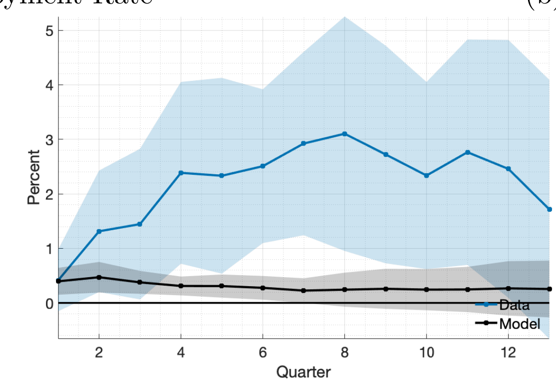
(a) Unemployment Rate



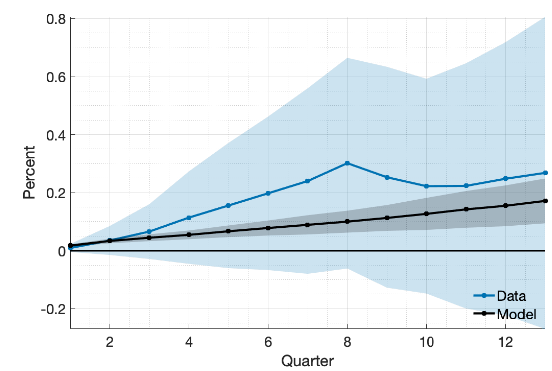
(b) GDP



(c) Exports



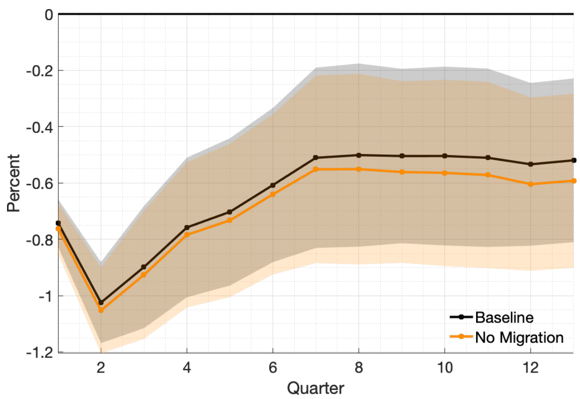
(d) Imports



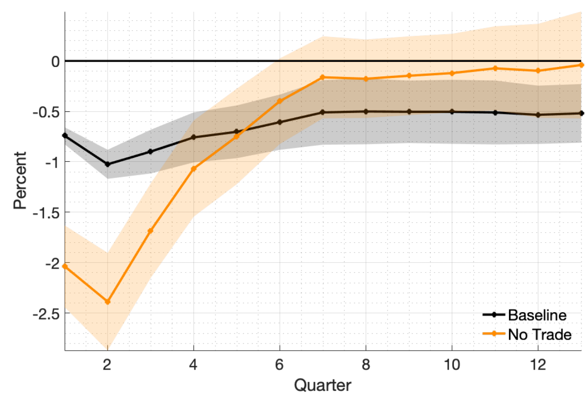
(e) Net immigration

Figure 7: Impulse Response to a Real Effective Exchange Rate Depreciation

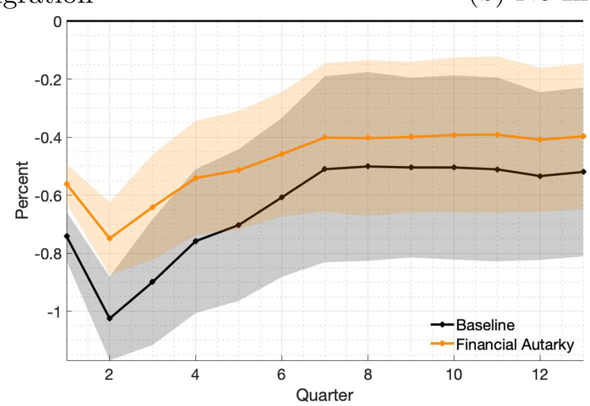
Notes: Figure displays the local projection of (a) the unemployment rate, (b) state GDP, (c) exports, (d), imports, and (e) net immigration to a 1 percent depreciation of the effective exchange rate based on regression (2.4). The definition of the (export) effective exchange rate covers the U.S. market, including the state itself. Both the response in the actual data and the simulated benchmark model are displayed. Bands are 90 percent confidence intervals.



(a) No Migration



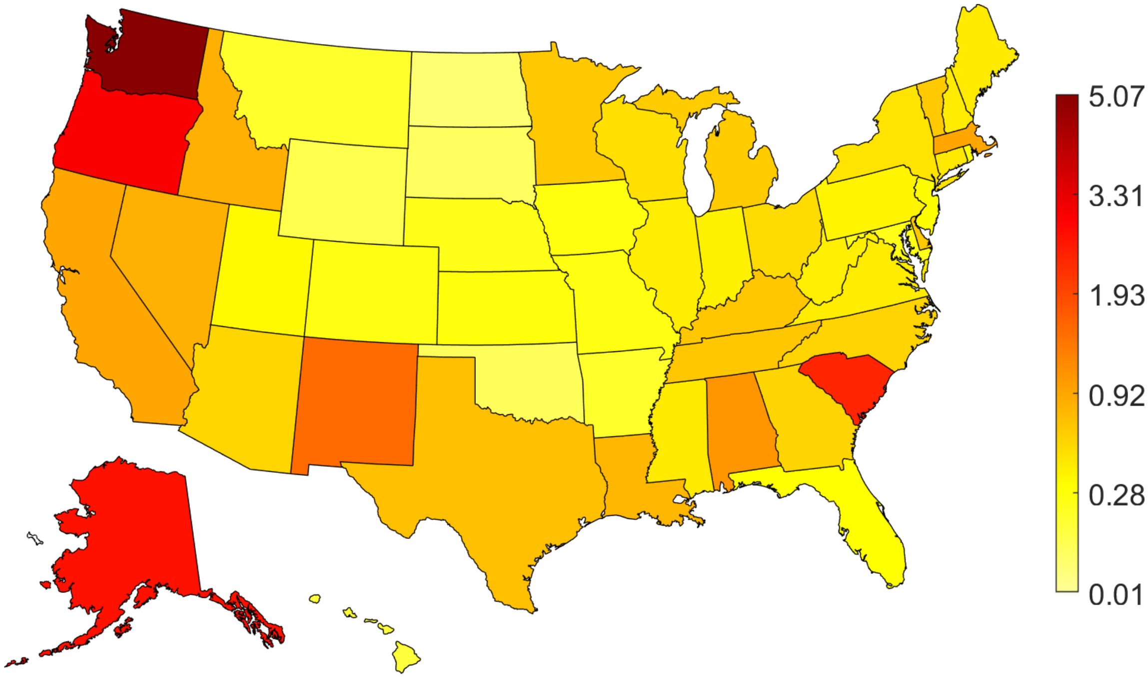
(b) No Interstate Trade



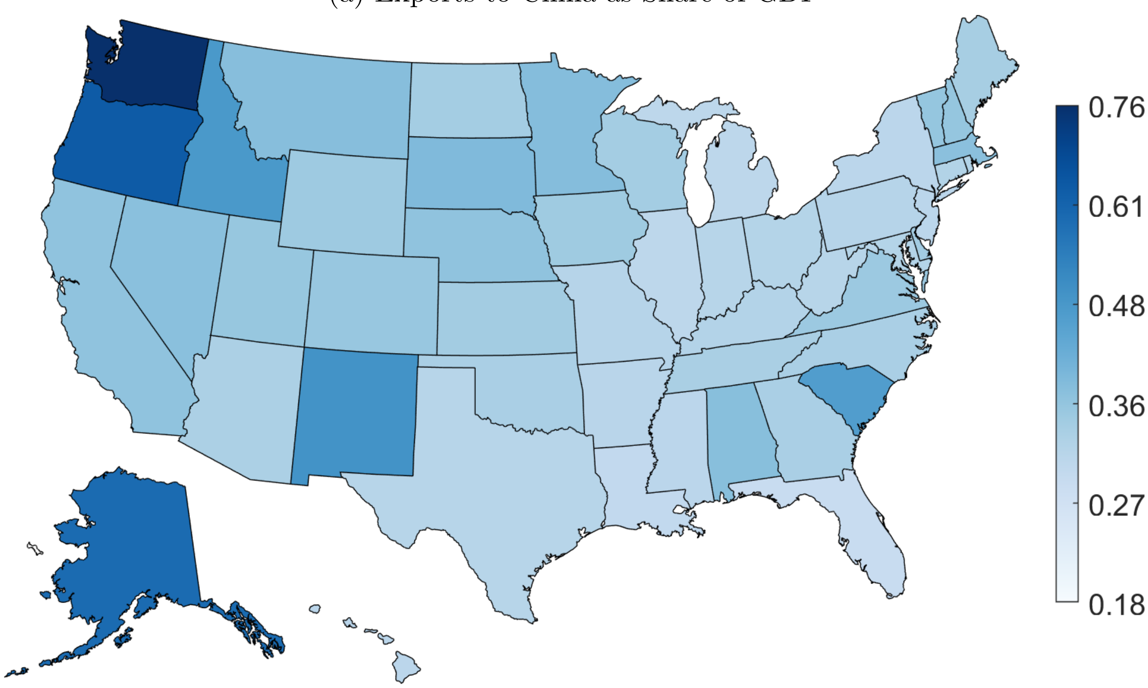
(c) Financial Autarky

Figure 8: Model Response of Unemployment to an Exchange Rate Depreciation

Notes: See Figure 7. Only impulse responses based on the benchmark model and the various counterfactuals are displayed.



(a) Exports to China as Share of GDP



(b) Unemployment Response to a 25% China Tariff

Figure 9: Export Exposure to China and Effects of Tariff on Unemployment.

Notes: Figure (a) displays exports to China as a share of state GDP (in percent, as of 2018). Figure (b) displays the model-implied change in the unemployment rate in response to a 25 percent tariff imposed by China on U.S. exports averaged over the first year.

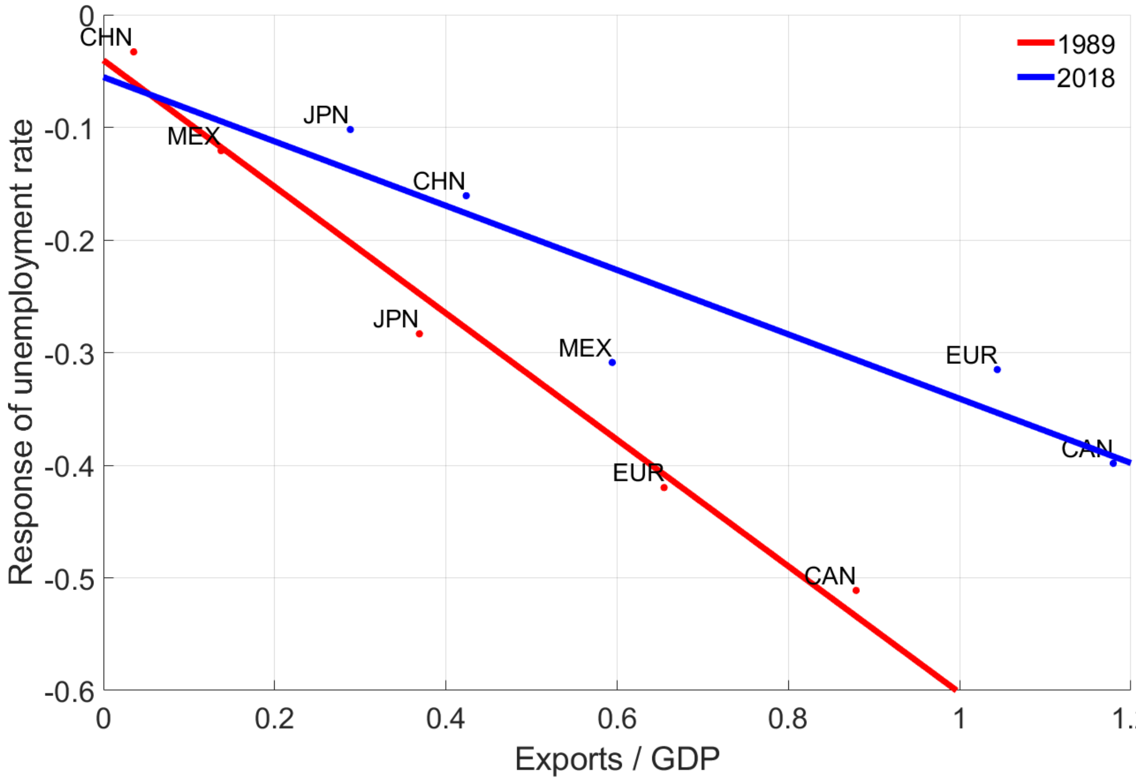


Figure 10: Export Share and Unemployment Response Over Time

Notes: Figure plots the model-implied median responses (across U.S. states) of the unemployment rate to a 10% real exchange rate appreciation of either one of the top 5 destination markets (the Canadian dollar, the Mexican peso, the euro, the Japanese yen or the Chinese yuan) versus the median export share (across U.S. states) for the U.S. top 5 destination markets. The blue dots refer to a calibration for 1989, the red dots refer to a calibration for 2018. The unemployment response is the average response over the first four quarters and measured in percentage points. The share of exports to GDP is measured in percent.