European Economic Review 180 (2025) 105163

Contents lists available at ScienceDirect

European Economic Review

journal homepage: www.elsevier.com/locate/eer

Spatial consumption risk sharing☆

Prateek Arora [a], Dongwan Choo [b], Chenyue Hu [c]

[a] Union College, United States of America
[b] Massey University, New Zealand
[c] UC Santa Cruz, United States of America

ARTICLE INFO

JEL classification:
Codes
F41
F44
F36

Keywords:
Open economy DSGE model
Real business cycles
Intranational risk sharing
Migration
Portfolio choice
Macro aspects of trade and finance

ABSTRACT

This paper investigates how bilateral economic linkages influence consumption synchronization across economies in response to idiosyncratic shocks. Using the US state-level data, we find the degree of bilateral consumption smoothing to decrease with geographic distance. To explain this fact, we develop an open economy DSGE model that incorporates trade, migration, and finance as channels of risk sharing subject to bilateral frictions that potentially covary with distance. Calibrated to the US data, this structural model enables us to examine interactions of different channels in general equilibrium and quantify their impacts on states' consumption. Through counterfactual exercises, we find that turning off the three channels weakens consumption correlations across states in general, while trade is more effective than migration and financial channels in stabilizing consumption fluctuations.

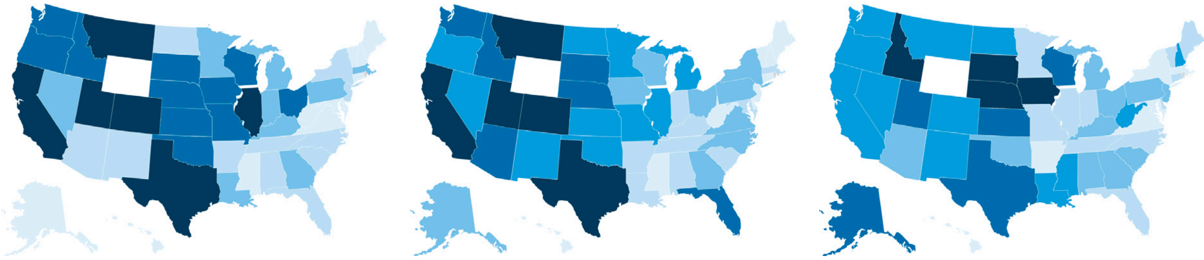
1. Introduction

Consumption risk sharing allows agents from different economies to yield welfare gains by reducing consumption fluctuations caused by idiosyncratic income shocks. However, frictions in economic exchanges impede consumption from being smoothed across space and time. This paper explores the patterns and determinants of consumption smoothing by exploiting the variation in bilateral economic linkages shaped by geography.

What drives imperfect consumption correlations across economies remains a central question of interest as the phenomenon attests to the failure of complete markets. Obstfeld and Rogoff (2000) consider the low cross-country consumption correlations as a major puzzle in international macroeconomics. Besides trade costs in the commodity market discussed by these authors, migration costs in the labor market and financial frictions in the asset market potentially affect risk sharing since they pose barriers for resources to be freely mobile in the presence of local shocks. While most existing literature studies one channel, this paper extends the workhorse open economy DSGE model developed by Backus et al. (1992) (BKK) into a unified framework with trade, migration, and finance. This comprehensive structure allows for a general equilibrium analysis of how these channels interact to jointly shape consumption dynamics.

☆ We deeply appreciate the helpful feedback from the two editors and two anonymous referees. We also would like to thank Carl Walsh, Alan Spearot, Galina Hale, Gianluca Violante, Enrico Moretti, Doireann Fitzgerald, Ken Kletzer, Grace Gu, Hikaru Saijo, Brenda Samaniego, Ajay Shenoy, Rob Fairlie, Gueyon Kim, Julian Martinez-Iriarte, Alonso Villacorta, and participants at UCSC seminar and California Macroeconomics Conference for comments. Any mistakes are ours.
E-mail addresses: prateek@ucsc.edu (P. Arora), dchoo@ucsc.edu (D. Choo), chu78@ucsc.edu (C. Hu).

https://doi.org/10.1016/j.euroecorev.2025.105163
Received 13 January 2025; Received in revised form 19 September 2025; Accepted 28 September 2025
Available online 10 October 2025
0014-2921/



(a) Bilateral Trade (b) Bilateral Migration (c) Consumption Correlation

Fig. 1. Wyoming's bilateral linkages with other states.
This figure plots bilateral ties between Wyoming (in white) and other states in the U.S. averaged over the period of 1997–2017. A darker color suggests a greater value of bidirectional flows (sum of inflows and outflows) for trade and migration as well as a higher correlation coefficient of real consumption per capita.

Our macro analysis features a geographic dimension, since bilateral linkages in these channels covary with distance as documented by the gravity model of trade, finance, and migration.[1] If these channels facilitate risk sharing but face frictions related to distance, consumption comovement is expected to exhibit similar geographic characteristics. To exemplify this, Fig. 1 plots trade, migration, and consumption correlation between other states and Wyoming, and confirms its bilateral economic linkages are generally stronger with neighboring states.[2] This spatial pattern requires modeling frictional bilateral linkages in a multi-economy framework, where we exploit geographic variations to elucidate mechanisms of shock propagation and consumption smoothing across economies. This paper performs cross-state analysis of the US as an example, but our framework is general enough to be tailored to other contexts including cross-country analysis of the EU.[3]

The empirical section consists of two parts. The first establishes a gravity model of consumption smoothing using the US states' output and consumption data from 1977–2019. We measure a state's consumption smoothing as the response of its relative consumption to output growth following Asdrubali et al. (1996) and compute the degree of smoothing for all state pairs. Our analysis suggests that every 1% increase in distance deteriorates bilateral consumption smoothing by 0.0015 (or 0.004 standard deviations). The empirical finding remains robust when we control for state-pairs' political dissimilarity measured by voters' choices in presidential elections, industrial dissimilarity measured by sectoral composition of aggregate output, and geographic variables including a contiguity dummy and land size. This spatial pattern of consumption synchronization points to the existence of barriers to risk sharing influenced by geography. The second empirical analysis examines the 2006 North Dakota (ND) oil boom as an event study to verify the importance of geography in spreading consumption gains. We find that ND witnessed greater migration and trade inflows from states located in closer proximity. These states also experienced larger consumption increases above their long-term trend following the ND oil shock.

Motivated by these empirical findings, we develop a DSGE model to examine mechanisms for spatial consumption synchronization. Our model is populated by homogeneous households which reside in different states connected by three channels of risk sharing. When modeling frictional bilateral linkages across states, we modify the frameworks developed by Armignton (1969), Artuc et al. (2010), Heathcote and Perri (2013) for trade, migration, and financial channels respectively. While these classic literatures have inspired many works to study each of the channels, less is known about interactions of all these channels in general equilibrium. Our paper fills this gap by providing a comprehensive assessment of complementarity and substitution effects among these channels.

To highlight the mechanisms, we begin our analysis with comparative statics in a symmetric two-economy model à la BKK following the international macro literature. Calibrated to the median moments across the US states, the model quantifies the joint influences of three channels on cross-state consumption correlation. We find the correlation to approach one when either trade or financial friction is absent. Meanwhile, migration cost yields non-monotonic predictions for consumption correlation. When migration cost is high, reducing the cost promotes labor mobility and equalizes consumption per capita across states in response to idiosyncratic shocks. However, if migration cost is already in the low range, reducing the cost further to increase population inflows to a state after its positive shock may raise its aggregate expenditure, which tilts towards home goods in the presence of trade cost. Under this increased demand, the booming state's exports becomes more expensive relative to imports, which prevents terms-of-trade adjustments from working in the direction that would facilitate risk sharing through the trade channel and consequently

[1] For example, Anderson and Van Wincoop (2003) develop a theory-grounded econometric framework to revive the gravity model of trade flows across countries. Portes and Rey (2005) document that bilateral equity flows decrease with distance between country pairs. Lewer and Van den Berg (2008) develop and test a gravity model of migration among OECD countries.

[2] A detailed data description can be found in Appendix B. The US cross-state trade data are sourced from the CFS, migration data are from the IRS, and consumption data are from the BEA. Comprehensive data for state-to-state financial flows are not available unfortunately to our knowledge.

[3] The model can be applied to the European Union (EU) which exhibits a high degree of integration for goods, financial, and labor markets. Or it can be applied to the intranational analysis of another country. Given that frictions are relatively low across states in the US, our estimates provide a lower bound on the importance of these frictions for consumption patterns.

lowers consumption correlation across economies. This analysis underscores the importance of jointly studying these channels to examine consumption in an integrated general equilibrium setting.

We extend the analysis to a full-fledged asymmetric multi-state framework to quantify the impacts of different channels on consumption of the fifty US states. Specifically, we collect bilateral moments across states including time-averaged trade shares, migration shares, and degrees of consumption smoothing from the empirical section. These moments are sufficient statistics that already incorporate bilateral frictions in the three channels for the calibration of the steady state, around which we shut down these channels sequentially to disentangle their impacts on consumption comovement and volatility. From these counterfactual exercises, the median value of bilateral consumption correlations across states drops from 0.420 in the original case to 0.037, 0.109, 0.407 when trade, finance, and migration are turned off respectively. Therefore, these three are all effective channels of risk sharing that facilitate consumption synchronization, although the first two are more important in comparison. Furthermore, we find the negative covariance between consumption correlation and geographic distance to weaken by about 50% without trade or financial channel and by 14% without migration. Hence, all these channels contribute to the geographic pattern of consumption synchronization documented in the empirical section. By strengthening cross-state consumption comovement, these channels also affect states' consumption volatility under idiosyncratic shocks. We find that model-predicted standard deviations of consumption uniformly rise for all the states absent trade. In contrast, finance and migration generate heterogenous impacts, without which lower-income states expect larger consumption fluctuations. It is therefore important for policy makers to consider these distributional effects of bilateral economic linkages on the welfare of households in different states when designing macro policy.

This paper contributes to the international macro literature on consumption risk sharing by exploiting variations in bilateral linkages across economies shaped by geography. To explain low cross-country consumption correlations, Lewis (1996) finds that consumption growth rates in countries facing capital market restrictions based on IMF's AREAER covary more strongly with domestic output variations relative to the world than those in unrestricted countries do. This empirical finding suggests that financial frictions contribute to the lack of international risk sharing. On the theoretical front, Broner and Ventura (2011) and Bai and Zhang (2012) introduce limited enforcement of sovereign debt as a source of financial frictions and evaluate their impact on risk sharing. Due to such frictions that generate asset market incompleteness, Cole and Obstfeld (1991) and Corsetti et al. (2008) examine the trade channel where terms-of-trade movements provide insurance against countries' production risk. However, such relative price changes, which reduce relative consumption loss from country-specific shocks, are affected by the existence of trade costs. Obstfeld and Rogoff (2000) survey the empirical estimates and argue that these trade costs can explain the low international consumption correlations among other major puzzles in international macroeconomics. Most of these existing works focus on one channel in a symmetric two-country framework, which does not fully characterize general equilibrium effects in the real world that consists of many economies connected through bilateral linkages in multiple channels. From this perspective, this paper is closer to the multi-country framework built by Fitzgerald (2012), Eaton et al. (2016), House et al. (2018), and Caliendo et al. (2018). A major departure of our paper from these works is that we enrich financial analysis with endogenous portfolio choice in incomplete markets. Finance is an essential channel of risk sharing, whose bilateral frictions also contribute to the spatial pattern of consumption smoothing based on our quantitative analysis. By incorporating financial, trade, and migration channels in a unified multi-economy setting, we are able to conduct counterfactual exercises where we shut down the three channels sequentially. These exercises, by disentangling the influences of different channels on consumption, establish that trade costs and financial frictions jointly account for imperfect consumption risk sharing across economies. Without these impediments, trade and financial channels are substitutable to ensure consumption smoothing in the US. Furthermore, we find from these counterfactual exercises that variations in bilateral frictions in these three channels generate large distributional impacts on different economies, which provides guidance for the design of macro policies including fiscal transfers.

In the domestic context, Asdrubali et al. (1996), Athanasoulis and Van Wincoop (2001), and Kalemli-Ozcan et al. (2010) pioneered the work on risk sharing using the US state-level data. At the micro level, seminal papers including Storesletten et al. (2004) and Heathcote et al. (2014) explore impacts of heterogeneous income on consumption across households. Neither these macro nor micro perspectives focus on the influences of bilateral frictions across states on households' consumption, migration, and investment decisions. We therefore complement this literature by adding these important channels of intranational risk sharing.

Lastly, this paper contributes to literature on the gravity model. Since being introduced by Isard (1954) and Tinbergen (1962), the model has emerged as a classic framework in the trade literature. In addition to trade, the gravity model has wide applications including to financial assets (e.g. Portes and Rey, 2005, Aviat and Coeurdacier, 2007, and Okawa and Van Wincoop, 2012) and population flows (e.g. Lewer and Van den Berg, 2008 and Ramos and Suriñach, 2017). Nevertheless, less is known about the effects of geographic distance on macroeconomic fundamentals, especially second-moment (covariance and variance) macro variables under stochastic shocks. These second-moment variables are as essential as first-moment (level) variables for the welfare of any risk-averse agent. Therefore, this study adds an important dimension to the gravity literature by exploring the role of geography in affecting consumption fluctuations.

2. Empirical motivation

This section empirically establishes the importance of geography for consumption synchronization. First, we use the US state-level consumption and output data to compute the degree of bilateral consumption smoothing and explore its sources of variation including distance. Second, we conduct an event study of the 2006 North Dakota oil discovery to verify the role of geography in spreading consumption gains from a local shock.

We measure consumption smoothing as the response of an economy's consumption growth relative to its output growth following the macro literature including Asdrubali et al. (1996). Different from many existing works that examine an individual economy's own inter-temporal consumption smoothing, we also acknowledge the importance of intra-temporal risk sharing across economies in reducing their consumption fluctuations in response to idiosyncratic shocks. Essential channels for cross-economy risk sharing studied in the international economics literature include trade, finance, and migration. Each channel operates through bilateral linkages across individual economies, which together constitute the global aggregate. To evaluate the influence of these channels of risk sharing built through bilateral linkages on economies' consumption patterns, we focus on bilateral smoothing so that we can exploit pair-specific factors, including geographic distance that covaries with frictions in these channels, to examine the drivers of consumption synchronization across economies under their idiosyncratic shocks.

Specifically, we evaluate consumption smoothing between state i and j from

$$\Delta \log\ c_{it} - \Delta \log\ c_{jt} = \alpha_{ij} + \beta_{ij}(\Delta \log\ y_{it} - \Delta \log\ y_{jt}) + \epsilon_{ijt}, \tag{1}$$

where $\Delta \log\ c_{it}$ ($\Delta \log\ c_{jt}$) and $\Delta \log\ y_{it}$ ($\Delta \log\ y_{jt}$) denote the growth of log real per-capita consumption and output of state $i(j)$ at time t. The coefficient β_{ij} measures the degree of bilateral consumption smoothing. In the case where states are in complete autarky with no trade, financial, or migration linkages, there is no interstate consumption smoothing through these channels. A state's consumption is solely determined by its own output, which implies a coefficient of 1. In the opposite case with perfect smoothing, consumption is equalized across states regardless of their relative output growth, which yields a coefficient of 0.[4] Therefore, a lower β_{ij} suggests a higher degree of bilateral consumption smoothing.

The data with which we evaluate Eq. (1) are obtained from the following sources (see Appendix B for details). The US Bureau of Economic Analysis (BEA) reports real gross state product (GSP) since 1977 and state-level consumption but only since 1997, which is not ideal for our analysis that requires long-horizon data. Therefore, we follow Asdrubali et al. (1996)'s method of constructing state-level consumption by rescaling state-level retail sales by the country-level ratio of private consumption to retail sales, both of which are available from the BEA. Moreover, we use Nakamura and Steinsson (2014)'s state-level inflation series to convert nominal to real consumption.

Panel A of Table 1 presents the summary statistics of bilateral correlations of HP-filtered real consumption and output per capita (in logs). The median bilateral output correlation (0.479) is higher than the consumption correlation (0.388). This empirical pattern across states is consistent with that across countries, which contradicts the theoretical prediction in complete markets. This phenomenon remains a major puzzle in international macroeconomics, which is referred to as the consumption correlations puzzle (by Obstfeld and Rogoff (2000) or quantity puzzle by others). This paper uses domestic data to understand the drivers for consumption synchronization, which also potentially sheds light on the puzzle in the international context.

We establish an empirical gravity model of consumption smoothing by deriving a cross-sectional prediction for consumption comovement across states. In particular, we explore the implications of geographic distance for bilateral consumption smoothing by conducting a two-stage regression. In the first stage, we follow Eq. (1) to estimate bilateral smoothing coefficients for all the state pairs over the sample period. Panel B of Table 1 summarizes the statistics of the estimated coefficients $\hat{\beta}_{ij}$. Its median value is 0.501, which implies imperfect consumption smoothing since the value is between 0 and 1. In the second stage, we regress the estimated $\hat{\beta}_{ij}$ on the log of geographic distance:

$$\hat{\beta}_{ij} = \alpha + \gamma \log(dist_{ij}) + \Gamma X_{ij} + \nu_{ij}. \tag{2}$$

Our hypothesis is that state pairs with greater geographic distance exhibit weaker consumption smoothing, since bilateral economic exchanges which facilitate consumption comovement potentially face frictions that increase with bilateral distance. γ in Eq. (2) is therefore expected to be positive.

We compile the following variables to test this hypothesis with regression analysis. First, we measure cross-state geographic distance by applying the Haversine formula to state capitals' longitude and latitude. In addition, we consider distance based on trade data from the CFS to verify the robustness of our empirical findings.[5] The results reported in Table 2 confirm our hypothesis that bilateral geographic distance and smoothing coefficients are significantly and positively correlated. In column (1), when distance rises by 1%, bilateral consumption smoothing weakens by 0.00151 (or 0.004 standard deviations). In column (2) we control for state pairs' time-averaged GSP per capita and find consumption smoothing is stronger for states with higher income levels. Therefore, bilateral smoothing covaries with distance and income per capita in the same direction as in the gravity model of international trade. In column (3) we consider other geographic variables of a state pair including the product of states' land sizes in square miles (in logs), the number of mainland and coastal states, a contiguity dummy which equals one for a state pair sharing borders,

[4] Perfect consumption smoothing across states is potentially attainable through the three channels, which work as follows in a scenario where a positive productivity shock in state i raises its output relative to state j's. First, a terms-of-trade appreciation happens to state j whose goods become scarcer than i's under the shock. This price adjustment offsets the shortfall of j's output and leaves its relative consumption unaffected. Second, lending to j from the booming state i would increase j's financial resources for expenditure and hence mitigate its decline in relative consumption. Third, migration out of state j reduces the local population among which aggregate consumption is allocated and hence equalizes consumption per-capita across states. Therefore, these three channels can counteract idiosyncratic shocks of states to facilitate cross-state consumption smoothing (see detailed theoretical analyses in Section 3).

[5] The Commodity Flow Survey (CFS) reports shipment mileage between origin and destination ZIP code points for commodity flows used for domestic expenditure within the US. We use the average mileage of shipments between two states to calculate this CFS-based bilateral distance. See Table A.1 for this robustness check.

Table 1
Summary statistics of output, Consumption, and Smoothing coefficient.

	Mean	Median	Std. Dev.	Observations
A. Bilateral Correlation				
Output	0.422	0.479	0.316	1225
Consumption	0.340	0.388	0.329	1225
B. Bilateral Consumption Smoothing Coefficient				
$\hat{\beta}_{ij}$	0.515	0.501	0.292	1225

Bilateral correlation of output (consumption) is calculated as the correlation of HP-filtered real output (consumption) per capita in logarithms across all the state pairs over the sample period from 1977–2019. $\hat{\beta}_{ij}$ is estimated as the response of the relative consumption growth to the relative output growth as specified in Eq. (1).

and the total number of neighboring states to capture the state pair's multilateral ties with adjacent states.[6] Besides, we have the total number of Metropolitan Statistical Area (MSA) and number of MSA that geographically spans the state pair, which matters for the percentage of commuters whose location of residence and consumption differs from location of income. Column (4) also includes political and industrial dissimilarity as potential factors for consumption comovement based on the macro literature.[7] We measure a state-pair's political dissimilarity based on their voters' preference during presidential elections. For the dissimilarity of industrial profiles, we compute a pair of states' difference in sectoral composition with the BEA production data.[8] As suggested in Table 2 column (4), state pairs with greater political similarity and industrial dissimilarity exhibit a higher level of consumption smoothing. A one-standard-deviation increase in political similarity and decrease in industrial similarity are associated with an increase in consumption smoothing by 0.251 and 0.053 standard deviations respectively. Meanwhile, after these similarity measures are controlled for, the coefficient of distance remains economically and statistically significant: a 1% increase in geographic distance weakens consumption smoothing by 0.006 standard deviations.

In addition to the baseline estimation reported in Table 2, we perform three sets of tests to verify the robustness of the gravity model. First, we consider alternative data sources for state-level consumption, price, and bilateral geographic distance. Second, we reconstruct measures of bilateral smoothing after controlling for (1) state-level demographic variables which potentially shift aggregate demand over time including age, gender ratio, and education level, and (2) states' distinct exposure to aggregate country-level shocks. Third, we run a dynamic gravity model where we regress relative consumption growth on output growth over time and its interaction with distance. The results reported in Appendix A suggest that our finding remains robust.

The gravity model of consumption smoothing established above suggests the existence of frictions in the channels of risk sharing that covary with distance. We test for the underlying mechanism by examining the joint influences of distance and potential channels including trade, migration, and finance on consumption. Specifically, we compute bilateral linkages in these channels as the state-pair's mean value of bidirectional flows averaged over time. Bilateral trade and migration flows are obtained from the CFS and IRS respectively (see Appendix B for details). Financial flows are based on FDIC's deposit amount collected by financial institutions headquartered in one state and located in another.[9] Column (5) of Table 2 reports that after controlling for these three types of flows, distance plays a less important role in shaping consumption smoothing as reflected by a smaller coefficient estimate. This suggests that distance is a proxy for frictions in these channels, which contributes to the spatial pattern of consumption smoothing.

After empirically validating the covariance between consumption smoothing and distance using long-term data, we conduct an event study to verify the importance of geography for bilateral linkages including consumption comovement. Specifically, we focus on the North Dakota oil supply shock that started in 2006 with the surprising oil discovery by a petroleum geologist. The discovery provides a natural experiment to evaluate the impacts of a local income boost. The rapid oil extraction since the discovery has not only fueled the economic boom of North Dakota (ND hereafter) but also positively affected other states through their economic exchanges with ND.

To establish the spatial pattern of economic linkages in the wake of the oil shock, we run a panel regression with all the state pairs formed by ND over the period from 1991 to 2019 where migration and trade data are available. The regression is specified

[6] The number of mainland and coastal states takes values 0, 1, or 2 for a pair of states. Mainland states refer to the 48 contiguous states, excluding Alaska and Hawaii from the full sample of states. Coastal states refer to the states that have a coastline and are not landlocked.

[7] For example, Parsley and Popper (2021) document stark business cycle asynchronicity among blue versus red states in the US, and reason that differences in fiscal policies potentially explain how political division shapes this pattern of risk sharing. Meanwhile, the complementarity of industrial structures influences and is influenced by economies' output and consumption synchronization, according to the empirical findings by Kalemli-Ozcan et al. (2003).

[8] We locate a state's position on the political spectrum based on whether its voters chose a Republican or a Democratic candidate ($Pol_{it} = 0$ or 1) during presidential elections from 1976 to 2020, and take a state-pair's squared difference in the time-averaged values ($\bar{P}ol_i$) to measure political remoteness $Pol_{ij} = (\bar{P}ol_i - \bar{P}ol_j)^2$. Meanwhile, we calculate a state-pair's sectoral composition of output and aggregate the squared difference over sectors to measure industrial dissimilarity: $Ind_{ij} = \sum_{s=1}^{S}(b_{i,s} - b_{j,s})^2$, where $b_{i,s} = \frac{\bar{Y}_{i,s}}{\sum_{s=1}^{S}\bar{Y}_{i,s}}$ and $\bar{Y}_{i,s}$ denotes the output of sector s in state i averaged over the sample period. To calculate sectoral shares in state-level output ($b_{i,s}$), we use the real sectoral output series (SAGDP9N) from the BEA, which reports data at the 3-digit NAICS level.

[9] Comprehensive data for the US state-to-state financial flows are not existent to our knowledge, but the Federal Deposit Insurance Corporation (FDIC) bank statistics lists branch locations and deposits of its insured financial institutions. States i and j are deemed to exhibit stronger financial ties when banks headquartered in i collect more deposits from branches located in j. It is the among the most comprehensive public data to document financial linkages across states. However, given the geographic concentration of the US banking industry and under-representation of bank deposits in total financial exchanges, it is not sufficient to empirically reflect bilateral financial flows or to structurally estimate the theoretical model with in the next section. We will hence consider alternative (consumption-based) moments to measure bilateral financial frictions.

Table 2
Spatial pattern of consumption smoothing.

Dep. Var: $\hat{\beta}_{ij}$	(1)	(2)	(3)	(4)	(5)
$\log(dist_{ij})$	0.151 ***	0.156 ***	0.220 ***	0.211 ***	0.207 ***
	(0.010)	(0.010)	(0.012)	(0.012)	(0.011)
$\log(\bar{y}_i \cdot \bar{y}_j)$		−0.099 ***	−0.061 *	0.052	−0.163 ***
		(0.032)	(0.035)	(0.038)	(0.041)
Land Area			−0.038 ***	−0.022 ***	−0.053 ***
			(0.006)	(0.006)	(0.006)
Mainland			0.117 ***	0.079 ***	0.145 ***
			(0.025)	(0.024)	(0.023)
Coastal			0.018	0.023 *	−0.011
			(0.014)	(0.014)	(0.014)
Contiguity			0.128 ***	0.102 ***	−0.005
			(0.033)	(0.033)	(0.033)
Number of Neighboring States			−0.002	−0.005	−0.004
			(0.004)	(0.004)	(0.004)
Number of MSA			0.001	−0.002 *	−0.010 ***
			(0.001)	(0.001)	(0.001)
Number of Shared MSA			0.021	0.022	−0.013
			(0.023)	(0.022)	(0.023)
Industrial Dissimilarity (Ind_{ij})				−5.480 ***	−4.700 ***
				(0.754)	(0.817)
Political Dissimilarity (Pol_{ij})				0.069 **	0.103 ***
				(0.032)	(0.030)
Trade					−0.010
					(0.019)
Migration					0.169
					(0.155)
Finance					0.005
					(0.007)
Observations	1225	1225	1225	1225	1225
R^2	0.161	0.169	0.255	0.288	0.355

Robust standard errors in parentheses. *** significant at 1%. The dependent variable is the consumption smoothing coefficient $\hat{\beta}_{ij}$, which is estimated using the real consumption and output data over 1977–2019. $dist_{ij}$ denotes the geographic distance between state i and j. $\bar{y}_i$ denotes the time-averaged output per capita of state i. Other control variables include a state-pair's geographic characteristics as well as political and industrial dissimilarity, time-averaged bidirectional flows in trade, migration, and financial channels.

as follows

$$X_{ijt} = \alpha_0 + \alpha_1 Oil_t + \sum_{m=1}^{M} \alpha_{2m} Oil_{t-m} + \alpha_3 \log(dist_{ij}) + \sum_{n=0}^{M} \alpha_{4n} Oil_{t-n} \times \log(dist_{ij}) + \alpha_{5t} I_t + \alpha_{6j} I_j + \zeta_{ijt}. \quad (3)$$

X_{ijt} represents bilateral variables of interest including migration flows (mig_{ijt}), trade values (trd_{ijt}), and relative per-capita consumption growth between state i as ND and j as any other state.[10] For migration and trade, we focus on the log of ND's population and goods inflows from other states to capture the spillover of the positive shock. For the relative consumption growth, we consider two measures: $\Delta c_{ijt} \equiv \Delta \log c_{it} - \Delta \log c_{jt}$ and $\Delta \tilde{c}_{ijt} \equiv (\Delta \log c_{it} - \Delta \log c_{jt}) - \hat{\beta}_{ij}(\Delta \log y_{it} - \Delta \log y_{jt})$. The latter uses $\hat{\beta}_{ij}$ estimated from Eq. (1) which provides a robust measure of consumption smoothing. To isolate the responses of these variables to the oil shock as deviations from their long-term trend, we take the difference between the realization of these bilateral variables at time t and their mean values over the sample period, and use these demeaned values as dependent variables. In addition, we control for time fixed effects (denoted as I_t) to capture any aggregate shock at time t and state fixed effects (I_j) to control for cross-state differences independent of the oil shock. Oil_t is a binary variable which is unity when t represents year 2006 and zero otherwise. We also consider medium-run effects of the shock by including lagged dummies Oil_{t-m} which equal one when the oil shock happens m years ago. In the baseline case, we set the maximum number of lags as three years for migration and consumption, and as eleven years for trade to get sufficient observations under its five-year data frequency. The key variable of interest to verify the importance of geography for economic linkages is $\sum_{n=0}^{M} \alpha_{4n}$, the linear combination of coefficient estimates for the interaction terms of the oil shock and bilateral distance.

Table 3 reports the regression results. Based on the interaction terms, bilateral economic linkages exhibit strong spatial patterns. In columns (1) and (2), a 1% increase in geographic distance lowers trade and migration flows from another state to ND by 0.578% and 0.394% respectively due to the oil shock.[11] This result points to barriers in these two channels that covary with geography

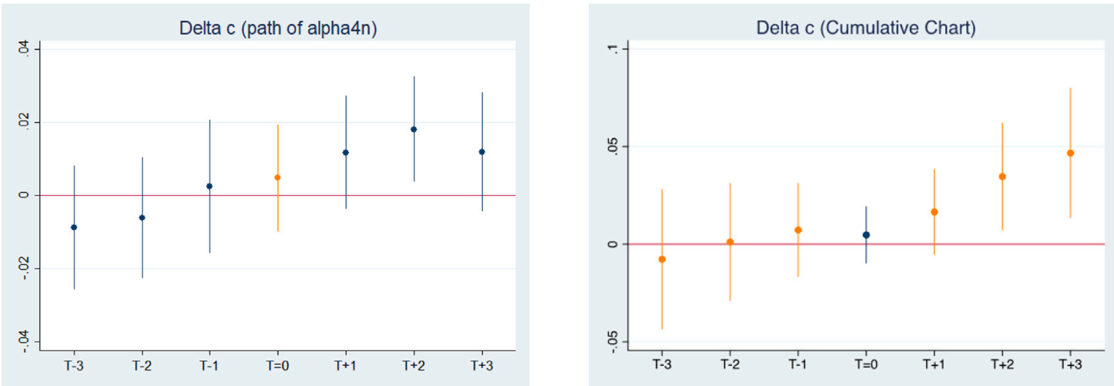
[10] We do not include finance in this event analysis due to the lack of financial data. Even with FDIC's banking data, ND's observations are very scarce since it is not a major hub for the banking industry.

[11] These results from columns (1) and (2) become weaker in columns (3) and (4) where state fixed effects are added, particularly given the limitation of trade data with low frequency and high sparsity.

Table 3
ND's bilateral linkages after the oil shock.

Dep. Var:	(1) log(trd)	(2) log(mig)	(3) log(trd)	(4) log(mig)	(5) Δc	(6) $\Delta\tilde{c}$
Oil_t		0.124		0.123	−0.010	−0.002
		(0.465)		(0.473)	(0.051)	(0.044)
$\sum_{m=1}^{M} Oil_{t-m}$	1.883 *	−0.974	1.836 *	−0.974	−0.045	−0.010
	(0.967)	(0.599)	(0.992)	(0.608)	(0.079)	(0.067)
log($dist$)	0.012	0.013	0.006	0.014	−0.002	−0.001
	(0.075)	(0.014)	(0.352)	(0.057)	(0.008)	(0.008)
$\sum_{n=0}^{M} Oil_{t-n} \times \log(dist)$	−0.578 *	−0.394 ***	−0.339	−0.393 ***	0.049 ***	0.038 **
	(0.325)	(0.146)	(0.363)	(0.149)	(0.017)	(0.016)
State FE	N	N	Y	Y	Y	Y
Time FE	Y	Y	Y	Y	Y	Y
Observations	244	1,360	244	1,360	1,372	1,372
R^2	0.657	0.645	0.688	0.645	0.650	0.555

Robust standard errors in parentheses. *** significant at 1%, ** at 5%, and * at 10%. The dependent variables include North Dakota (ND)'s demeaned migration and trade inflows in logs from other states, as well as ND's per-capita consumption growth relative to other states (Δc), and the relative consumption adjusted for output growth ($\Delta\tilde{c}$). log($dist$) denotes the geographic distance between ND and other states. Oil_t is a dummy variable for the oil shock to ND in 2006. Its coefficient is missing in columns (1), (3) since the CFS trade data are not available that year.



(a) α_{4n} (b) $\sum_{n=0} \alpha_{4n}$

Fig. 2. ND's relative consumption growth after the oil shock.
This figure plots the time series pattern of the coefficient estimate α_{4_n} when ND's relative consumption growth Δc over other states is the dependent variable and the interaction term for the oil shock and distance is the independent variable (column (5) in Table 3). (a) shows α_{4_n}'s estimate and 95% confidence interval at each time point, where $T = 0$ represents year 2006 where the oil shock happened. (b) shows cumulative changes $\sum_{n=0}^{M} \alpha_{4n}$ over time.

which limit the scope of positive spillovers brought forth by ND's economic success. Consequently, residents from distant states are constrained from physically moving to or exporting goods to the booming state. Such barriers can also account for the spatial pattern of consumption. As reported in columns (5) and (6), ND's per-capita consumption growth is larger in magnitude relative to that of more distant states. From column (5), a 1% increase in distance raises ND's relative consumption growth driven by its oil shock by 0.049%. Fig. 2 plots the time path of α_{4n} and its cumulative change, which shows a noticeable slope increase after the oil shock. Using specific states as an example, we find the cumulative consumption growth three years after the shock in Nebraska is 8.7% higher than in Florida. This finding that ND's consumption is more synchronized with neighboring states' indicates geography plays an essential role in shaping the variation in consumption comovement. The result remains robust in column (6) where we adjust consumption for output differentials, which further implies that consumption smoothing deteriorates as distance rises.

To conclude this empirical section, both the gravity model and the ND event study suggest geographic distance is important in shaping bilateral consumption comovement. The next section develops a structural model where we investigate the three channels in detail and quantify their influences on this spatial consumption pattern.

3. Theoretical analysis

This section develops a real business cycle model to examine how geography influences consumption synchronization through frictional trade, migration, and financial channels. Section 3.1 describes the setup of the model. 3.2 illustrates how different channels interact to jointly affect consumption in a symmetric two-state setting. 3.3 conducts counterfactual analyses to quantify impacts of these channels in an asymmetric fifty-state setting.

3.1. Model setup

The economy is populated by a mass of infinitely-lived homogeneous households which reside in different states indexed by $i \in \{1, 2, \dots, I\}$. States are connected through bilateral exchanges in trade, migration, and finance channels.

3.1.1. Trade

State i produces an intermediate good with a Cobb–Douglas production technology that combines i's productivity $T_{i,t}$, capital $K_{i,t}$, and labor $L_{i,t}$ at time t:

$$Y_{i,t} = T_{i,t} K_{i,t}^{\mu} L_{i,t}^{1-\mu}. \tag{4}$$

Output and price of the intermediate good are denoted as $Y_{i,t}$ and $p_{i,t}$ respectively. State-level productivity $T_{i,t}$ follows a joint AR(1) process with mean $\bar{T}_i$, persistence ρ, and stochastic shocks $\epsilon_{i,t}$ drawn from a joint normal distribution with a cross-state covariance matrix denoted as Σ_T.

State i's final good for local expenditure is a CES bundle of intermediate goods imported from all the states. Exports from j to i are subject to an iceberg cost $\tau_{ji} \geq 1$, which influences the share of j's intermediate good in i's expenditure denoted as $\pi_{ji,t}$:

$$\pi_{ji,t} = (\frac{\tau_{ji} p_{j,t}}{P_{i,t}})^{-\phi} \quad \text{where} \quad P_{i,t} = [\sum_{j=1}^{I} (\tau_{ji} p_{j,t})^{1-\phi}]^{\frac{1}{1-\phi}}, \tag{5}$$

where ϕ is the elasticity of substitution and $P_{i,t}$ is i's aggregate price level decided jointly by prices of intermediate goods from different economies $p_{j,t}$. Given bilateral trade shares $\pi_{ji,t}$, the market clearing condition of j's intermediate good is

$$Y_{j,t} = \sum_{i=1}^{I} \pi_{ji,t} X_{i,t}. \tag{6}$$

The final good for expenditure $X_{i,t}$ is used for consumption $C_{i,t}$ and investment $IV_{i,t}$:

$$X_{i,t} = C_{i,t} + IV_{i,t}. \tag{7}$$

Investment $IV_{i,t}$ will add to i's capital stock $K_{i,t}$ subject to depreciation δ. The law of motion for physical capital hence follows

$$K_{i,t} = (1-\delta) K_{i,t-1} + IV_{i,t}. \tag{8}$$

3.1.2. Finance

In modeling the financial market, we develop a portfolio choice problem following the international macro literature including Coeurdacier and Rey (2013) and Heathcote and Perri (2013) to assume that each state issues equities as claims to capital income. The dividend payout is capital rental fee net of investment expenditure

$$DV_{i,t} = \mu p_{i,t} Y_{i,t} - P_{i,t} IV_{i,t}. \tag{9}$$

Dividends $DV_{i,t}$ and asset prices $q_{i,t}$ will decide asset returns $R_{i,t}$:

$$R_{i,t} = \frac{q_{i,t} + DV_{i,t}}{q_{i,t-1}}. \tag{10}$$

The purpose of setting up the portfolio choice problem is to capture any variation of bilateral financial linkages that potentially shapes consumption comovement in a multi-economy setting.[12] The bilateral variation requires modeling asset holdings and financial frictions at state-pair instead of at state levels. Therefore, we introduce bilateral financial friction $e^{-f_{ij}}$ as a transaction cost when state j repatriates returns from state i.[13]

There is a mutual fund in every state that makes investment decisions on behalf of its households. The mutual fund constructs a portfolio of assets to maximize the expected lifetime utility from consumption of a household living in the state:

$$\max \sum_{t=0}^{\infty} \beta^t \frac{c_{i,t}^{1-\sigma}}{1-\sigma}, \tag{11}$$

where $c_{i,t}$ denotes consumption per-capita of state i at time t and σ governs risk aversion in the CRRA utility. A household has the right to an equal share of the fund as long as it resides there.[14] To solve the portfolio choice problem in a DSGE model, we

[12] Empirical evidence for this bilateral variation includes the gravity model of cross-country financial flows (Portes and Rey, 2005), the 'home bias at home' phenomenon in the domestic context (Coval and Moskowitz, 1999), and the FDIC banking statistics used in this paper.

[13] Modeling financial frictions as iceberg transaction costs is a common modeling strategy in the international macro literature (see, for example, Aviat and Coeurdacier, 2007) and Tille and Van Wincoop, 2010. Okawa and Van Wincoop (2012) discuss alternative forms of these financial frictions including information costs and find them to yield similar predictions for cross-economy financial flows.

[14] To simplify the computation of the portfolio choice problem, we assume households are myopic and expect themselves to stay in the state when deciding on saving for the next period. Under this assumption, households only care about the expected consumption per-capita in their state of residence during the next period, based on which the local mutual fund makes investment decisions (Eq. (11)). An extension for future research is to allow households to consider their own migration probabilities, which prompt them to reduce saving and raise current consumption when making investment decisions.

use the solution method developed by Devereux and Sutherland (2011), who combine a second-order approximation of the Euler equations and a first-order approximation of other equations to determine a zero-order (steady state) portfolio. Specifically, we take a second-order Taylor expansion of any state i's Euler equation

$$E_t[\frac{c_{i,t+1}^{-\sigma}}{P_{i,t+1}} R_{i,t+1}] = E_t[\frac{c_{i,t+1}^{-\sigma}}{P_{i,t+1}} e^{-f_{ji}} R_{j,t+1}], \qquad \forall i,j \in \{1,2,\dots,I\}, \tag{12}$$

and take its difference from state j's expanded Euler equation to derive a portfolio determination equation[15]:

$$E_t\{[\sigma(\widetilde{c}_{i,t+1} - \widetilde{c}_{j,t+1}) + \widetilde{P}_{i,t+1} - \widetilde{P}_{j,t+1}]\widetilde{R}_{x,t+1}\} = \frac{1}{2}F. \tag{13}$$

A tilde above a variable denotes its log-deviation from the steady state: $\widetilde{A}_t = \ln(A_t) - \ln(\bar{A})$. $R_{x,t+1}$ is the vector of excess financial returns and F is a matrix of relative financial frictions. If markets are complete such that the Backus-Smith condition holds:

$$\sigma(\widetilde{c}_{i,t+1} - \widetilde{c}_{j,t+1}) + \widetilde{P}_{i,t+1} - \widetilde{P}_{j,t+1} = 0, \tag{14}$$

the friction matrix F equals zero. Hence, we can infer financial frictions from (13)–(14) given states' price-adjusted consumption comovement. Since these financial frictions are estimated as the wedge that generates the deviation of consumption allocation from the prediction in complete markets, they can be interpreted as all barriers to financial arrangements that may cause market incompleteness and impair consumption risk sharing.[16]

Let $v_{ik,t}$ be the mutual fund in i's purchase of k's assets at the end of period t, and the supply of assets issued by any state k be normalized at unity $\sum_{i=1}^{I} v_{ik,t} = 1$. If we define net holdings as

$$\alpha_{ii,t} = q_{i,t}(v_{ii,t} - 1), \alpha_{ij,t} = q_{j,t}v_{ij,t}, \forall j \neq i, \tag{15}$$

they will add to a state's net wealth position denoted as

$$D_{i,t} = \sum_{k=1}^{I} \alpha_{ik,t}. \tag{16}$$

We then obtain k's asset market clearing condition as

$$\sum_{i=1}^{I} \alpha_{ik,t} = 0, \tag{17}$$

and i's wealth constraint as[17]

$$D_{i,t+1} = \sum_{j=1}^{I} \alpha_{ij,t} e^{-f_{ij}} R_{j,t} + p_{i,t}Y_{i,t} - P_{i,t}X_{i,t}. \tag{18}$$

3.1.3. Migration

Households make optimal decisions to maximize expected lifetime utility. At the beginning of every period, a household living in state i supplies labor, collects wage and financial income, and decides on consumption. It derives utility from per-capita consumption $c_{i,t} = \frac{C_{i,t}}{N_{i,t}}$ and disutility from labor hours $l_{i,t} = \frac{L_{i,t}}{N_{i,t}}$ in its state of residence with a population $N_{i,t}$:

$$U_{i,t} = \frac{c_{i,t}^{1-\sigma}}{1-\sigma} - \frac{l_{i,t}^{1+\eta}}{1+\eta}. \tag{19}$$

After earning and spending its income in state i, the household decides where it wants to live in the next period. When it makes the decision, it considers a non-pecuniary migration cost $d_{ij} \geq 0$ when moving from state i to j and an idiosyncratic benefit $\omega_{j,t}$ from being located in state j at the end of the period. The value function for the household $V_{i,t}$ is the sum of its current utility $U_{i,t}$ and the expected continuation value based on its optimal choice of location with cost d_{ij} and benefit $\omega_{j,t}$ taken into consideration:

$$V_{i,t} = U_{i,t} + \max_j[\beta E(V_{j,t+1}) - d_{ij} + \omega_{j,t}]. \tag{20}$$

Following Artuc et al. (2010), we assume that $\omega_{j,t}$ is i.i.d over time and across space and households. It is drawn from an extreme-value zero-mean distribution with parameters θ, γ:

$$F(\omega) = \exp[-e^{\omega/\theta - \gamma}]. \tag{21}$$

[15] See Appendix C.1 for its derivation and other technical details of the portfolio choice problem.

[16] This estimation strategy based on consumption allows us not to take a strong stand on the exact form these financial frictions take in the real world, which may include borrowing constraints faced by states when they raise funds, information asymmetries that prohibit bilateral capital flows, and asset transaction costs that cause market inefficiency. It would be difficult to identify and quantify all of these barriers to financial allocation, especially given the lack of state-to-state financial flows data. In a classic study on risk sharing, Fitzgerald (2012) also infers financial frictions from consumption.

[17] Future extensions of the model can include a tax transfer in the wealth constraint, as fiscal federalism is important for intranational risk sharing. The equilibrium wealth $\check{D}_i$ in this model will be calibrated to trade balance from the CFS, which also maps to a state's difference between income and expenditure. Therefore, it already considers such tax transfers although they are not modeled explicitly.

Under these assumptions, the share of households in i migrating to j at t is[18]

$$m_{ij,t} = \frac{\exp[(\beta E(V_{j,t+1}) - d_{ij})/\theta]}{\sum_{k=1}^{I} \exp[(\beta E(V_{k,t+1}) - d_{ik})/\theta]}. \tag{22}$$

The law of motion for population based on migration shares hence follows

$$N_{j,t+1} = \sum_{i=1}^{I} m_{ij,t} N_{i,t}. \tag{23}$$

To summarize the model setup, general equilibrium of the economy consists of prices and quantities such that (1) firms set output and price to maximize profit, (2) households make consumption, labor hours, capital investment, and migration decisions, as well as mutual funds construct portfolios to maximize households' expected lifetime utility, (3) goods, factors, and asset markets all clear.[19]

3.2. Two-state analysis

Before discussing predictions from a full-fledged fifty-state model in the next section, we build theoretical foundations by delivering mechanisms in a symmetric two-economy setting following the international macro literature including Backus et al. (1992) (BKK). In particular, we perform comparative statics analysis where different frictions take alternative values, to examine the interactions among channels of risk sharing in jointly shaping cross-state consumption synchronization in general equilibrium.

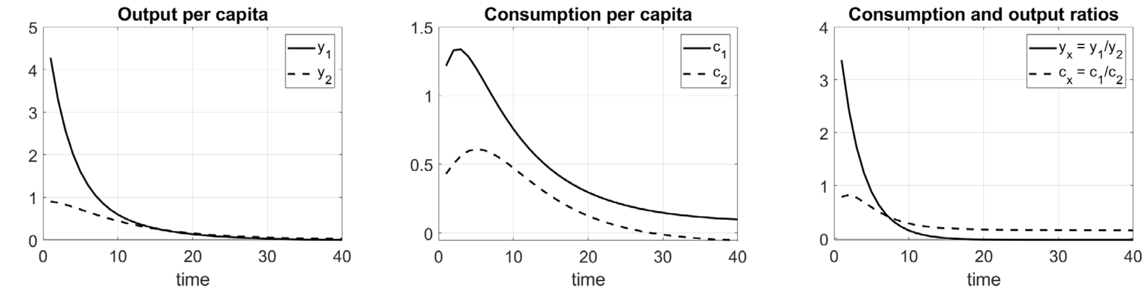
The steady state of this two-state model is calibrated with median values of variables across all the US states. Specifically, we estimate model-consistent frictions in the three channels to match target moments including median cross-state trade shares $\bar{\pi}_{ij}$, migration shares $\bar{m}_{ij}$, and degrees of consumption smoothing $\hat{\beta}_{ij}$ from the empirical section. Since financial frictions only enter the second-order Taylor expansion of the Euler equation and hence do not change the steady state of the economy, we first calibrate trade and migration costs jointly to match $\bar{\pi}_{ij}$ and $\bar{m}_{ij}$ on the real side of the economy. In the second step, we perform portfolio analysis with linear methods in this DSGE model around the calibrated steady state, where financial frictions which covary with second-moment macro variables are estimated to match $\hat{\beta}_{ij}$, with the influences of migration and trade costs on consumption already considered from the first step of estimation. Following this approach, we calibrate the three frictions τ, d, f in the benchmark two-economy case targeting states' median moments. Appendix D.1 provides calibration details, evaluates model performance, and discusses magnitude of frictions.

Our analysis begins with two symmetric states indexed by $i = \{1, 2\}$ originally in the calibrated steady state, where we simulate a one standard deviation shock to state 1's productivity to study the dynamics of endogenous variables in this benchmark case. From Fig. 3 that plots the impulse response functions (IRFs) of output and consumption per capita, both states experience improvements in these variables even though the shock is limited to state 1. The positive spillover to state 2 is not only driven by productivity covariances but also by bilateral economic linkages in different channels, implied by a lower cross-state correlation of productivity (0.37) than that of consumption and output (0.40 and 0.43) predicted from the model. Nevertheless, synchronization across states is not perfect due to various frictions in economic linkages, hence state 1 witnesses a larger increase of output and consumption shown in 3(a)–3(b). If we compare cross-state ratio of output ($y_x = \frac{y_1}{y_2}$) and consumption ($c_x = \frac{c_1}{c_2}$) in 3(c), consumption c_x is less volatile than output y_x. This result provides theoretical evidence for consumption smoothing, which mitigates cross-state consumption disparity in response to relative output fluctuations.

To diagnose mechanisms of consumption risk sharing, we examine the dynamics of key variables in the three channels including state 1's terms-of-trade (ToT, $p_x = p_1/p_2$), net wealth (D_1), and population (N_1), whose IRFs around the steady state of the economy are drawn in Fig. 4. Right after its productivity shock, state 1 experiences a ToT depreciation in 4(a) where a larger supply devalues its exports relative to imports under the goods market clearing condition. This price adjustment in favor of state 2 partially offsets its relative output shortfall to raise its nominal income and consumption. In the financial channel, 4(b) shows state 1 accumulates net wealth after its productivity shock, different from the prediction by BKK. This difference can be explained by the existence of financial frictions in our model that prohibit efficient capital allocation across states, such that state 2 cannot lend to 1 despite its economic boom. Meanwhile in 4(c), population flows into the booming state, which increases the number of households in state 1 among which the state's aggregate consumption is shared. This migration channel helps to equalize consumption per capita across states and therefore facilitates consumption synchronization. Both wealth and population accumulation boost state 1's aggregate expenditure, whose composition skews towards home goods in the presence of cross-state trade cost. Consequently, state 1's high demand for its home goods causes a ToT appreciation in the long run 4(a), which limits state 2's consumption gain from state 1's supply shock through price adjustment in the trade channel. Hence, it is important to consider interactions of different channels in jointly driving consumption synchronization, which we emphasize in the following comparative statics analysis.

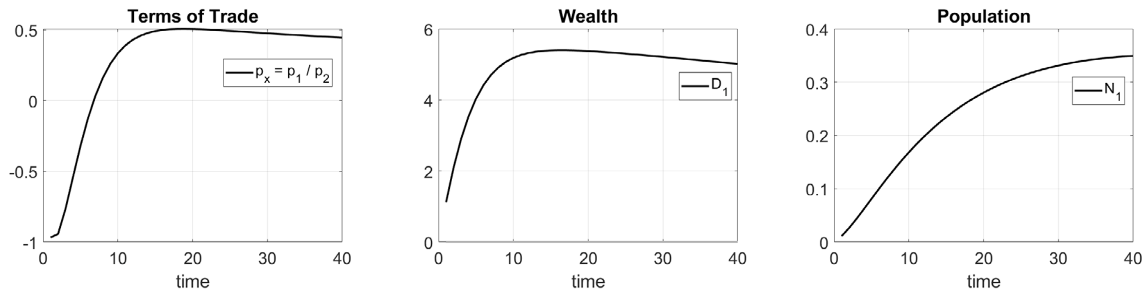
[18] See Appendix C.2 for more details of the migration problem and the online appendix of Artuc et al. (2010) for technical derivations of the expression for bilateral migration shares.

[19] The goods and asset market clearing conditions are Eqs. (6) and (17) respectively. The factor market clearing condition ensures households' labor supply and capital accumulation decided by utility maximization equal firms' demand for labor and capital driven by profit maximization in each state.



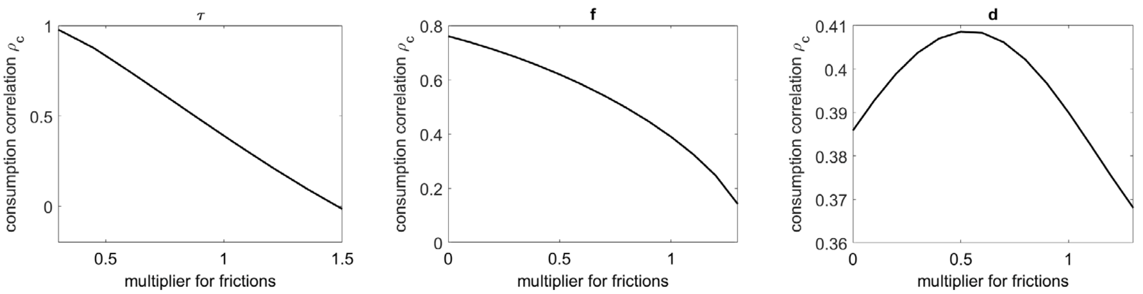
(a) IRF of output p.c. (b) IRF of consumption p.c. (c) IRF of cross-state ratios

Fig. 3. Impulse response functions of consumption and output.
This figure plots the impulse response functions (IRFs) of output and consumption per capita (p.c.) in percentage terms in response to a one-standard-deviation shock to state 1's productivity. The solid and dashed lines in 3(a)–3(b) show state 1's and state 2's variables respectively. Fig. 3(c) plots the IRFs of cross-state ratios of output $y_x = y_1/y_2$ and consumption $c_x = c_1/c_2$ per capita.



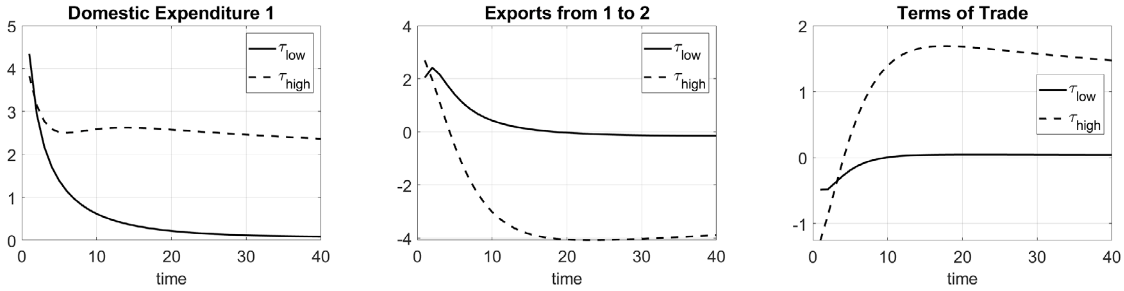
(a) IRF of ToT (b) IRF of net wealth (c) IRF of population

Fig. 4. Impulse response functions of state 1's macro variables.
This figure plots the impulse response functions (IRFs) of key macro variables in the three channels of risk sharing in percentage terms in response to a one-standard-deviation shock to state 1's productivity. Variables include state 1's terms of trade (ToT) $p_x = p_1/p_2$, net wealth D_1, and population N_1. In this symmetric two-economy setting, state 2's IRFs are the mirror images of state 1's for these variables.



(a) $\rho(c_1, c_2)$ and τ (b) $\rho(c_1, c_2)$ and f (c) $\rho(c_1, c_2)$ and d

Fig. 5. Bilateral consumption correlation under varying frictions.
This figure presents comparative statics analysis for cross-state correlation of consumption per capita $\rho(c_1, c_2)$ under different trade costs τ, financial frictions f, and migration costs d in plots 5(a), 5(b), and 5(c) respectively. Multipliers for the calibrated frictions are on the horizontal axis. For example, a multiplier equal to 1 for a friction represents the case where the value of that friction equals its calibrated value. A multiplier equal to 0.5 (2) represents the case where the value of that friction is half (twice) of its calibrated value while other parameters in the model remain unchanged. Model-predicted consumption correlations under these multiplied frictions are on the vertical axis.



(a) IRF of $\pi_{11}X_1$ (b) IRF of $\pi_{12}X_2$ (c) IRF of $p_x = p_1/p_2$

Fig. 6. Comparative statics under different trade costs.
This figure plots the impulse response functions (IRFs) of state 1's domestic expenditure ($\pi_{11}X_1$), exports ($\pi_{12}X_2$), and ToT ($p_x = p_1/p_2$) in percentage terms in response to a one-standard-deviation shock to state 1's productivity. Solid lines are IRFs under 0.5 times the calibrated trade cost (τ_{low}), while dashed lines are IRFs under 1.5 times the calibrated value (τ_{high}). Model-predicted bilateral consumption correlation under different multipliers for the calibrated trade cost τ is shown earlier in Fig. 5(a).

Fig. 5 presents comparative statics for consumption correlation under alternative values of frictions in the three channels.[20] Under the calibrated frictions τ, d, f in the benchmark case (where multipliers for the frictions are equal to 1 in the figure), cross-state consumption correlation is around 0.4. The correlation drops drastically to almost zero when trade or financial frictions rise to 1.5 times their calibrated values in 5(a) and 5(b). When these two frictions are turned off, consumption correlation approaches one which represents perfect consumption smoothing. Therefore, both trade and financial channels are effective channels for risk sharing, whose frictions potentially contribute to the relatively low cross-state consumption correlation observed in the data. Compared to these two, the impact of migration costs on consumption correlation is less pronounced and not monotonic in 5(c). These patterns of consumption synchronization depicted in Fig. 5 are shaped by the joint dynamics of key variables from the three channels, which we examine in detail below for each of the channels.

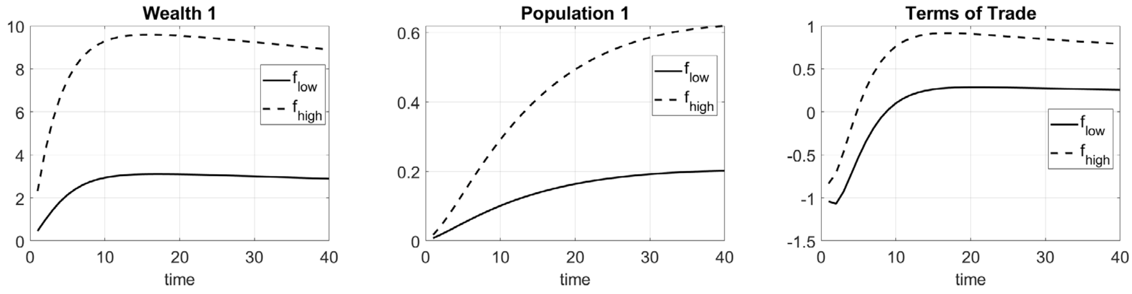
Fig. 6 plots variables' impulse responses when trade costs are 0.5 (τ_{low}) and 1.5 (τ_{high}) times their calibrated values with solid and dashed lines respectively. Shortly after its productivity shock, state 1 experiences a ToT depreciation in both cases but the trend is reverted in the long term under τ_{high}. This long-term ToT appreciation is mostly driven by an increase in domestic expenditure 6(a) that dominates a decrease in exports 6(b) to raise the aggregate demand for state 1's goods.[21] As discussed earlier for 4(a), a ToT depreciation of state 1 would benefit state 2 by spreading consumption gains through the trade channel. Therefore, a higher trade cost, by strengthening expenditure home bias and hindering bilateral trade exchanges to generate a ToT appreciation, prohibits price adjustment in the direction that would facilitate consumption risk sharing. This explains the negative covariance between trade cost and consumption correlation in 5(a).

We perform a similar analysis for the financial channel in Fig. 7. A higher financial friction impedes cross-state asset holdings and causes wealth to accumulate predominantly in state 1 after its positive productivity shock 7(a). The wealth gap worsens consumption inequality, which also induces more households from state 2 to migrate to state 1 7(b). Wealth and population accumulation enable state 1 to expand its expenditure especially on domestic goods, which causes a greater ToT appreciation in the trade channel 7(c) that further exacerbates consumption inequality. These channels jointly contribute to the negative covariance between financial friction and consumption correlation in 5(b).

Last but not least, we examine the non-monotonic covariance between migration cost and consumption correlation in 5(c) by plotting IRFs when the migration cost is 0 (d_{low}), 0.5 (d_{mid}), and 1.5 (d_{high}) times its calibrated value in Fig. 8. From 8(a), state 1's ToT depreciation after its productivity shock is the greatest under d_{mid}. A ToT depreciation not only facilities risk sharing through the trade channel, but also exerts downward pressure on wage in general equilibrium. This requires more population flows into state 1 to clear the labor market 8(b), which mitigates inequality in cross-state consumption per capita through the migration channel. Hence, both trade and migration channels contribute to a higher consumption correlation under d_{mid} than d_{low} in 5(c). State 1's productivity shock boosts its demand for labor while the supply of labor per capita decreases under households' income effect soon after the shock 8(c). Therefore, the population inflows are large in magnitude in 8(b) under d_{low} and d_{mid} to satisfy the increased labor demand. Another migration pattern we observe from the figure is that the peak under d_{mid} is about 5 periods later than that

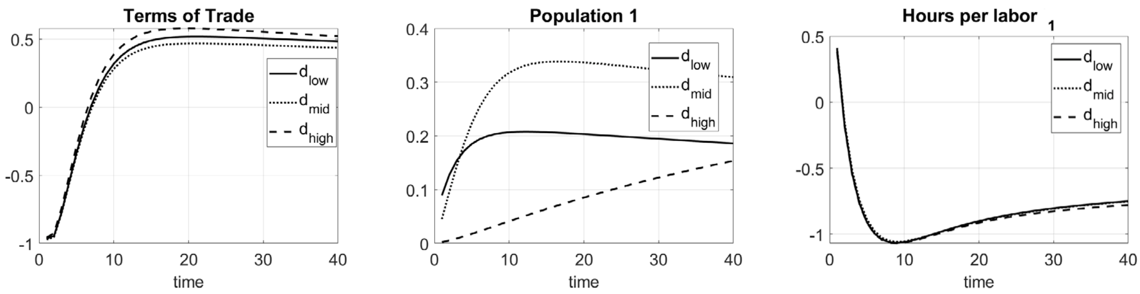
[20] Appendix D.1 describes the computation strategy for comparative statics where we alter values of frictions from their calibrated values. If trade or migration costs τ, d change values, we re-solve the steady state of the model under their new values. Around the steady state, we solve the portfolio problem where possible changes to financial frictions f are taken into consideration. Under the derived portfolios, we compute the model-predicted consumption correlation with linear methods for DSGE models.

[21] The magnitude of domestic expenditure dominates for two reasons. First, the size effect that state 1's productivity shock expands its expenditure size more than state 2's ($\widetilde{X}_1 > \widetilde{X}_2$). Second, the composition effect that trade costs skew states' expenditure towards home goods ($\bar{\pi}_{11} > \bar{\pi}_{12}$). In 6(b), exports from state 1 to 2 decline under τ_{high} due to state 1's ToT appreciation, which induces households in state 2 to switch their expenditure to the relatively affordable home goods of their own.



(a) IRF of net wealth D_1 (b) IRF of population N_1 (c) IRF of $p_x = p_1/p_2$

Fig. 7. Comparative statics under different financial frictions.
This figure plots the impulse response functions (IRFs) of state 1's net wealth (D_1), population (N_1), and ToT ($p_x = p_1/p_2$) in percentage terms in response to a one-standard-deviation shock to state 1's productivity. Solid lines are IRFs under 0.5 times the calibrated financial friction (f_{low}), while dashed lines are IRFs under 1.5 times the calibrated value (f_{high}). Model-predicted bilateral consumption correlation under different multipliers for the calibrated financial friction f is shown earlier in Fig. 5(b).



(a) IRF of $p_x = p_1/p_2$ (b) IRF of population N_1 (c) IRF of labor hours l_1

Fig. 8. Comparative statics under different migration costs.
This figure plots the impulse response functions (IRFs) of state 1's ToT ($p_x = p_1/p_2$), population (N_1), and labor hours (1_1) in percentage terms in response to a one-standard-deviation shock to state 1's productivity. Solid, dotted, and dashed lines represent IRFs when the migration cost is 0 (d_{low}), 0.5 (d_{mid}), and 1.5 (d_{high}) times the calibrated value respectively. Model-predicted bilateral consumption correlation under different multipliers for the calibrated migration cost d is shown earlier in Fig. 5(c).

under d_{low}. Forcing more population to stay temporarily as labor force in state 2 would flatten out cross-state aggregate income differential over time, especially right after the shock where the productivity gap is the largest. Hence, this delay in population adjustment under d_{mid} helps to strengthen consumption synchronization across states relative to in the d_{low} case. Nonetheless, when the migration cost rises further from d_{mid} to d_{high}, it deters population inflows 8(b) and hence raises the relative wage of state 1 under the labor market clearing condition, which also generates a stronger ToT appreciation 8(a). As a result, cross-state consumption correlation declines, since neither migration nor trade channel works effectively to facilitate risk sharing under the high migration cost.

These comparative statics analyses shed light on mechanisms of risk sharing to provide theoretical foundations for our quantitative assessment of a full-fledged model, where we disentangle contributions of different channels to consumption synchronization.

3.3. Fifty-state analysis

To quantify the impacts of different channels on consumption risk sharing, this section conducts counterfactual exercises where the three channels are shut down sequentially. Different from the symmetric two-state setting in the previous section, we perform analysis in an asymmetric setting with all the fifty states in the US.

The large number and sparse feature of bilateral linkages across $\frac{I(I-1)}{2} = 1225$ state pairs make it nearly impossible to accurately estimate bilateral frictions simultaneously. Nonetheless, we can perform comparative statics analysis with sufficient statistics to predict counterfactual outcomes without knowing the exact values of these frictions. In particular, observed bilateral trade weights, migration shares, and degrees of consumption smoothing are sufficient statistics that have embedded unobserved bilateral trade, migration, and financial costs, so that we do not need to estimate these frictions when predicting counterfactual consumption correlations around the calibrated steady state characterized by these statistics.

To conduct the exercises, we start with calibrating the steady state of the economy. We collect data on state-level output $\bar{Y}_i$, population $\bar{N}_i$, wealth $\check{D}_i$, bilateral migration $\bar{m}_{ij}$ and trade shares $\bar{\pi}_{ij}$ averaged over the sample period to characterize the equilibrium of the US economy.[22] It is sufficient to calibrate the steady state with these observed moments, including $\bar{m}_{ij}$ and $\bar{\pi}_{ij}$ that already capture effects of bilateral migration costs d_{ij} and trade costs τ_{ij} on second moments including consumption correlations in the equilibrium. Around this calibrated steady state, we solve the DSGE model with linear methods to derive coefficient matrices necessary for the portfolio problem (see Appendix D.2 for details). Using the degree of consumption smoothing $\hat{\beta}_{ij}$ estimated from the data, we can then quantify the matrix of relative financial frictions from the portfolio equations without the need to estimate bilateral financial frictions f_{ij}.[23] This completes our calibration for both real and financial sides of the asymmetric fifty-state economy in its steady state, around which we conduct counterfactual exercises.

Our objective for these exercises is to disentangle contributions of different channels to cross-state consumption comovement. Therefore, we turn off each of the three channels sequentially and predict counterfactual bilateral consumption correlations. The design of counterfactual exercises is guided by the mechanisms for risk sharing discussed in the previous section. As a benchmark, consumption allocation would satisfy the Backus-Smith condition across state pairs in complete markets:

$$\sigma(\widetilde{c}_{i,t} - \widetilde{c}_{j,t}) + \widetilde{P}_{i,t} - \widetilde{P}_{j,t} = 0, \forall i \neq j \in \{1, 2, \dots, I\}. \tag{24}$$

The portfolio Euler equation in the original scenario under financial frictions is replaced by this equation in the counterfactual scenario under complete markets, from which we predict counterfactual consumption correlations. In the trade channel, risk sharing occurs through price adjustments that redistribute nominal income across states. To shut down this channel, we assume that states' prices no longer fluctuate with productivity shocks:

$$\widetilde{P}_{i,t} = 0, \forall i \in \{1, 2, \dots, I\}, \tag{25}$$

such that price fluctuations $\widetilde{P}_{i,t}$ and their corresponding linearized price determination equations in the original model are excluded from the new setting where we predict counterfactuals. Similarly, to shut down the financial channel, we assume that states cannot adjust net wealth positions in response to shocks:

$$\widetilde{D}_{i,t} = 0, \forall i \in \{1, 2, \dots, I\}, \tag{26}$$

such that a state's expenditure is determined by its own income fluctuations in the new wealth constraint. Lastly if migration is turned off for risk sharing, states' population no longer follows its original law of motion (23) or responds to shocks:

$$\widetilde{N}_{i,t} = 0, \forall i \in \{1, 2, \dots, I\}. \tag{27}$$

Eq. (25), (26), and (27) characterize the counterfactual scenarios where trade, finance, and migration are turned off respectively. We re-solve the model with these equations to predict counterfactual consumption correlations across states.[24] Based on earlier analysis in Section 3.2 that when one channel is shut down, other channels may take over more responsibilities in facilitating consumption comovement. These counterfactual exercises can quantify the implications of different channels for consumption risk sharing, with such interactions in general equilibrium taken into consideration.

Table 4 presents model predictions on cross-state consumption correlations in different scenarios. The original model performs reasonably well in matching the key statistics of bilateral consumption correlations including the median value and standard deviation across all the state pairs. More importantly, it predicts a negative correlation between bilateral consumption correlations and geographic distance (−0.280) quantitatively similar to that in the data (−0.316), consistent with the geographic pattern of consumption synchronization documented in the empirical section. In the counterfactual scenario where markets are complete and hence frictions which potentially covary with distance are absent, consumption correlations no longer exhibit any geographic pattern, verified in column (3) where their correlation with distance drops to almost zero while the median value of consumption correlations rises to almost one.

In columns (4) through (6) which report the counterfactual predictions where trade, finance, and migration channels for risk sharing are turned off, the median value of bilateral consumption correlations drops from 0.420 in the original model to 0.037, 0.109, and 0.407 respectively. From these values, the trade channel accounts for the largest share of cross-state consumption synchronization, followed by finance and then by migration. The standard deviation of consumption correlations also marks the highest increase when trade is shut down, which implies the trade channel is more essential than others in reducing the disparity of consumption comovement among state pairs. In terms of the geographic pattern, the negative correlation between bilateral consumption comovement and geographic distance drops by about a half (from −0.316 to −0.141 or −0.133) when either trade or financial channel is turned off, and by 14% (to −0.272) when migration is shut down. These results suggest the three channels, with their frictions potentially covarying with distance, all contribute to the geographic pattern of consumption synchronization.

[22] See Appendix B for data sources and D.2 for calibration details. State-level output and trade based on the CFS data add up to country-level variables of the US, which does not run a balanced trade with the rest of the world. Under this US trade imbalance consistent with data, our quantitative model focuses on intra-national risk sharing across states. One challenge we face is the lack of other countries' data comparable to the US state-level data that allows us to calibrate the foreign economy in a consistent way. Future research can extend our analysis to include multiple countries and investigate inter-national risk sharing once the data challenge does not exist.

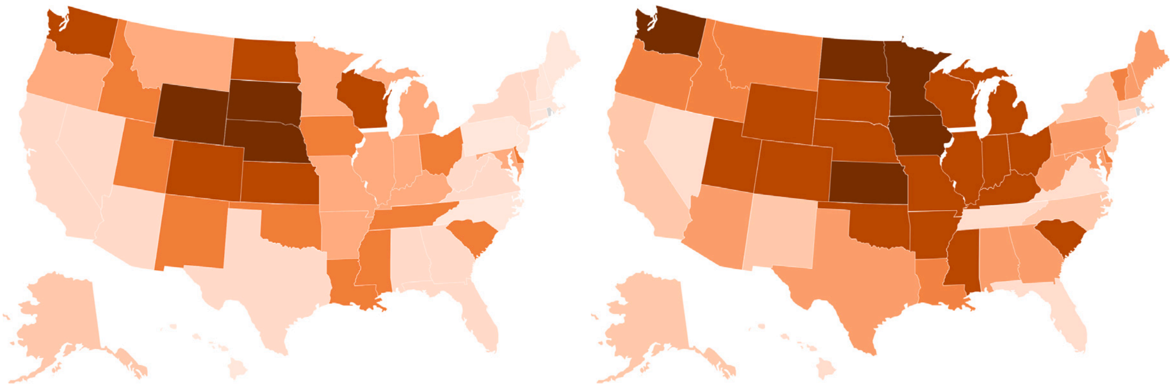
[23] After solving the model, we compare elements in the relative financial friction matrix (F) predicted from the model and find these relative bilateral financial frictions negatively correlate with time-averaged bilateral banking linkages from the FDIC data. This finding provides external validity for our calibrated financial frictions in terms of their ability to reflect barriers in the financial channel.

[24] Using linear methods for DSGE models such as Blanchard and Kahn (1980) and Uhlig (1995), we can characterize first-order dynamics and compute second-moment variables around the calibrated steady state of the model in both original and counterfactual scenarios for comparison.

Table 4
Bilateral consumption correlations in different scenarios.

	Data (1)	Original model (2)	Complete markets (3)
Median of $\rho(c_i, c_j)$	0.388	0.420	0.959
Std Dev of $\rho(c_i, c_j)$	0.329	0.413	0.108
Corr of $\rho(c_i, c_j)$ and $dist_{ij}$	−0.316	−0.280	−0.010
	No Trade (4)	No Finance (5)	No Migration (6)
Median of $\rho(c_i, c_j)$	0.037	0.109	0.407
Std Dev of $\rho(c_i, c_j)$	0.708	0.528	0.430
Corr of $\rho(c_i, c_j)$ and $dist_{ij}$	−0.141	−0.133	−0.272

This table presents the median values, standard deviations, and correlations with geographic distance $dist_{ij}$ (in logs) for bilateral correlations of consumption per capita $\rho(c_i, c_j)$ across 1225 state pairs. Column (1) reports the statistics in the data, column (2) reports the statistics in the original model calibrated to the data, and column (3) reports results in complete markets. Columns (4), (5), and (6) present model predictions where trade, migration, and financial channels are turned off respectively.



(a) Impulse Response to ND's Shock (b) Bilateral Consumption Correlation

Fig. 9. Consumption synchronization with North Dakota.
This figure plots consumption synchronization between North Dakota (ND) and other states predicted from the model. 9(a) illustrates the instantaneous impulse response of states' consumption per capita to a one standard deviation shock to ND's productivity. 9(b) shows the model-predicted bilateral correlation of consumption per capita under the general covariance structure of exogenous and endogenous variables. A darker color suggests a larger percentage increase of consumption in response to the shock or a higher consumption correlation with North Dakota, whose numeric values are reported in Table A.4.

To provide a detailed diagnosis of consumption risk sharing, we revisit the event study on the North Dakota (ND) oil shock. In Fig. 9(a), we simulate a one standard deviation shock to ND's productivity in the fifty-state DSGE framework and plot the instantaneous impulse responses of states' consumption per capita to the shock. The model predicts that besides ND itself, states in its geographic proximity — especially South Dakota, Nebraska, Kansas, and Colorado — witness the highest rises in consumption in response to ND's positive shock. This strong spatial pattern of consumption synchronization is also verified in Fig. 9(b), which shows bilateral consumption correlation of ND with other states predicted from the model under the general covariance structure of exogenous shocks and endogenous variables. Through a simple bivariate regression, we find a 1% increase of geographic distance from ND is associated with a decrease of consumption correlation by 0.014 standard deviations with ND, in both the model and data, with the negative covariance between distance and consumption correlation being significant at 1%. These theoretical predictions are hence consistent with empirical findings from Section 2.

To investigate the mechanisms behind this geographic pattern, we turn off the three channels sequentially and predict ND's bilateral consumption correlation in counterfactual scenarios characterized by Eqs. (25)–(27). The departure of counterfactual from original correlation quantifies the relevance of these channels for spatial consumption synchronization. Fig. 10 plots changes in bilateral consumption correlations: a darker orange (blue) color represents a greater increase (decrease) of consumption correlation with ND in counterfactual relative to in original scenarios:

$$\Delta\rho(c_i, c_{ND}) = \rho(c_i, c_{ND})^{\text{counterfactual}} - \rho(c_i, c_{ND})^{\text{original}}, \qquad \forall i \in \{1, 2, \dots, I\}. \tag{28}$$

Fig. 10(a) illustrates that when the trade channel is shut down for risk sharing, ND mainly strengthens consumption synchronization with neighboring states including Nebraska, Wyoming, and South Dakota, while weakening consumption comovement with more geographically distant states to a greater extent. This geographic pattern is almost the opposite of Fig. 10(c) for the case

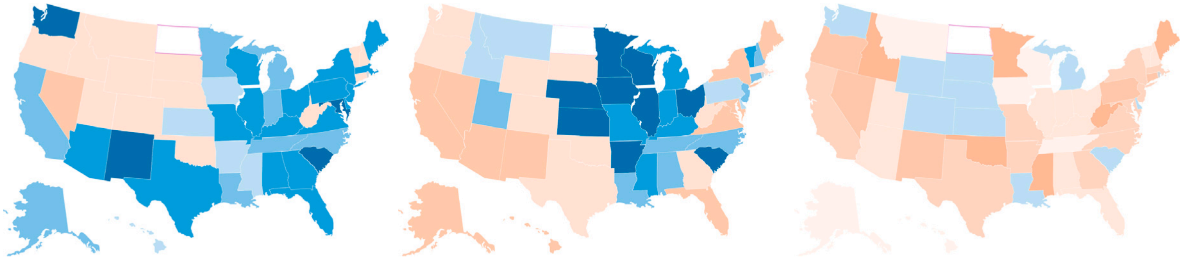


Fig. 10. Counterfactual change of consumption correlation with ND.
This figure plots model-predicted changes of bilateral correlation of consumption per capita with North Dakota (ND, in white) under counterfactual scenarios where trade, migration, and financial channels are turned off respectively. A darker orange (blue) color represents a greater increase (decrease) of consumption correlation in counterfactual relative to in original scenarios. See Fig. A.1 for the US state map and Table A.4 for detailed numeric values.. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

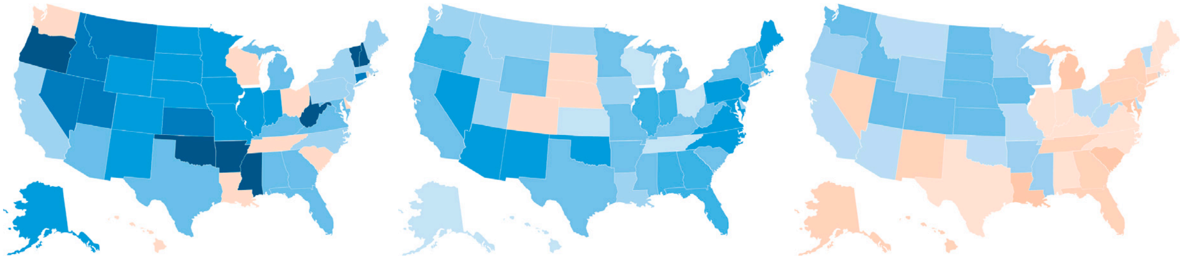
where the migration channel is turned off: those aforementioned states in proximity are among the few states whose consumption correlation with ND becomes lower if population is immobile. The difference between the two scenarios is understandable from the fact that the US cross-state population flows have been low in level and small in radius in recent decades, which restricts the impact of migration on consumption comovement to a few neighboring states. When migration is turned off, residents in Nebraska and South Dakota no longer move to ND, which would reduce the consumption disparity across states in response to the oil shock. Therefore, these states' consumption correlations with ND are lower under this counterfactual scenario. Meanwhile, non-neighboring states are not negatively affected since migration from or to ND is not feasible for them anyway under the original migration costs. Shutting down migration only induces the other two channels to play a more important role in risk sharing, which generates a higher consumption correlation between those states and ND. In contrast to migration, trade as essential means of economic linkages is an important channel of risk sharing for nearly all the state pairs. Under extreme trade costs, price adjustments no longer occur to offset the impact of supply shocks on expenditure, which exacerbates cross-state consumption disparity especially for geographically distant state pairs whose original trade costs are high already. Compared to trade and migration, the relation between bilateral distance and shifts in consumption correlation when the financial channel is turned off is not as pronounced in 10(b), consistent with the general expectation that finance is less subject to geographic constraints than the other two channels. Among the states with the largest decrease in consumption correlation with ND are neighbors including Wisconsin, Minnesota, and Iowa, which happen to run large state-level trade surplus and negative net wealth positions based on the CFS data. Therefore, shutting down financial adjustments to productivity shocks severely impairs those states' consumption synchronization with others including ND.

After studying ND as an example, we evaluate general consumption patterns of all the states. Fig. 11 plots changes to the median value of a state's bilateral consumption correlations with others under counterfactual scenarios absent different channels. From the plots, turning off these channels of risk sharing weakens the overall consumption correlations for a majority of states, which implies that all the three channels contribute to stronger consumption synchronization in the US. Compared to trade and finance that hinder consumption comovement for a larger number of states and by a greater magnitude, the impact of migration is less pronounced and monotonic, consistent with its features discussed earlier in Section 3.2. Based on the geographic pattern in 11(c), shutting down migration affects cross-state consumption correlations of inland states more severely than coastal states. These inland states also incur greater losses when trade is shut down in 11(a) but they appear less affected when financial adjustment is constrained in 11(b).

Bilateral linkages in channels of risk sharing also play an important role in shaping state-level consumption moments including volatility. Fig. 12 plots the ratio of states' counterfactual to original standard deviation of consumption:

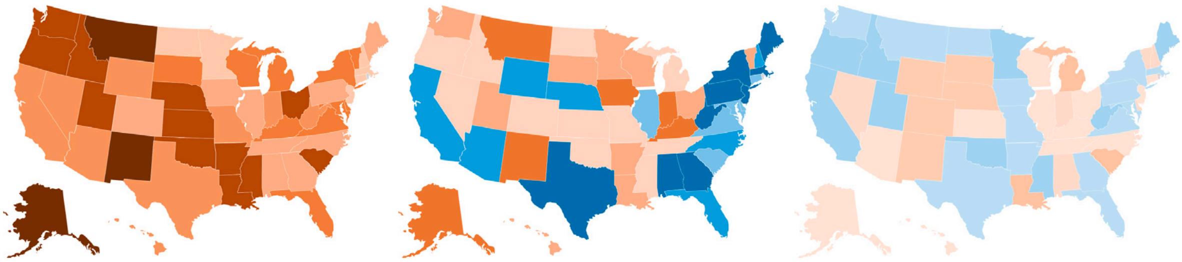
$$\widehat{\sigma}(c_i) = \frac{\sigma(c_i)^{\text{counterfactual}}}{\sigma(c_i)^{\text{original}}}, \quad \forall i \in \{1, 2, \dots, I\}. \tag{29}$$

Among the three channels, trade is predicted to be the most effective in stabilizing consumption fluctuations, without which consumption volatility rises substantially across nearly all states 12(a). Meanwhile, shutting down financial or migration would generate disparate outcomes across states. From 12(b), wealthier states are generally predicted to reduce consumption volatility when their net asset positions no longer fluctuate with productivity shocks of all the states. Nonetheless, financial autarky leaves consumption more vulnerable to idiosyncratic shocks in lower-income states, as shown in the figure. A similar unequal pattern is documented in 12(c) for the counterfactual scenario absent migration. If cross-state population mobility is prohibited, nearly half of states (23 out of 50) expect lower consumption volatility, which include higher-income states such as California, Texas, and New York. For the other 27 states, migration is an effective channel of risk sharing that reduces not only inequality across space but also consumption volatility over time. For any risk-averse household, a lower consumption volatility means a higher lifetime utility. Therefore, it is important for policy makers to consider these distributional impacts of bilateral economic linkages on the welfare of households in different states when designing fiscal or monetary policy.



(a) No Trade (b) No Finance (c) No Migration

Fig. 11. Counterfactual change of median consumption correlation.
This figure plots model-predicted changes of each state's median correlation of consumption with others under counterfactual scenarios where trade, migration, and financial channels are turned off respectively. A darker orange (blue) color represents a greater increase (decrease) of consumption correlation in counterfactual relative to in original scenarios. See Fig. A.1 for the US state map and Table A.5 for numeric values of these results.. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)



(a) No Trade (b) No Finance (c) No Migration

Fig. 12. Counterfactual change of consumption volatility.
This figure plots model-predicted changes of states' standard deviation of consumption per capita under counterfactual scenarios where trade, migration, and financial channels are turned off respectively. A darker orange (blue) color represents a higher (lower) ratio of consumption volatility in counterfactual relative to in original scenarios. See Fig. A.1 for the US state map and Table A.5 for numeric values of these results.. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

4. Conclusion

This paper empirically and theoretically examines how bilateral economic linkages shape the geographic pattern of consumption comovement. We exploit variations across state pairs in the US to evaluate mechanisms of cross-economy risk sharing including trade, migration, and finance. Quantitative analysis with our structural model offers insights into how these channels interact to influence consumption in general equilibrium, generates predictions about the effects of different frictions on consumption fluctuations, and yields implications for macro policies aimed at reducing consumption inequality.

This study focuses on the US state-level analysis but is general enough to be tailored to another setting such as the European Union with a high degree of bilateral exchanges in these three channels. Moreover, it can be extended to include both intra- and inter-national linkages to diagnose the border effect of risk sharing proposed by Devereux and Hnatkovska (2020). This extension of our model, which considers frictional bilateral linkages across many economies both within and across borders, enables policy analysis in the international context including on the distributional impacts of tariffs and exchange rate regimes.

Another extension of our analysis is to consider heterogeneous agents and model their individual decisions to smooth consumption under personal income shocks. Classic literature on households' risk sharing includes Storesletten et al. (2004) and Heathcote et al. (2014), but these works do not have households grouped into different economies subject to economy-specific macro shocks and frictions in cross-economy linkages under geographic considerations. Therefore, it will be important for future research to combine heterogeneity of households at the micro level and linkages across economies at the macro level to examine channels of consumption risk sharing at both levels in a thorough and comprehensive way.

Appendix A. Tables and figures

Tables A.1, A.2, and A.3 report the results of three sets of robustness checks for the gravity model of consumption smoothing. First, we consider alternative data sources for state-level consumption and inflation, and for bilateral geographic distance. Second, we reconstruct measures of bilateral smoothing after adjusting for additional time-series and cross-section variations. Results reported in the tables suggest that our finding about the comovement between geographic distance and consumption smoothing remains

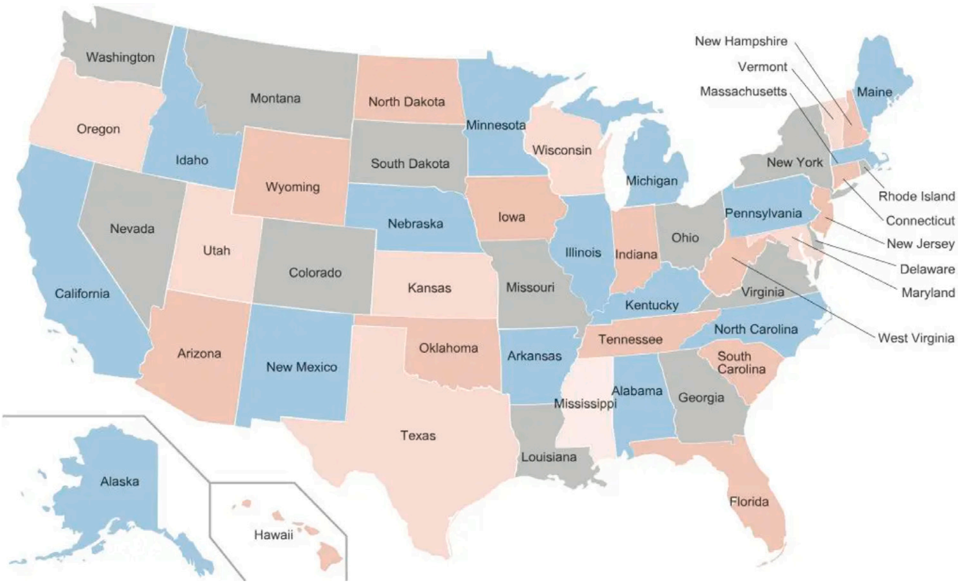


Fig. A.1. U.S. state map.

Table A.1
Spatial pattern of consumption smoothing – Alternative data sources.

Dep. Var.: $\hat{\beta}_{ij}$	A. alternative price		B. alternative consumption		C. alternative distance	
	(1)	(2)	(3)	(4)	(5)	(6)
$\log(dist_{ij})$	0.119 ***	0.176 ***	0.041 ***	0.050 ***	0.151 ***	0.211 ***
	(0.017)	(0.024)	(0.005)	(0.007)	(0.010)	(0.012)
Geographic Variables	N	Y	N	Y	N	Y
Political Dissimilarity	N	Y	N	Y	N	Y
Industrial Dissimilarity	N	Y	N	Y	N	Y
Observations	528	528	1225	1225	1225	1225
R^2	0.077	0.183	0.056	0.148	0.161	0.288

Robust standard errors in parentheses. *** significant at 1%. The dependent variable is the estimated consumption smoothing coefficient $\hat{\beta}_{ij}$. $dist_{ij}$ denotes the geographic distance between state i and j. Panel A uses the state-level CPI data by Hazell et al. (2022), Panel B uses the BEA consumption data, and Panel C uses the shipment distance from the CFS. Geographic variables and political/industrial dissimilarity measures remain the same as in the baseline estimation (Table 2).

robust. Third, we run a dynamic gravity model where we regress relative consumption growth on output growth over time and its interaction with distance to confirm the spatial pattern of consumption smoothing.

When constructing alternative measures of bilateral consumption smoothing, first we consider demographic variables whose dynamics potentially shift consumption demand over time. These state-level variables (denoted as $A_{i,t}$) include average age, gender ratio, and education levels, whose data are obtained from the American Community Survey conducted by the Census Bureau. The estimation of smoothing coefficients becomes

$$\Delta \log\ c_{it} - \Delta \log\ c_{jt} = \alpha_{ij} + \beta_{ij}(\Delta \log\ y_{it} - \Delta \log\ y_{jt}) + \mu_i A_{i,t} + \mu_j A_{j,t} + \epsilon_{ijt}. \tag{A.1}$$

Second, we adjust for states' distinct exposure to aggregate risks when measuring output fluctuations, as the difference in output growth between a pair of states in Eq. (1) may reflect the two states' heterogeneous exposure to national shocks. To address this potential mismeasurement of local output shocks, we first estimate β_i and β_j from

$$\Delta \log\ y_{it} = \alpha_i + \beta_i \Delta \log\ y_{USt} + \epsilon_{it}, \Delta \log\ y_{jt} = \alpha_j + \beta_j \Delta \log\ y_{USt} + \epsilon_{jt}, \tag{A.2}$$

where $\Delta \log\ y_{USt}$ denotes the growth of log real per-capita output of the US, and hence β_i captures the impact of aggregate shocks on state i's output. We then estimate β_{ij} from

$$\Delta \log\ c_{it} - \Delta \log\ c_{jt} = \alpha_{ij} + \beta_{ij}[(\Delta \log\ y_{it} - \beta_i \Delta \log\ y_{USt}) - (\Delta \log\ y_{jt} - \beta_j \Delta \log\ y_{USt})] + \epsilon_{ijt}. \tag{A.3}$$

We also consider the bootstrap method for the potential finite sample bias from Eq. (A.2). Specifically, we draw a random sample with replacement (30 out of 43 years of sample) when running regression (A.3) to generate β_{ij}. When we regress the obtained β_{ij} on distance 1000 times for its estimate γ, we find the result to remain significant given the confidence interval at the 2.5% and 97.5% quantiles of the $\hat{\gamma}$ distribution.

Table A.2
Spatial pattern of consumption smoothing – Alternative β.

Dep. Var.: $\hat{\beta}_{ij}$	A. β_{ij} adjusted for demand shifters		B. β_{ij} adjusted for aggregate shocks	
	(1)	(2)	(3)	(4)
$\log(dist_{ij})$	0.128 ***	0.143 ***	0.147 ***	0.214 ***
	(0.013)	(0.017)	(0.010)	(0.012)
Geographic Variables	N	Y	N	Y
Political Dissimilarity	N	Y	N	Y
Industrial Dissimilarity	N	Y	N	Y
Observations	1225	1225	1225	1225
R^2	0.067	0.205	0.148	0.315

Robust standard errors in parentheses. *** significant at 1%. The dependent variable in panel A (B) is the estimated β_{ij} based on Eq. (A.1) (A.3). $dist_{ij}$ denotes distance between i and j. Geographic variables and political/industrial dissimilarity measures remain the same as in the baseline estimation.

Table A.3
Spatial pattern of consumption smoothing.

Dep. Var: $\Delta\log\ c_{i/jt}$	(1)	(2)	(3)	(4)	(5)
$\Delta\log\ y_{i/jt}$	0.441***	−0.077	0.517 ***	0.523 ***	0.449 ***
	(0.005)	(0.047)	(0.070)	(0.069)	(7.08E−02)
$\log(dist_{ij})$		−2.90E−18	−3.17E−18	2.91E−04	3.43E−04 *
		(0.000)	(0.000)	(1.91E−04)	(2.06E−04)
$\Delta\log\ y_{i/jt} \times \log(dist_{ij})$		0.073 ***	0.118 ***	0.118 ***	0.101 ***
		(0.007)	(0.006)	(6.38E−03)	(6.80E−03)
$\log(\bar{y}_i \cdot \bar{y}_j)$			−1.35E−18	6.88E−04	6.95E−04
			(0.000)	(5.33E−04)	(5.62E−04)
$\Delta\log\ y_{i/jt} \times \log(\bar{y}_i \cdot \bar{y}_j)$			−0.307 ***	−0.309 ***	−0.319 ***
			(0.019)	(0.019)	(0.019)
Land Area				2.32E−05	0.0000261
				(9.03E−05)	(9.19E−05)
Mainland				1.92E−03 ***	1.99E−03 ***
				(4.09E−04)	(4.14E−04)
Coastal				−4.07E−04 **	−4.20E−04 **
				(2.06E−04)	(2.11E−04)
Contiguity				1.66E−05	−6.87E−05
				(4.58E−04)	(4.86E−04)
Number of Neighboring States				−1.56E−04 **	−1.58E−04 ***
				(5.98E−05)	(6.03E−05)
Number of MSA				3.40E−07	1.54E−06
				(1.61E−05)	(1.98E−05)
Number of Shared MSA				1.39E−04	1.76E−05
				(3.40E−04)	(3.61E−04)
Industrial Dissimilarity (Ind_{ij})				7.22E−03	7.69E−03
				(1.28E−02)	(1.31E−02)
Political Dissimilarity (Pol_{ij})				−8.51E−05	−8.14E−05
				(5.23E−04)	(5.24E−04)
Bilateral Trade ($\bar{t}_{ij}$)					9.31E−08
					(1.39E−07)
Bilateral Migration ($\bar{m}_{ij}$)					−5.50E−08
					(2.70E−07)
Bilateral Finance ($\bar{f}_{ij}$)					5.60E−11
					(2.61E−10)
Bilateral Trade ($\Delta\log\ y_{i/jt} \times \bar{t}_{ij}$)					−3.41E−06 ***
					(1.05E−06)
Bilateral Migration ($\Delta\log\ y_{i/jt} \times \bar{m}_{ij}$)					1.60E−05
					(1.96E−06)
Bilateral Finance ($\Delta\log\ y_{i/jt} \times \bar{f}_{ij}$)					1.76E−09
					(1.81E−09)
Observations	102,900	102,900	102,900	102,900	102,900
R^2	0.139	0.141	0.146	0.147	0.148

Robust standard errors in parentheses. *** significant at 1% and ** significant at 5%. The dependent variable is relative bilateral consumption growth $\Delta\log c_{i/jt} = \Delta\log c_{it} - \Delta\log c_{jt}$, and the independent variable $\Delta\log y_{i/jt} = \Delta\log y_{it} - \Delta\log y_{jt}$ is relative output growth over 1977–2019. $dist_{ij}$ denotes the geographic distance between state i and j. $\bar{y}_i$ denotes the time-averaged output per capita of state i. $\bar{t}_{ij}, \bar{m}_{ij}, \bar{f}_{ij}$ are time-averaged bidirectional bilateral trade, migration, and financial flows across states. Other control variables also found in the baseline gravity model (Table 2) include a state-pair's geographic characteristics as well as political and industrial dissimilarity.

Table A.4
Bilateral consumption correlation with North Dakota.

State	Original correlation	Counterfactual changes in correlation		
		No trade	No finance	No migration
Alabama	0.172	−0.622	−0.480	0.008
Alaska	0.042	−0.438	0.863	0.004
Arizona	0.148	−0.733	0.741	0.009
Arkansas	0.509	−0.086	−0.888	0.010
California	0.097	−0.595	0.621	0.010
Colorado	0.563	0.249	0.135	−0.045
Connecticut	−0.073	0.151	−0.548	0.012
Delaware	0.273	−0.707	−0.169	0.000
Florida	−0.124	−0.675	1.035	0.009
Georgia	0.145	−0.697	0.525	0.012
Hawaii	−0.374	−0.271	0.904	0.005
Idaho	0.375	0.378	−0.080	0.017
Illinois	0.430	−0.639	−0.985	0.008
Indiana	0.444	−0.519	−0.786	0.006
Iowa	0.671	−0.165	−0.974	0.003
Kansas	0.684	−0.238	−1.238	−0.013
Kentucky	0.479	−0.636	−0.796	0.007
Louisiana	0.360	−0.598	−0.555	−0.216
Maine	0.108	−0.684	0.691	0.016
Maryland	0.113	−0.839	0.802	0.012
Massachusetts	0.044	−0.688	0.520	0.011
Michigan	0.514	−0.581	−0.654	−0.149
Minnesota	0.623	−0.548	−1.017	0.016
Mississippi	0.488	−0.014	−0.773	0.015
Missouri	0.440	−0.631	−0.738	0.011
Montana	0.317	0.518	−0.181	0.003
Nebraska	0.537	0.065	−0.804	−0.047
Nevada	−0.069	0.955	0.946	0.013
New Hampshire	0.111	0.541	−0.534	0.008
New Jersey	0.014	−0.619	−0.597	0.012
New Mexico	0.066	−0.874	0.820	0.014
New York	0.033	−0.738	0.692	0.010
North Carolina	0.021	−0.585	−0.416	0.011
North Dakota	1.000	0.000	0.000	0.000
Ohio	0.551	−0.708	−1.016	0.005
Oklahoma	0.441	0.359	0.477	0.017
Oregon	0.270	0.362	0.574	0.013
Pennsylvania	0.104	−0.661	−0.345	0.012
Rhode Island	−0.059	0.571	−0.247	0.011
South Carolina	0.517	−0.978	−0.942	−0.374
South Dakota	0.540	0.232	0.138	−0.044
Tennessee	−0.100	−0.485	−0.590	0.003
Texas	0.169	−0.615	0.470	0.011
Utah	0.579	0.169	−0.509	0.005
Vermont	0.287	0.334	−0.757	0.006
Virginia	−0.047	−0.726	0.929	0.010
Washington	0.612	−1.176	0.323	−0.003
West Virginia	0.169	0.479	0.544	0.019
Wisconsin	0.506	−0.604	−1.138	0.002
Wyoming	0.443	0.369	0.387	−0.039
Median	0.280	−0.565	−0.214	0.009
Std Dev	0.273	0.507	0.699	0.066

This table shows model-predicted bilateral correlation of consumption per capita between North Dakota and other states. The left panel reports the bilateral correlation in the original model calibrated to the data. The right panel reports the difference between counterfactual and original bilateral correlation under counterfactual scenarios where trade, migration, and financial channels are turned off, characterized by Eqs. (25)–(27) respectively. A positive (negative) value means a higher (lower) correlation in counterfactual than original scenarios.

Appendix B. Data

B.1. State-level output, consumption, and price

To measure the degree of cross-state consumption smoothing, we compile state-level data for output, consumption, and price. The US Bureau of Economic Analysis (BEA) reports the real GDP by state (GSP) since 1977, with data from 1977–1997 reported in the Standard Industrial Classification (SIC) and those from 1997–2019 in the North American Industry Classification (NAICS). To

Table A.5
Counterfactual change of consumption.

State	Median bilateral correlation			Standard deviation		
	No trade	No finance	No migration	No trade	No finance	No migration
Alabama	−0.098	−0.649	0.006	2.736	0.293	1.016
Alaska	−0.323	−0.197	0.030	15.381	9.935	1.007
Arizona	−0.062	−0.699	−0.001	3.060	0.592	1.000
Arkansas	−1.226	−0.555	−0.012	5.152	2.823	0.998
California	−0.036	−0.542	−0.005	3.295	0.480	0.983
Colorado	−0.326	0.425	−0.139	2.914	1.236	1.055
Connecticut	−0.938	−0.488	0.027	2.478	0.964	1.009
Delaware	0.045	−0.347	0.000	4.761	0.742	1.019
Florida	−0.090	−0.639	0.028	4.748	0.568	0.990
Georgia	−0.083	−0.667	0.015	2.993	0.286	0.998
Hawaii	0.127	−0.122	0.012	3.322	1.962	1.001
Idaho	−1.048	−0.344	−0.047	9.047	1.235	0.968
Illinois	−0.152	−0.641	0.003	2.935	0.737	1.007
Indiana	−0.203	−0.595	0.007	3.484	3.153	1.016
Iowa	−0.287	−0.251	−0.047	2.600	3.533	0.997
Kansas	−0.942	−0.043	−0.093	8.751	1.572	1.008
Kentucky	−0.112	−0.560	0.001	4.354	3.930	1.008
Louisiana	0.013	−0.279	0.124	6.967	2.114	2.978
Maine	−0.013	−0.697	0.009	2.678	0.343	0.983
Maryland	−0.107	−0.743	0.031	4.642	0.765	0.993
Massachusetts	−0.044	−0.652	0.008	2.287	0.314	0.999
Michigan	−0.119	−0.460	0.039	3.543	1.538	1.996
Minnesota	−0.197	−0.542	−0.032	2.290	2.397	0.981
Mississippi	−1.187	−0.534	−0.011	5.149	1.097	0.984
Missouri	−0.168	−0.551	−0.002	3.190	1.229	0.995
Montana	−1.093	−0.353	−0.010	12.669	17.754	0.995
Nebraska	−0.417	0.438	−0.138	5.321	0.502	1.062
Nevada	−0.992	−0.691	0.021	3.488	1.322	1.018
New Hampshire	−1.256	−0.628	0.006	1.791	0.625	1.012
New Jersey	−0.033	−0.711	0.013	2.216	0.339	1.002
New Mexico	−0.200	−0.705	0.029	12.679	5.067	1.048
New York	−0.032	−0.504	0.013	4.193	0.268	0.996
North Carolina	−0.025	−0.787	0.008	2.547	0.452	1.007
North Dakota	−0.430	−0.203	−0.085	1.774	1.301	0.999
Ohio	0.217	−0.156	−0.003	5.209	2.469	1.003
Oklahoma	−1.194	−0.722	−0.005	7.918	1.508	0.977
Oregon	−1.203	−0.636	−0.025	5.940	1.401	0.963
Pennsylvania	−0.037	−0.747	0.021	2.855	0.279	1.000
Rhode Island	−1.196	−0.706	0.028	2.173	0.533	1.017
South Carolina	0.029	−0.470	0.079	5.553	0.828	2.711
South Dakota	−0.280	0.180	−0.100	4.972	1.643	1.057
Tennessee	0.408	−0.194	0.021	2.858	1.598	1.003
Texas	−0.074	−0.445	0.001	3.133	0.248	0.995
Utah	−1.005	−0.205	−0.082	7.681	2.507	0.979
Vermont	−1.317	−0.619	−0.004	3.610	2.570	1.012
Virginia	−0.115	−0.697	0.004	3.916	0.917	0.992
Washington	0.304	−0.263	−0.077	7.751	1.670	0.998
West Virginia	−1.412	−0.545	−0.009	3.376	0.267	0.975
Wisconsin	0.282	−0.142	−0.027	3.750	2.644	1.004
Wyoming	−0.172	−0.521	−0.017	3.131	0.443	1.055
Median	−0.160	−0.542	0.001	3.516	1.232	1.002
Standard Deviation	0.514	0.285	0.048	2.912	2.807	0.388

This table shows model-predicted changes of consumption per capita under counterfactual scenarios where trade, migration, and financial channels are turned off, characterized by Eqs. (25)–(27) respectively. The left panel reports the difference between counterfactual and original median value of bilateral consumption correlation between each states and all others. A positive (negative) value represents a higher (lower) correlation in counterfactual than original scenarios. The right panel reports each state's ratio of counterfactual to original standard deviation of consumption. A value greater (less) than one represents a higher (lower) consumption volatility in counterfactual than original scenarios.

address this discontinuity, we first calculate the annual growth rate based on the SIC-based real GSP, and then reconstruct the time series of real GSP from 1977 to 1997 using this annual growth rate and the NAICS-based real GSP in 1997.

The nominal consumption data from the BEA are only available after 1997, which is not ideal for our analysis over a long horizon. Therefore, we follow Asdrubali et al. (1996)'s method of constructing state-level private consumption by rescaling state-level retail sales by the country-level ratio of private consumption to retail sales, both obtained from the BEA. To convert nominal to real consumption, we use the state-level inflation series constructed by Nakamura and Steinsson (2014) over the period from 1966 to

2008. They obtain the inflation series from 1966 to 1995 from Del Negro (1998), who combines the BLS regional inflation data and cost-of-living estimates from the American Chamber of Commerce Realtors Association (ACCRA). For the estimates between 1995 and 2008, they multiply a population-weighted average of cost-of-living indices from the ACCRA across states with the US aggregate CPI. After 2008, we use the Regional Price Parities (RPP) from the BEA that measure price differences within the United States. RPP is a weighted average of the price level of goods and services for the average consumer in one geographic region compared to all other regions in the US. We merge these data to construct a state-level CPI index over the full sample period, using which we deflate the nominal consumption data to calculate real consumption at the state level.

We also use alternative data sources to verify the robustness of the gravity model. Table A.1 Panel A uses state-level inflation from Hazell et al. (2022) who construct the CPI with micro data gathered by the BLS from 1978 to 2017. Panel B uses only the recent BEA data of consumption expenditure and real GSP between 1997 and 2018.

B.2. Bilateral trade and migration flows

Our data sources for cross-state trade and migration flows are the Commodity Flow Survey (CFS) and Internal Revenue Service (IRS) respectively. The CFS is conducted every five years by the Census Bureau in partnership with the Department of Transportation. The survey provides detailed information on commodity flows within the US, including the type of commodities shipped, origin and destination, value and weight, and mode of transport. There are six waves of surveys so far (1993, 1997, 2002, 2007, 2012, 2017). The most recent waves of CFS (2012 and 2017) distinguish between shipment for domestic use and that for the purposes of exporting to an international destination. We examine the former when conducting quantitative analysis since we focus on bilateral trade flows across states for the US expenditure. We also impute the domestic usage of earlier samples (1993–2007) by scaling the aggregate bilateral shipment in the samples by the share of shipment for domestic use based on the most recent two waves.

State-to-state migration data are based on year-to-year address changes reported on individual income tax returns filed with the IRS. Specifically, we use the reported number of returns filed every year to track migration across states. The data are available for the filing years from 1991 to present.

B.3. State-level productivity

We estimate the state-level total factor productivity (TFP) as the Solow residual from

$$\log(A_{i,t}) = \log(Y_{i,t}) - \alpha \log(K_{i,t}) - (1-\alpha)\log(L_{i,t}), \tag{B.1}$$

where $Y_{i,t}$, $K_{i,t}$, and $L_{i,t}$ are output, capital, and labor hours in state i at time t respectively, while α denotes capital share in production. We estimate $1-\alpha$ to be 0.59 by dividing the labor earnings by the economic output based on the BEA data.[25] Moreover, we use the GSP and employment data reported by the BEA for $Y_{i,t}$ and $L_{i,t}$ over the period 1977–2019 for the estimation.

We construct the estimates for state-level capital stock $K_{i,t}$ following Garofalo and Yamarik (2002). Namely, we apportion the national private capital stock to states using sectoral income data from the BEA. For each two-digit NAICS industry:

$$K^s_{i,t} = \left(\frac{Y^s_{i,t}}{Y^s_{US,t}}\right) K^s_{US,t}, \tag{B.2}$$

where $K^s_{i,t}$ ($Y^s_{i,t}$) refers to capital (output) of industry s in state i at time t, while $K^s_{US,t}$ ($Y^s_{US,t}$) represents country-level capital (output). Each state's capital stock estimate, $K_{i,t}$, is then the sum of sectoral-level capital stock:

$$K_{i,t} = \sum_{s=1}^{S} K^s_{i,t}. \tag{B.3}$$

After obtaining the values of all the variables in Eq. (B.1), we compute states' dynamic TFP with which we estimate the productivity process following the international business cycle literature such as BKK. Based on the median estimate across states, the standard deviation of normalized productivity shocks is 0.015, the median correlation of productivity shocks across country pairs is 0.37, the persistence of state-level productivity is 0.72. We use these values for the calibration of the symmetric two-state model (see Table D.1 for details). For the asymmetric multi-state model, we calibrate the full covariance matrix of shocks Σ_T for the fifty states with their TFP.

Appendix C. Details of the model

C.1. Finance

This section characterizes the portfolio problem in a multi-economy DSGE model (similar to the analysis from Hu (2024) but in a domestic context). To solve the model, we perform log-linearization around the steady state of the economy and denote the

[25] The BEA reports the data of labor earning (SAINC5), which consists of compensation of employees and proprietors' income with inventory valuation adjustment and capital consumption adjustment.

deviation of a variable from its steady state as

$$\widetilde{A}_t = \ln(A_t) - \ln(\bar{A}). \tag{C.1}$$

Following the approach developed by Devereux and Sutherland (2011), we derive equilibrium portfolios from any state i's Euler equations for different assets:

$$E_t[\frac{c_{i,t+1}^{-\sigma}}{P_{i,t+1}} e^{-f_{i1}} R_{1,t+1}] = \cdots = E_t[\frac{c_{i,t+1}^{-\sigma}}{P_{i,t+1}} e^{-f_{iI\text{-}1}} R_{I\text{-}1,t+1}] = E_t[\frac{c_{i,t+1}^{-\sigma}}{P_{i,t+1}} e^{-f_{iI}} R_{I,t+1}]. \tag{C.2}$$

i's portfolio is obtained from the second-order Taylor expansion of Eq. (C.2) while taking the difference in returns between the numeraire asset I and all the other assets:

$$E_t[\widetilde{R}_{x,t+1} + \frac{1}{2}\widetilde{R}^2_{x,t+1} - \widetilde{R}_{x,t+1}(\sigma\widetilde{c}_{i,t+1} + \widetilde{P}_{i,t+1})] = -\frac{1}{2}F_i + \mathcal{O}(\epsilon^3), \tag{C.3}$$

where $R_{x,t+1}$ denotes a vector of excess returns relative to the numeraire asset

$$\widetilde{R}'_{x,t+1} = [\widetilde{R}_{1,t+1} - \widetilde{R}_{I,t+1}, \widetilde{R}_{2,t+1} - \widetilde{R}_{I,t+1}, \ldots, \widetilde{R}_{I\text{-}1,t+1} - \widetilde{R}_{I,t+1}], \tag{C.4}$$

$R^2_{x,t+1}$ denotes the vector of excess squared returns

$$\widetilde{R}^{2\prime}_{x,t+1} = [\widetilde{R}^2_{1,t+1} - \widetilde{R}^2_{I,t+1}, \widetilde{R}^2_{2,t+1} - \widetilde{R}^2_{I,t+1}, \ldots, \widetilde{R}^2_{I-1,t+1} - \widetilde{R}^2_{I,t+1}], \tag{C.5}$$

and F_i denotes i's vector of financial frictions defined as

$$F'_i = [f_{iI} - f_{i1}, f_{iI} - f_{i2}, \ldots, f_{iI} - f_{iI\text{-}1}], \tag{C.6}$$

whose kth element represents the additional financial friction state i incurs when holding I's relative to k's asset. $\mathcal{O}(\epsilon^3)$ captures all terms of order higher than two.

The difference between i's and numeraire state I's expanded Euler Eq. (C.3) is

$$E_t[(\widetilde{c}^p_{i,t+1} - \widetilde{c}^p_{I,t+1})\widetilde{R}'_{x,t+1}] = \frac{1}{2}F_{iI} + \mathcal{O}(\epsilon^3), \forall i \in \{1, 2, \ldots, I\text{-}1\}, \tag{C.7}$$

where $c^p_{i,t+1}$ is i's price-adjusted marginal utility of consumption $c^p_{i,t+1} = P_{i,t+1}/c^{-\sigma}_{i,t+1}$ and $\widetilde{c}^p_{i,t+1} - \widetilde{c}^p_{I,t+1}$ is hence the price- and utility-adjusted consumption differential

$$\widetilde{c}^p_{i,t+1} - \widetilde{c}^p_{I,t+1} = \sigma(\widetilde{c}_{i,t+1} - \widetilde{c}_{I,t+1}) + (\widetilde{P}_{i,t+1} - \widetilde{P}_{I,t+1}), \tag{C.8}$$

while F_{iI} denotes the excess financial frictions faced by i relative to by I

$$F_{iI} = F'_i - F'_I. \tag{C.9}$$

(C.7) is state i's portfolio determination equation: the variables on its left covary with i's relative asset positions which are also influenced by financial frictions F_{iI} on the right. Let $\check{\alpha}_i$ be a vector of the equilibrium portfolio adjusted for i's output and discount factor

$$\check{\alpha}_i = [\check{\alpha}_{i1}, \check{\alpha}_{i2}, \ldots, \check{\alpha}_{iI\text{-}1}] = \frac{1}{\beta\bar{Y}_i}[\bar{\alpha}_{i1}, \bar{\alpha}_{i2}, \ldots, \bar{\alpha}_{iI\text{-}1}], \tag{C.10}$$

then the excess portfolio return that adds to i's relative to I's wealth denoted as

$$\xi_{i,t+1} = (\check{\alpha}_i - \check{\alpha}_I)\widetilde{R}_{x,t+1}, \tag{C.11}$$

is computed as the weighted sum of individual assets' excess returns.

Eq. (C.7), if stacked vertically with each row representing a holder state, constructs a system of equations to solve for the bilateral portfolio matrix[26]:

$$\begin{bmatrix} \check{\alpha}_{11} & \check{\alpha}_{12} & \cdots & \check{\alpha}_{1I\text{-}1} \\ \check{\alpha}_{21} & \ddots & & \vdots \\ \vdots & & \ddots & \vdots \\ \vdots & & & \check{\alpha}_{I\text{-}2I\text{-}1} \\ \check{\alpha}_{I\text{-}11} & \cdots & \check{\alpha}_{I\text{-}1I\text{-}2} & \check{\alpha}_{I\text{-}1I\text{-}1} \end{bmatrix} \tag{C.12}$$

whose element in the ith row jth column is state i's equilibrium holding of asset from j.

If $\widetilde{c}^p_{x,t+1}$ is the vector of all the states' consumption differential (defined in (C.8)) relative to the numeraire state I

$$\widetilde{c}^{p\prime}_{x,t+1} = [\widetilde{c}^p_{1,t+1} - \widetilde{c}^p_{I,t+1}, \widetilde{c}^p_{2,t+1} - \widetilde{c}^p_{I,t+1}, \ldots, \widetilde{c}^p_{I-1,t+1} - \widetilde{c}^p_{I,t+1}], \tag{C.13}$$

[26] The portfolio matrix's dimension is $(I\text{-}1)\times(I\text{-}1)$ instead of $I \times I$. For the remaining assets positions, country i's holding of the numeraire asset is decided by the difference between its aggregate asset position and its bilateral holding of other assets. Meanwhile, numeraire country I's holding of any asset j is decided by j's market clearing condition that the supply of the asset equals the demand.

F is the vector of countries' relative financial frictions

$$F' = [F_{1I}, F_{2I}, \dots, F_{I-1I}], \tag{C.14}$$

then the portfolio matrix consisting of non-numeraire states' asset holdings relative to I's

$$\breve{\alpha}' = [\breve{\alpha}_1, \breve{\alpha}_2, \dots, \breve{\alpha}_{I-1}] - \breve{\alpha}_I \tag{C.15}$$

can be obtained from the system of portfolio determination equations summarized by

$$E_t(\widetilde{c}^p_{x,t+1} \widetilde{R}'_{x,t+1}) = \frac{1}{2} F + \mathcal{O}(\epsilon^3). \tag{C.16}$$

To solve the portfolio problem, we express the two components $\widetilde{c}^p_{x,t+1}$ and $\widetilde{R}_{x,t+1}$ on the left hand side of (C.16) in terms of the vector of productivity innovations in the model

$$\epsilon'_t = [\epsilon_{1,t}, \epsilon_{2,t}, \dots, \epsilon_{I,t}], \tag{C.17}$$

whose coefficients as functions of asset positions should satisfy the portfolio Eq. (C.16). In this process, we need to consider that these two components covary with states' wealth influenced by excess portfolio returns (defined in (C.11)), which constitute a vector

$$\xi'_t = [\xi_{1,t}, \xi_{2,t}, \dots, \xi_{I-1,t}]. \tag{C.18}$$

ξ_t can be treated as zero-mean i.i.d. random variables like ϵ_t, as assets are expected to carry the same returns ex-ante which implies $E_t(\widetilde{R}_{x,t+1}) = 0$.[27] Since ξ_t and ϵ_t are potentially interdependent, Devereux and Sutherland (2011) suggest a two-step procedure: In the first step, the two components $\widetilde{c}^p_{x,t+1}$ and $\widetilde{R}_{x,t+1}$ are expressed as functions of ϵ_t and ξ_t. In the second step, ξ_t is expressed as a function of ϵ_t so that the two components can be expressed in terms of ϵ_t only. Evaluating the coefficients of ϵ_t in (C.16), which are functions of equilibrium asset positions $\breve{\alpha}$, allows us to solve the portfolio choice problem.

To implement the procedure, we write components from (C.16) in the first step following Devereux and Sutherland (2011)'s notations as

$$\widetilde{c}^p_{x,t+1} = D_1 \xi_{t+1} + D_2 \epsilon_{t+1} + D_3 \widetilde{z}_{t+1} + \mathcal{O}(\epsilon^2), \tag{C.19}$$

$$\widetilde{R}_{x,t+1} = R_1 \xi_{t+1} + R_2 \epsilon_{t+1} + \mathcal{O}(\epsilon^2), \tag{C.20}$$

where R_1, R_2, D_1, D_2, D_3 are the coefficient matrices extracted from the first-order dynamics of the model. D_1, D_2, and D_3 capture the responses of consumption differential $c^p_{x,t+1}$ to excess portfolio returns (ξ_{t+1}), to productivity shocks (ϵ_{t+1}), and to other state variables in the model summarized by z_{t+1} respectively. R_1 and R_2 capture the responses of excess asset returns $\widetilde{R}_{x,t+1}$ to excess portfolio returns and to productivity shocks:

$$D_1 = \frac{\partial c^p_{x,t+1}}{\partial \xi_{t+1}}, D_2 = \frac{\partial c^p_{x,t+1}}{\partial \epsilon_{t+1}}, D_3 = \frac{\partial c^p_{x,t+1}}{\partial z_{t+1}} R_1 = \frac{\partial R_{x,t+1}}{\partial \xi_{t+1}}, R_2 = \frac{\partial R_{x,t+1}}{\partial \epsilon_{t+1}}. \tag{C.21}$$

In the second step, we substitute out ξ_t as a function of ϵ_t:

$$\xi_{t+1} = H \epsilon_{t+1}, \quad \text{where} \quad H = \frac{\breve{\alpha} R_2}{1 - \breve{\alpha} R_1}, \tag{C.22}$$

in order to express variables in (C.16) in terms of ϵ_t only:

$$\widetilde{c}^p_{x,t+1} = \mathfrak{D} \epsilon_{t+1} + D_3 \widetilde{z}_{t+1} + \mathcal{O}(\epsilon^2), \quad \text{where} \quad \mathfrak{D} = D_1 H + D_2, \tag{C.23}$$

$$\widetilde{R}_{x,t+1} = \mathfrak{R} \epsilon_{t+1} + \mathcal{O}(\epsilon^2), \quad \text{where} \quad \mathfrak{R} = R_1 H + R_2. \tag{C.24}$$

Once we express these two components separately as functions of ϵ_{t+1}, we multiply them to evaluate Eq. (C.16) in order to solve for portfolio $\breve{\alpha}$ embedded in H:

$$E_t(\widetilde{c}^p_{x,t+1} \widetilde{R}'_{x,t+1}) = \mathfrak{D} \Sigma_T \mathfrak{R}' = (D_1 H + D_2) \Sigma_T (H' R'_1 + R'_2) = \frac{1}{2} F + \mathcal{O}(\epsilon^3). \tag{C.25}$$

Eq. (C.25) is a general portfolio determination equation, where coefficient matrices R_1, R_2, D_1, D_2 are derived from the linear solution of the DSGE model. Around the calibrated steady state, countries' observed moments including wealth $\breve{D}$, output $\bar{Y}$, population $\bar{N}$, trade and migration shares $\bar{\pi}, \bar{m}$ are sufficient to determine these coefficient matrices. If financial frictions exist in the real world to affect portfolios $\breve{\alpha}$ and the corresponding $H = \frac{\breve{\alpha} R_2}{1 - \breve{\alpha} R_1}$, we can follow this Eq. (C.25) to quantify the financial frictions embedded in F that potentially contribute to imperfect consumption risk sharing. The quantified element in the ith row jth column of the F matrix is

$$F(i, j) = f_{iI} - f_{ij} - f_{II} + f_{Ij}, \tag{C.26}$$

which denotes country i's frictions when holding j's assets f_{ij} in relative terms to numeraire I's frictions with f_{iI}, f_{Ij}, f_{II} considered.

[27] This is an important property to ensure the feasibility of the portfolio solution method in a DSGE model. See Devereux and Sutherland (2011) and Tille and Van Wincoop (2010) for technical details.

C.2. Migration

This section characterizes the migration problem in a multi-economy setting. We modify the migration framework developed by Artuc et al. (2010), who characterize cross-sector job adjustment, to our cross-state consumption analysis.

Eq. (20) gives a household's expected value of being in state i at time t, which is based on its current utility and on its optimal choice of location j:

$$V_{i,t} = U_{i,t} + \max_j [\beta E_t(V_{j,t+1}) - d_{ij} + \omega_{j,t}], \tag{C.27}$$

where d_{ij} is the migration cost from i to j and $\omega_{j,t}$ is the household's idiosyncratic benefit from being in state j at the end of time t. If we introduce a cutoff benefit that makes the household indifferent between staying in i and moving to j at t as

$$\bar{\omega}_{ij,t} = \beta[E_t(V_{j,t+1}) - E_t(V_{i,t+1})] - d_{ij}, \tag{C.28}$$

we can rewrite (C.27) and take its expectation with respect to ω:

$$V_{i,t} = U_{i,t} + \beta E_t(V_{i,t+1}) + \max_j \{\bar{\omega}_{ij,t} + \omega_{j,t}\} \tag{C.29}$$

$$= U_{i,t} + \beta E_t(V_{i,t+1}) + \Omega(\bar{\omega}_{i,t}) \tag{C.30}$$

$$\text{where} \Omega(\bar{\omega}_{i,t}) = \sum_j^I \int (\bar{\omega}_{ij,t} + \omega_{j,t}) f(\omega_j) \Pi_{k\neq j} F(\bar{\omega}_{ij,t} - \bar{\omega}_{ik,t} + \omega_{j,t}) d\omega_j. \tag{C.31}$$

From the three components on the right side of Eq. (C.30), $V_{i,t}$ as the expected value of the household to be in i at t depends on the current utility the household obtains $U_{i,t}$, the base value of staying in the state $\beta E_t(V_{i,t+1})$, and the option value of moving from i to others in the future $\Omega(\bar{\omega}_{i,t})$, whose expression (C.31) represents the aggregate benefit of moving from i to all the destinations j when each j provides higher ω than an alternative destination k. This option value $\Omega(\bar{\omega}_{i,t})$ varies with the distribution of benefit $\omega_j \sim F(\omega)$.

We assume that ω is i.i.d across space and time, drawn from an extreme-value distribution with a zero mean:

$$F(\omega) = \exp[-e^{\omega/\theta-\gamma}]. \tag{C.32}$$

Under this assumption, Artuc et al. (2010) in their online appendix derive the cutoff benefit from (C.28) and option value from (C.31):

$$\bar{\omega}_{ij,t} = \theta(\ln m_{ij,t} - \ln m_{ii,t}), \qquad \Omega(\bar{\omega}_{i,t}) = -\theta \ln m_{ii,t}. \tag{C.33}$$

From (C.33), we obtain the share of i's population that migrates to j at t as

$$m_{ij,t} = \frac{\exp(\bar{\omega}_{ij,t}/\theta)}{\sum_{k=1}^I \exp(\bar{\omega}_{ik,t}/\theta)} = \frac{\exp[(\beta E(V_{j,t+1}) - d_{ij})/\theta]}{\sum_{k=1}^I \exp[(\beta E(V_{k,t+1}) - d_{ik})/\theta]}, \tag{C.34}$$

and the share of j's population that stays in the state as

$$m_{jj,t} = \frac{\exp(\bar{\omega}_{jj,t}/\theta)}{\sum_{k=1}^I \exp(\bar{\omega}_{jk,t}/\theta)} = \frac{\exp[(\beta E(V_{j,t+1}))/\theta]}{\sum_{k=1}^I \exp[(\beta E(V_{k,t+1}) - d_{jk})/\theta]}. \tag{C.35}$$

Appendix D. Calibration and computation

D.1. Symmetric two-state framework

This section describes the calibration strategy for quantitative analysis in Section 3.2. Panel (I) in Table D.1 summarizes the common parameters whose values are taken from the macro or trade literature. Panel (II) lists the variables calibrated to the median moments across all the states. For example, persistence and volatility of productivity are set as their median values based on state-level TFP estimated in Appendix B.3. States' equilibrium migrant-to-population $\bar{m}_{ij}$ and export-to-output $\bar{\pi}_{ij}$ ratios are calibrated to these moments' time-averaged median values across states based on the IRS and CFS data (see Appendix B.2). Bilateral productivity correlation $corr(\epsilon_i, \epsilon_j)$ and degree of consumption smoothing $\hat{\beta}_{ij}$ are set as their median values across all state pairs in the sample. In this symmetric two-economy framework, net wealth position of both states $\check{D}_i$ is zero. Besides, we can assume any value for states' equilibrium wage $\bar{w}_i$ without violating market clearing conditions.

In the benchmark model, bilateral frictions in the three channels are estimated to match target moments including $\bar{\pi}_{ij}$, $\bar{m}_{ij}$, and $\hat{\beta}_{ij}$. To estimate their values, we calibrate trade costs τ_{ij} and migration costs d_{ij} jointly to match $\bar{\pi}_{ij}$ and $\bar{m}_{ij}$ on the real side of the economy in the first step. After that, we conduct portfolio choice analysis around the steady state, in order to calibrate financial frictions f_{ij} to match $\hat{\beta}_{ij}$. Financial frictions are estimated in the second step since they only enter the second-order Taylor expansion

Table D.1
Parametrization.

Parameter	Description	Value	Source
	(I)		
β	Annual discount factor	0.95	
σ	Coefficient of relative risk aversion	2	Macro
η	Inverse of elasticity of labor supply	0.5	Literature
δ	Capital depreciation rate	0.06	
α	Capital intensity in production	0.41	BEA Output Data
θ	Elasticity of trade	1.5	Backus et al. (1992)
ϕ	Elasticity of migration	4.5	Artuc et al. (2010)
	(II)		
ρ	Productivity Persistence	0.72	States' (Normalized) Productivity (Estimated in Appendix B.3)
$std(\epsilon_i)$	Productivity Volatility	0.015	
$corr(\epsilon_i, \epsilon_j)$	Productivity Correlation	0.37	
$\bar{m}_{ij}$	Emigrant-to-Population Ratio	0.032	IRS Data
$\bar{\pi}_{ij}$	Export-to-Output Ratio	0.167	CFS Data
β_{ij}	Degree of Consumption Smoothing	0.501	States' Consumption and Output Data

of the Euler equation and hence do not change the zero-order (i.e. steady state) of the real economy.[28] These financial frictions covary with second-moment macro variables including consumption and output comovement, which allows us to recover their values from the consumption smoothing measure $\hat{\beta}_{ij}$, with the influences of migration and trade patterns on consumption already considered in the first step of estimation. Our detailed calibration procedure of the symmetric two-state model is as follows.

Step 1. Calibrate the Real Side of the Economy in Steady State

(1.1) Form guesses about trade and migration costs τ_{ij}, d_{ij} and set a value for wage $\bar{w}_i$.

(1.2) Given wage $\bar{w}_i$, solve for capital rent $\bar{r}_i$, output price $\bar{p}_i$, and consumption price $\bar{P}_i$ jointly from the following price determination equations

$$\bar{r}_i = (\frac{1}{\beta} + \delta - 1)\bar{P}_i, \tag{D.1}$$

$$\bar{P}_i^{1-\phi} = \sum_{j=1}^{I} (\tau_{ji}\bar{p}_j)^{1-\phi}, \tag{D.2}$$

$$\bar{p}_j = \mu^{-\mu}(1-\mu)^{\mu-1}\bar{r}_j^{\mu}\bar{w}_j^{1-\mu}/\bar{T}_j. \tag{D.3}$$

(1.3) Use these prices to derive labor hours $\bar{l}_i$ and consumption $\bar{C}_i$ simultaneously from the optimal labor supply and goods market clearing conditions:

$$\frac{\bar{l}_i^{\eta}}{\bar{w}_i} = \frac{(\bar{c}_i)^{-\sigma}}{\bar{P}_i} = \frac{(\bar{C}_i/\bar{N}_i)^{-\sigma}}{\bar{P}_i}, \tag{D.4}$$

$$\bar{C}_i = \bar{X}_i - \bar{I}V_i, \tag{D.5}$$

where expenditure $\bar{X}_i$ is linked to wealth $\check{D}_i$ and output $\bar{Y}_i$ through the wealth constraint, and investment $\bar{I}_i$ is proportional to capital stock $\bar{K}_i$ in the steady state:

$$\bar{X}_i = [1 - \check{D}_i(1-\frac{1}{\beta})]\bar{Y}_i = [1 - \check{D}_i(1-\frac{1}{\beta})]\frac{\bar{w}_i\bar{l}_i\bar{N}_i}{(1-\mu)\bar{p}_i},$$

$$\bar{I}V_i = \delta\bar{K}_i = \delta\frac{\mu}{1-\mu}\frac{\bar{w}_i\bar{l}_i\bar{N}_i}{\bar{r}_i}.$$

(1.4) Compute the corresponding trade and migration shares $\bar{\pi}, \bar{m}$ to $\bar{p}_i, \bar{P}_i$ from Step (1.2) and $\bar{c}_i, \bar{l}_i$ from Step (1.3)

$$\bar{\pi}_{ji} = (\frac{\tau_{ji}\bar{p}_j}{\bar{P}_i})^{-\phi} \quad \text{where} \quad \bar{P}_i = [\sum_{j=1}^{I}(\tau_{ji}\bar{p}_j)^{1-\phi}]^{\frac{1}{1-\phi}}, \tag{D.6}$$

$$\bar{m}_{ij} = \frac{\exp[(\beta\bar{V}_j - d_{ij})/\theta]}{\sum_{k=1}^{I}\exp[(\beta\bar{V}_k - d_{ik})/\theta]} \quad \text{where} \quad \bar{V}_i = \frac{1}{1-\beta}\bar{U}_i = \frac{1}{1-\beta}(\frac{\bar{c}_i^{1-\sigma}}{1-\sigma} - \frac{\bar{l}_i^{1+\eta}}{1+\eta}). \tag{D.7}$$

[28] Financial frictions do not change the steady state of the real economy to retain the certainty equivalence of assets to the first-order approximation of the model, which is a necessary condition for the portfolio solution method by Devereux and Sutherland (2011) and Tille and Van Wincoop (2010) to be valid in a DSGE model. See Appendix C.1 for a detailed discussion of the portfolio problem, where portfolio weights $\check{\alpha}$ shaped by financial frictions f_{ij} appear as coefficients for excess asset returns $\widetilde{R}_{x,t+1}$ with mean 0. Therefore, financial frictions do not influence the steady-state values of real variables.

(1.5) Update trade and migration costs (τ_{ij} and d_{ij}), repeat Steps (1.2)–(1.4) until $\bar{\pi}$ and $\bar{m}$ match the data.

(1.6) Under these two calibrated frictions from Step (1.5), follow (1.2)–(1.4) again to obtain variables' steady-state values to calibrate the real side of the economy.

Step 2. Calibrate the Financial Side of the Economy in Steady State

(2.1) Solve the DSGE model around the calibrated steady state from Step 1.

Use linear methods such as Blanchard and Kahn (1980) and Uhlig (1995) to derive the first-order responses of control and state variables to stochastic shocks.

(2.2) Obtain coefficient matrices for portfolio analysis (see Appendix C.1 for details).

Extract coefficient matrices R_1, R_2, D_1, D_2, D_3 (defined in (C.21)) from the first-order dynamics of the model.

(2.3) Form an initial guess about equilibrium portfolio $\breve{\alpha}$ and derive its corresponding response of portfolio return to productivity shocks (defined in (C.22))

$$H = \frac{\breve{\alpha} R_2}{1 - \breve{\alpha} R_1}. \tag{D.8}$$

Similar to (C.21)–(C.24), express the responses of variables, including states' per-capita consumption c_i and output y_i, to productivity shocks ϵ as a function of $\breve{\alpha}$ through H:

$$D_{ci} = D_{ci,1} H + D_{ci,2}, \quad D_{yi} = D_{yi,1} H + D_{yi,2}, \tag{D.9}$$

$$\text{where} D_{ci,1} = \frac{\partial c_{i,t+1}}{\partial \xi_{t+1}}, \quad D_{ci,2} = \frac{\partial c_{i,t+1}}{\partial \epsilon_{t+1}}, \quad D_{yi,1} = \frac{\partial y_{i,t+1}}{\partial \xi_{t+1}}, \quad D_{yi,2} = \frac{\partial y_{i,t+1}}{\partial \epsilon_{t+1}}. \tag{D.10}$$

Iterate over $\breve{\alpha}$, follow (D.8)–(D.10) to obtain D_{ci}, D_{yi}, and then compute the ratio of relative consumption $(\widetilde{c}_i - \widetilde{c}_j)$ to output changes $(\widetilde{y}_i - \widetilde{y}_j)$ in response to ϵ

$$\beta_{ij} = \frac{D_{ci} - D_{cj}}{D_{yi} - D_{yj}}, \tag{D.11}$$

until this model-predicted consumption smoothing matches $\hat{\beta}_{ij}$ estimated from the data.

(2.4) Use portfolio $\breve{\alpha}$ from (2.3) as the initial guess, solve for unconditional β under unknown portfolios using this initial guess until differences of theoretical from empirical β_{ij} are minimized.

(2.5) Recover financial frictions f from portfolio determination equations.

Plug H solved with $\breve{\alpha}$ from Step (2.4) in the portfolio determination equation

$$(D_1 H + D_2) \Sigma_T (H' R_1' + R_2') = \frac{1}{2} F + \mathcal{O}(\epsilon^3). \tag{D.12}$$

to quantify the F matrix of financial frictions that embeds f_{ij}.

After calibrating the benchmark model with both real and financial variables, we change the values of frictions for comparative statics analysis to study the interaction of different channels and to disentangle their impacts on cross-state consumption comovement. If trade or migration costs take alternative values, we use these values in Steps (1.2)–(1.4) to solve the new steady state of the economy, around which we follow Step 2 to obtain the new coefficient matrices for portfolio analysis. Using these coefficient matrices and the calibrated F matrix, we derive portfolio $\breve{\alpha}$ whose corresponding $H = \frac{\breve{\alpha} R_2}{1 - \breve{\alpha} R_1}$ satisfies the portfolio Eq. (D.12). If financial frictions also take alternative values, we reflect them in F on the right side of the equation. After deriving $\breve{\alpha}$ and H from this equation, we can predict the dynamic response of any variable to productivity shocks under the new portfolio. Given these dynamics, we plot the impulse responses and compute the second-moment variables under alternative trade, migration, and financial frictions in Section 3.2.

Before conducting these analyze, it is useful for us to evaluate the performance of the benchmark model in terms of matching untargeted moments. Table D.2 lists the comovement of key macro variables including their cross-state correlations and correlations with a state's own output. Since our theoretical framework is modified from the two-country real business cycle (RBC) model by BKK, our theoretical moments are mostly comparable to those in the classic international RBC literature including BKK and Heathcote and Perri (2013). Moreover, most of our model-predicted moments perform well in matching empirical observations. For example, bilateral consumption correlation is about 0.40 in both our model and data, which is lower than bilateral output correlation. Quantitative results from Section 3.2 in Fig. 5 show that cross-state frictions in either trade or financial channel can explain this classic 'quantity puzzle' in international macroeconomics. In terms of cyclicality, the model predicts a high correlation of output with consumption and labor hours as well as a negative correlation between net exports and output, both of which are consistent with the data. The correlation between investment and output is higher in the model than in the data. Modeling strategies from the macro literature that can be used to mitigate this discrepancy include introducing capital adjustment costs (for example, Cooper and Haltiwanger, 2006 and Fiori, 2012) or endogenous capital utilization (Burnside et al., 1995 and Baxter and Farr, 2005). Given the already large number of frictions and our focus on spatial variation of this complex model, we defer these extensions to future research.

Another set of variables from the benchmark model to discuss is bilateral frictions. By following Steps 1–2, we calibrate the three frictions $\tau_{ij}, d_{ij}, f_{ij}$ to match the median values of observed bilateral linkages $\bar{\pi}_{ij}, \bar{m}_{ij}, \hat{\beta}_{ij}$ across state pairs. In this symmetric two-state setting, trade cost is estimated to be $\tau_{ij} = 1.29$, which suggests that for one unit of goods to arrive at the destination state, about 1.3 units need to be shipped from the origin state. In comparison to the existing literature, Hummels (1999)'s estimate on

Table D.2
Contemporaneous correlation at Business Cycles.

	Model	Data
	(I) Cross-state Correlation	
Consumption $\rho(c_1, c_2)$	0.40	0.39
Output $\rho(y_1, y_2)$	0.43	0.48
Investment $\rho(IV_1, IV_2)$	0.22	0.11
Labor Hours $\rho(l_1, l_2)$	0.54	0.69
	(II) Correlation with Self Output	
Consumption $\rho(y, c)$	0.79	0.73
Investment $\rho(Y, IV)$	0.74	0.42
Labor Hours $\rho(Y, l)$	0.61	0.77
Net Exports $\rho(Y, NX/Y)$	−0.21	−0.18
Price $\rho(Y, ToT)$	−0.27	−0.25

This table compares HP-filtered theoretical and empirical correlations of variables at business cycles. Data sources for empirical moments are described in Appendix B. Theoretical correlations are predicted from the DSGE model under the covariance structure of exogenous shocks and dynamic responses of endogenous variables to these shocks.

the within-US trade cost is around 1.1, but he does not account for the retail distribution sector which also contributes to price dispersions across states that would be multiples of trade cost (Burstein et al., 2003). Considering this contribution of the retail distribution sector together with the trade cost itself from these studies, our estimated trade cost's magnitude is in a reasonable range. In the meantime, the estimated financial friction is $f_{ij} = 1.14e\text{-}4$, which is small since the friction is assumed to be second-order in magnitude (proportional to the variance of the shock). This assumption, introduced by Tille and Van Wincoop (2010) to retain the certainty equivalence of assets to the first-order approximation of the model, is a necessary condition for their portfolio solution method to be valid in a DSGE model. Despite its small magnitude, the financial friction generates sizable impacts on consumption correlation through its influence on portfolio choice. In this two-state example, the share of home assets in equilibrium portfolio is 0.32 without the friction and 0.67 with the friction. Hence, the financial friction nearly doubles the degree of home bias by posing a barrier to cross-state asset holdings, which consequently limits states' risk sharing and consumption synchronization through the financial channel. In the migration channel, the bilateral migration cost is estimated to be $d_{ij} = 18.75$, or 22% of consumption's steady-state value predicted by the model. Based on the US annual consumption per capita $52,542 in 2022 reported by the BEA, this migration cost is estimated to be $11,559 for its monetary value. This high migration cost is consistent with and potentially accountable for the low cross-state population mobility in the US over the past few decades.

D.2. Asymmetric multi-state framework

This section describes the calibration strategy for quantitative exercises in an asymmetric setting with fifty states. As discussed in Section 3.3, we conduct comparative statics analysis around the calibrated steady state, which only requires a few sufficient statistics that already embed bilateral frictions across states, such that we do not need to estimate these frictions which would usually require additional assumptions and efforts.

To calibrate the steady state, we use the parametric values from Table D.1 Panel (I) and obtain data on state-level output $\bar{Y}_i$, working population $\bar{N}_i$, bilateral migration $\bar{m}_{ij}$ and trade shares $\bar{\pi}_{ij}$ averaged over the sample period to characterize the equilibrium of the US economy with fifty states (see Appendix B for data sources). States' equilibrium net wealth positions $\check{D}$ are recovered from the wealth constraint that implies $\check{D}_i = tb_i/(1 - \frac{1}{\beta})$ with trade balance tb_i obtained from the CFS.[29] Comprehensive state-to-state financial flows are not observable unfortunately, which makes it difficult to calibrate portfolio weights $\check{\alpha}_{ij}$. However, as explained in Footnote 28, portfolios do not influence the steady state of the real economy, but instead affect second moments around the calibrated steady state through excess portfolio returns ξ_i that add to i's relative wealth (see Appendix C.1 for the portfolio problem):

$$\xi_{i,t+1} = H_i \epsilon_{t+1}, \text{ where } H_i = \frac{(\check{\alpha}_i - \check{\alpha}_I)R_2}{1 - (\check{\alpha}_i - \check{\alpha}_I)R_{i1}} \quad \text{with } R_{i1} = \frac{\partial R_{x,t+1}}{\partial \xi_{i,t+1}},\ R_2 = \frac{\partial R_{x,t+1}}{\partial \epsilon_{t+1}}. \tag{D.13}$$

If our goal is to predict consumption correlations influenced by financial frictions, we only need to calibrate state-level H_i without the need to know bilateral portfolio weights $\check{\alpha}_{ij}$.

From now on, we denote I as a numeraire and $i \in \{1, 2, \dots, I\text{-}1\}$ as non-numeraires. H_i can be calibrated if we use the empirical measure of consumption smoothing $\hat{\beta}_{iI}$ as a target moment, whose theoretical counterpart in the model is the ratio of relative

[29] The median and mean values of time-averaged tb_i are both −3% across states, similar to the US country-level trade balance. A state's trade balance also maps to the difference between its income and expenditure. This difference already incorporates the existing fiscal transfer each state pays to or receives from the federal government. Therefore the model predictions have considered its influence even though the fiscal transfer is not modeled or quantified separately.

consumption $(\widetilde{c}_i - \widetilde{c}_I)$ to output growth $(\widetilde{y}_i - \widetilde{y}_I)$ in response to productivity shocks ϵ:

$$\beta_{iI} = \frac{D_{ci} - D_{cI}}{D_{yi} - D_{yI}} = \frac{D_{cix,1} H_i + D_{cix,2}}{D_{yix,1} H_i + D_{yix,2}}, \tag{D.14}$$

$$\text{where} \quad D_{cix,1} = \frac{\partial c_{i,t+1}}{\partial \xi_i} - \frac{\partial c_{I,t+1}}{\partial \xi_i}, \quad D_{cix,2} = \frac{\partial c_{i,t+1}}{\partial \epsilon} - \frac{\partial c_{I,t+1}}{\partial \epsilon},$$
$$D_{yix,1} = \frac{\partial y_{i,t+1}}{\partial \xi_i} - \frac{\partial y_{I,t+1}}{\partial \xi_i}, \quad D_{yix,2} = \frac{\partial y_{i,t+1}}{\partial \epsilon} - \frac{\partial y_{I,t+1}}{\partial \epsilon}. \tag{D.15}$$

These coefficient matrices are obtained from the first-order dynamics of endogenous variables to stochastic shocks solved with linear methods for a DSGE model around the steady state of the economy. After obtaining these coefficient matrices, we can re-arrange (D.14) to express H_i in terms of these coefficient matrices

$$H_i = \frac{D_{cix,2} - \beta_{iI} D_{yix,2}}{\beta_{iI} D_{yix,1} - D_{cix,1}}, \tag{D.16}$$

which allows us to calibrate H_i consistent with observed consumption smoothing $\hat{\beta}_{iI}$.

After calibrating H_i, which will be in the ith row of the H matrix that covers all the non-numeraire states, we can quantify the matrix of relative financial frictions F from the portfolio determination equation ((C.25) in Appendix C.1):

$$(D_1 H + D_2)\Sigma_T (H' R_1' + R_2') = \frac{1}{2} F, \tag{D.17}$$

where D_1, D_2, R_1, R_2 (introduced in (C.21)) are also obtained from model linearization. Once we calibrate the steady state of the economy including H, F on the financial side and $\bar{\pi}, \bar{m}$ on the real side, we can characterize first-order dynamics and second-moment variables around the calibrated steady state in both original and counterfactual scenarios with linear methods for DSGE models including Blanchard and Kahn (1980) and Uhlig (1995).

Appendix E. Supplementary data

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.euroecorev.2025.105163.

Data availability

Data will be made available on request.

References

Anderson, J.E., Van Wincoop, E., 2003. Gravity with gravitas: A solution to the border puzzle. Am. Econ. Rev. 93 (1), 170–192.
Armignton, P.S., 1969. A theory of demand for products distinguished by place of production. IMF Staff. Pap. 16 (1), 159–178.
Artuc, E., Chaudhuri, S., McLaren, J., 2010. Trade shocks and labor adjustment: A structural empirical approach. Am. Econ. Rev. 100 (3), 1008–1045.
Asdrubali, P., Sorensen, B., Yosha, O., 1996. Channels of interstate risk sharing: United States 1963–1990. Q. J. Econ. 111 (4), 1081–1110.
Athanasoulis, S.G., Van Wincoop, E.v., 2001. Risk sharing within the United States: What do financial markets and fiscal federalism accomplish? Rev. Econ. Stat. 83 (4), 688–698.
Aviat, A., Coeurdacier, N., 2007. The geography of trade in goods and asset holdings. J. Int. Econ. 71 (1), 22–51.
Backus, D.K., Kehoe, P.J., Kydland, F.E., 1992. International real business cycles. J. Political Econ. 100 (4), 745–775.
Bai, Y., Zhang, J., 2012. Financial integration and international risk sharing. J. Int. Econ. 86 (1), 17–32.
Baxter, M., Farr, D.D., 2005. Variable capital utilization and international business cycles. J. Int. Econ. 65 (2), 335–347.
Blanchard, O.J., Kahn, C.M., 1980. The solution of linear difference models under rational expectations. Econometrica 1305–1311.
Broner, F., Ventura, J., 2011. Globalization and risk sharing. Rev. Econ. Stud. 78 (1), 49–82.
Burnside, C., Eichenbaum, M., Rebelo, S., 1995. Capital utilization and returns to scale. NBER Macroecon. Annu. 10, 67–110.
Burstein, A.T., Neves, J.C., Rebelo, S., 2003. Distribution costs and real exchange rate dynamics during exchange-rate-based stabilizations. J. Monet. Econ. 50 (6), 1189–1214.
Caliendo, L., Parro, F., Rossi-Hansberg, E., Sarte, P.-D., 2018. The impact of regional and sectoral productivity changes on the US economy. Rev. Econ. Stud. 85 (4), 2042–2096.
Coeurdacier, N., Rey, H., 2013. Home bias in open economy financial macroeconomics. J. Econ. Lit. 51 (1), 63–115.
Cole, H.L., Obstfeld, M., 1991. Commodity trade and international risk sharing: How much do financial markets matter? J. Monet. Econ. 28 (1), 3–24.
Cooper, R.W., Haltiwanger, J.C., 2006. On the nature of capital adjustment costs. Rev. Econ. Stud. 73 (3), 611–633.
Corsetti, G., Dedola, L., Leduc, S., 2008. International risk sharing and the transmission of productivity shocks. Rev. Econ. Stud. 75 (2), 443–473.
Coval, J.D., Moskowitz, T.J., 1999. Home bias at home: Local equity preference in domestic portfolios. J. Financ. 54 (6), 2045–2073.
Del Negro, M., 1998. Aggregate Risk Sharing Across US States and Across European Countries. Yale University.
Devereux, M.B., Hnatkovska, V.V., 2020. Borders and nominal exchange rates in risk-sharing. J. Eur. Econ. Assoc. 18 (3), 1238–1283.
Devereux, M.B., Sutherland, A., 2011. Country portfolios in open economy macro-models. J. Eur. Econ. Assoc. 9 (2), 337–369.
Eaton, J., Kortum, S., Neiman, B., 2016. Obstfeld and rogoff? s international macro puzzles: a quantitative assessment. J. Econom. Dynam. Control 72, 5–23.
Fiori, G., 2012. Lumpiness, capital adjustment costs and investment dynamics. J. Monet. Econ. 59 (4), 381–392.
Fitzgerald, D., 2012. Trade costs, asset market frictions, and risk sharing. Am. Econ. Rev. 102 (6), 2700–2733.
Garofalo, G.A., Yamarik, S., 2002. Regional convergence: Evidence from a new state-by-state capital stock series. Rev. Econ. Stat. 84 (2), 316–323.
Hazell, J., Herreño, J., Nakamura, E., Steinsson, J., 2022. The slope of the phillips curve: evidence from US states. Q. J. Econ..
Heathcote, J., Perri, F., 2013. The international diversification puzzle is not as bad as you think. J. Political Econ. 121 (6), 1108–1159.

Heathcote, J., Storesletten, K., Violante, G.L., 2014. Consumption and labor supply with partial insurance: An analytical framework. Am. Econ. Rev. 104 (7), 2075–2126.

House, C.L., Proebsting, C., Tesar, L.L., 2018. Quantifying the Benefits of Labor Mobility in a Currency Union. Technical report, National Bureau of Economic Research.

Hu, C., 2024. Portfolio choice analysis in a multi-country macro model. J. Econom. Dynam. Control 105021.

Hummels, D.L., 1999. Toward a geography of trade costs. Available At SSRN 160533.

Isard, W., 1954. Location theory and trade theory: short-run analysis. Q. J. Econ. 305–320.

Kalemli-Ozcan, S., Reshef, A., Sørensen, B.E., Yosha, O., 2010. Why does capital flow to rich states? Rev. Econ. Stat. 92 (4), 769–783.

Kalemli-Ozcan, S., Sorensen, B.E., Yosha, O., 2003. Risk sharing and industrial specialization: Regional and international evidence. Am. Econ. Rev. 93 (3), 903–918.

Lewer, J.J., Van den Berg, H., 2008. A gravity model of immigration. Econom. Lett. 99 (1), 164–167.

Lewis, K.K., 1996. What can explain the apparent lack of international consumption risk sharing? J. Political Econ. 104 (2), 267–297.

Nakamura, E., Steinsson, J., 2014. Fiscal stimulus in a monetary union: Evidence from US regions. Am. Econ. Rev. 104 (3), 753–792.

Obstfeld, M., Rogoff, K., 2000. The six major puzzles in international macroeconomics: is there a common cause? NBER Macroecon. Annu. 15, 339–390.

Okawa, Y., Van Wincoop, E., 2012. Gravity in international finance. J. Int. Econ. 87 (2), 205–215.

Parsley, D., Popper, H., 2021. Risk sharing in a politically divided monetary union. Open Econ. Rev. 32 (4), 649–669.

Portes, R., Rey, H., 2005. The determinants of cross-border equity flows. J. Int. Econ. 65 (2), 269–296.

Ramos, R., Suriñach, J., 2017. A gravity model of migration between the ENC and the EU. Tijdschr. Voor Econ. En Soc. Geogr. 108 (1), 21–35.

Storesletten, K., Telmer, C.I., Yaron, A., 2004. Consumption and risk sharing over the life cycle. J. Monet. Econ. 51 (3), 609–633.

Tille, C., Van Wincoop, E., 2010. International capital flows. J. Int. Econ. 80 (2), 157–175.

Tinbergen, J., 1962. Shaping the world economy; suggestions for an international economic policy.

Uhlig, H., 1995. A toolkit for analyzing nonlinear dynamic stochastic models easily.