Globalization, Inflation Dynamics, and the Slope of the Phillips Curve*

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Abstract

We explore the relationship between trade openness and inflation dynamics by studying how the slope and intercept of the Phillips curve in the United States is affected by international trade. We develop a New Keynesian model of an open economy composed of multiple regions that delivers structural equations for regional Phillips curves with slopes that depend on regions' exposure to trade. In line with our model, we construct measures of exposure to international trade in final consumption goods and exploit variation in this measure across U.S. states to estimate regional Phillips curves. We find that increased exposure to imports contributed to a flattening of state-level Phillips curves since the late 1970s. We estimate that the slope of the national Phillips curve in the United States declined from around -0.2 in 1977-1990 to around -0.04 in 2003-2017. We find that about 40 percent of this flattening can be accounted for by increased exposure to imports. A simple counterfactual exercise shows that if the national Phillips curve had not flattened due to trade, then annual inflation would have been about 0.5 percentage points lower at the height of the Great Recession, and inflation would have been higher by about 0.3 percentage points in the years just before the global pandemic.

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1 Introduction

Over the last fifty years, international trade in goods and services and the exchange of financial assets across countries has grown markedly. The United States has been no exception, as it has been a key participant in this process of globalization. For instance, Figure 1 shows that the nominal share of goods imports in U.S. GDP more than tripled between 1970 and the early 2010s. The surge in trade flows of goods between the United States and other countries has had a myriad of consequences for the U.S. economy. For instance, research has highlighted consequences such as the reallocation of workers and economic activity across industries (Autor et al., 2013; Pierce and Schott, 2016), changes in internal migration (Greenland et al., 2019), changes in labor market dynamics (Dix-Carneiro et al., 2023), and changes in goods' prices—more specifically, in the relative price of imported goods (Amiti et al., 2020; Jaravel and Sager, 2019)—among others. However, the evidence on the effects of greater international trade on the dynamics of inflation in the United States is scant and inconclusive.

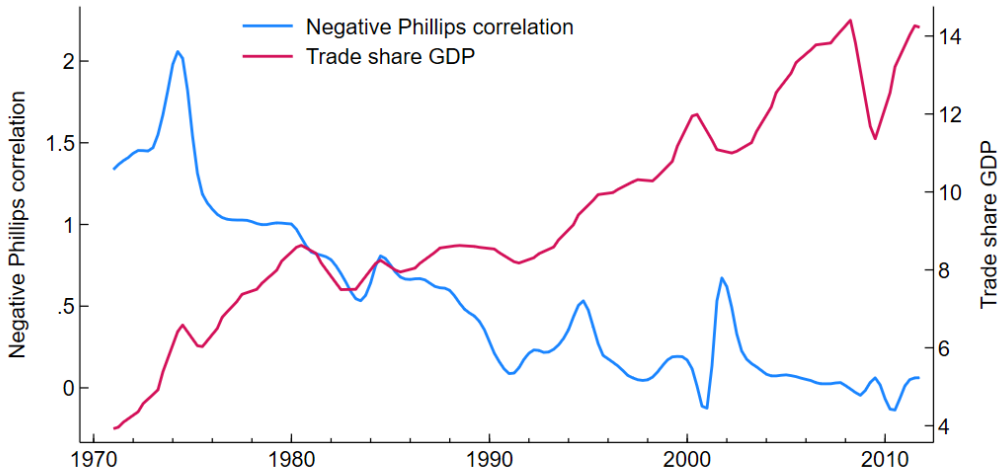
Whether globalization has altered the behavior of inflation is a key question for both academics and policy makers. For instance, some economists have suggested that globalization could be partially responsible for the recent challenge faced by researchers trying to explain inflation dynamics—an issue tightly linked to the growing disconnect between unemployment and inflation—known by some as the "Missing Inflation Puzzle" (Forbes, 2019; Heise et al., 2020). Simply as motivation, Figure 1 also plots the (negative of the) Stock and Watson (2019) "Phillips correlation" from the accelerationist Phillips curve. More specifically, we report the negative of the Phillips correlation, which is computed from a rolling regression (with a 33 quarter window starting in 1970) of the annual change in the 12-month core personal consumption expenditures inflation on the Congressional Budget Office unemployment gap. As the figure shows, the Phillips correlation has declined significantly at around the same time as the U.S. economy became more exposed to imports. Even though this figure could be seen as suggestive evidence of globalization affecting the Phillips correlation, it is still unclear how relevant globalization has been in explaining the apparently declining importance of domestic economic slack in the U.S. Phillips curve (Obstfeld, 2020). In terms of policy implications, even though globalization should in principle not have any direct effect on the ability of a country like the United States to achieve its inflation target, it may have an effect on wage/price dynamics and, therefore, it may require that monetary policy be recalibrated to account for these changes (Yellen, 2006).[1]

In this paper, we revisit the relationship between openness and inflation dynamics by studying how the slope and intercept of the Phillips curve in the United States is affected by international trade exposure.[2] In particular, we identify this relationship by exploiting variation in international

[1] See Obstfeld (2020) for a recent survey of the mechanisms through which global factors influence the tradeoffs faced by U.S. monetary policy.

[2] Previous work has focused on how supply-side factors related to openness affect inflation dynamics (Forbes, 2019).

Figure 1: Stock-Watson "Phillips Correlation" and U.S. Goods Import Share



trade exposure across U.S. states to estimate the effect on (state-level) Phillips curves.[3] Our analysis proceeds in two broad steps. First, we develop a theoretical framework that predicts that the slope of the Phillips curve should be decreasing in the level of import penetration, while the intercept should be related to the contemporaneous change in import penetration. Second, we quantify these effects empirically in line with our theoretical framework by exploiting variation in international trade openness across U.S. states to estimate regional Phillips curves in the spirit of recent work (Hazell et al., 2022; Fitzgerald et al., 2020). We find that increased exposure to imports contributed to a flattening of state-level Phillips curves since the late 1970s. Overall, we estimate that the slope of the national Phillips curve in the United States declined from around -0.2 in 1977-1990 to around -0.04 in 2003-2017. We find that about 40 percent of this decline can be accounted for by increased exposure to imports. A simple counterfactual exercise shows that if the national Phillips curve had not flattened due to trade, then annual inflation would have been about 0.5 percentage points lower at the height of the great recession, and inflation would have been higher by about 0.3 percentage points in the years just before the global pandemic.

We develop a model of a small open economy (SOE) with multiple regions and sticky prices to understand the mechanism driving the interaction between openness and inflation dynamics. Our model considers multiple regions with differing degrees of openness toward the rest of the world. The model delivers structural equations showing that, after controlling for productivity effects and direct effects of openness on changes in prices, more closed regions should have a steeper region-specific

Our analysis takes these factors into account, but also incorporates the effects on the slope of the Phillips Curve, more in line with recent research on inflation dynamics (Hazell et al., 2022). Benigno and Faia (2018) and Guilloux-Nefussi (2020) are examples of work with a theoretical emphasis studying the effects of globalization on the Phillips Curve.

[3] In line with recent research in both empirical macroeconomics and international trade, we rely on idiosyncratic regional variation for identification (Mian and Sufi, 2014; Chodorow-Reich, 2017; Nakamura and Steinsson, 2018; McLeay and Tenreyro, 2020; Autor et al., 2013). This strategy helps us overcome multiple issues that arise when one relies on variation along the time dimension only.

Phillips curve. Intuitively, the pass-through from unemployment to inflation depends on the degree of openness in a given period because demand shocks' pass-through to local costs of production, after controlling for expenditure switching, depends on the share of local firms supplying a local market. Hence, to the extent that there is heterogeneity in regions' exposure to trade in the United States, we should observe different inflation dynamics across these regions.[4]

Guided by the predictions of our model, we propose an identification strategy to estimate regional Phillips curves using differences across regions in inflation dynamics, unemployment rates, and exposure to international trade. Our identification strategy will combine elements of both recent empirical macroeconomics (Hazell et al. (2022)) and international trade literatures (Autor et al., 2013) together. For example, Figure 2 shows average annual inflation across U.S. states from 1990 to 2017 using the data constructed by Hazell et al. (2022). It is clear from the figure that there were sizable differences across state-specific non-housing inflation rates over this period of time. As another example of variation, Figure 3 shows the variation in unemployment rates across U.S. states at the height of the Great Recession.

Figure 2: Non-Housing inflation across U.S. States: 1990-2016

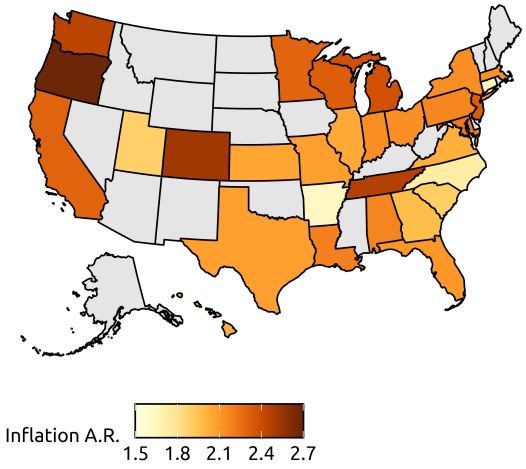
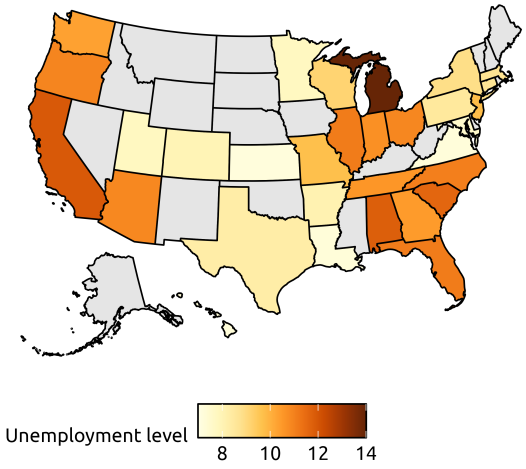


Figure 3: Unemployment rates across U.S. States: 2009



New to the literature, we construct a measure of import penetration for final consumption goods at the regional level. To do this, we first construct a nationwide measure of import penetration in a given year t for NAICS 4-digit sectors in agriculture, mining, and manufacturing. We then use state-level expenditures at the detailed product level (e.g., cars, men's shirts, jewelry, furniture, etc) for 1994 from the BLS Consumer Expenditure Survey public-use microdata to weight the aggregate NAICS import penetration rates differently across states. This results in a time-varying, but state-specific measure of the import share in final consumption that can vary from 0 (all

[4]In the appendix we provide an alternative model with flexible prices and real rigidities that would deliver similar predictions.

consumption is domestic) to 1 (all consumption is foreign-sourced).

Figure 4: Import penetration across U.S. states: 1977 and 2016

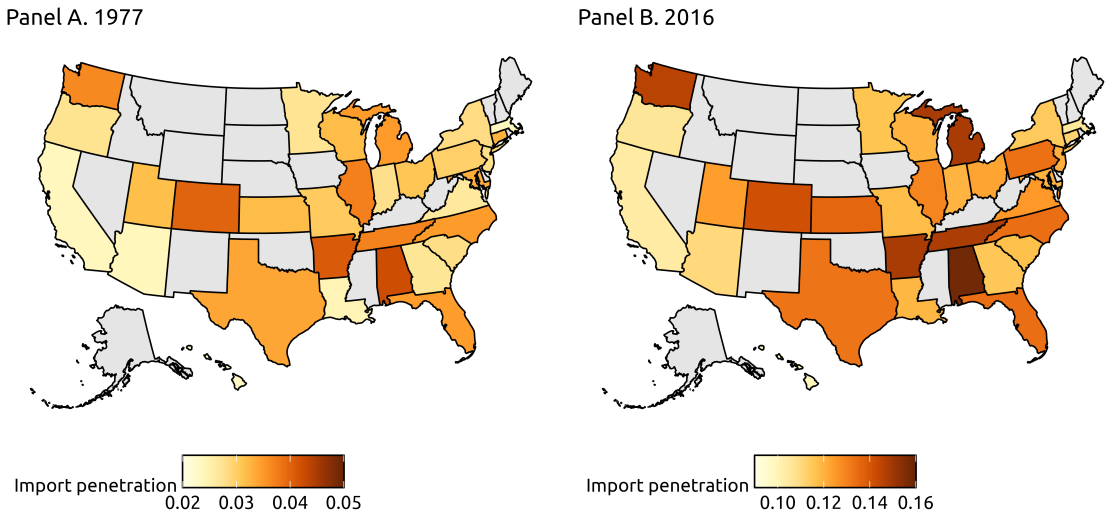


Figure 4 shows how our new measures of state-specific import shares of final consumption vary across states in two years (1977 and 2016). The typical state had an import penetration rate of about 3 percent in 1977, which grows to about 12 percent by 2016. However, there is variation in state exposure to the growth in import penetration, which we exploit in our estimation.

Returning to our estimation results, we find that the dramatic growth in U.S. exposure to trade over the past four decades contributed notably to the declining slope of state-level Phillips curves, and thus the national U.S. Phillips curve. In this way, globalization is estimated to have had a quantitatively important effect on the dynamics of U.S. inflation. A sizable reversal of globalization, if it were to occur, would indeed be a structural change that would need to be accounted for in monetary policy.

Related Literature Our work is related to multiple strands of the literature in macroeconomics, open economy macroeconomics, and international trade. In general terms, our work is closely related to works in applied macroeconomics that exploit regional data to estimate the macroeconomic effects of particular shocks (Charles et al., 2018; Nakamura and Steinsson, 2018; Hazell et al., 2022). Our paper is most closely related to the studies that have focused on using cross-regional variation to identify regional Phillips curves (Kumar and M. Orrenius, 2016; Fitzgerald et al., 2020; Hazell et al., 2022). Recent work analyzes the spatial domension of monetary policy shocks (Pedemonte and Herreño, 2022).

The remainder of this paper is organized as follows. Section 2 presents the model. Section 3 shows we can exploit our model's predictions to derive a simple empirical framework to understand the effects of openness on the Phillips Curve. Section 4 presents our data and empirical analysis.

Section 5 conducts some simple experiments relying on our previous estimates. Section 6 concludes.

2 A Multi-region Open Economy New-Keynesian Model

In this section we develop a model of the U.S. economy with sticky prices. Our framework extends a benchmark open economy model with nominal rigidities à la Calvo (Galí and Monacelli, 2005) to multiple regions that differ in their degree of openness towards the rest of the world. The United States is assumed to be an open economy composed of multiple regions indexed by $r \in \{1, \ldots, I\}$, each of which is a small open economy relative to the rest of the world. We denote by ν_{rt} the share of total U.S. population located in region r at time t, such that $\sum_{r=1}^{I} \nu_{rt} = 1$ for every t. The model we present here does not incorporate internal trade across regions in the United States, nor multiple sectors. Thus, we can think of these regions as islands. However, in Appendix D we show how to extend the model to include internal trade and multiple sectors without any crucial implications for our empirical analysis in Section 4.

2.1 Households

Region r is inhabited by a representative household that seeks to maximize the expected value of its lifetime utility,

$$E_0 \sum_{t=0}^{\infty} \beta^t U\left(C_{rt}, N_{rt}; Z_{rt}\right), \tag{1}$$

where C_{rt} is per capita consumption of a composite consumption index in region r, N_{rt} is per capita employment in region r, and Z_{rt} is an exogenous stochastic preference shifter in region r. The composite consumption index is defined by

$$C_{rt} = \left((1-\upsilon_r)^{\frac{1}{\eta}} \left(C_{H,rt}\right)^{1-\frac{1}{\eta}} + (\upsilon_r)^{\frac{1}{\eta}} \left(C_{F,rt}\right)^{1-\frac{1}{\eta}}\right)^{\frac{\eta}{\eta-1}}, \tag{2}$$

where $C_{H,rt}$ is an index of consumption of goods produced locally—that is, produced in region r—which is given by

$$C_{H,rt} \equiv \left(\int_0^1 C_{H,rt}\left(i\right)^{\frac{\varepsilon-1}{\varepsilon}} di\right)^{\frac{\varepsilon}{\varepsilon-1}}, \tag{3}$$

where $i \in [0,1]$ indexes varieties and $C_{F,rt}$ is the index of consumption of goods produced abroad.[5] We interpret the parameter $\upsilon_r \in [0,1]$ as a measure of openness and assume that it can differ across regions. This is in line with the evidence shown in Figure 4. More open regions will have higher values of υ_r, and therefore lower home bias. The parameter $\eta \geq 1$ determines the trade elasticity

[5] As shown in appendices D and C, the model can be extended to allow for trade across regions, in which case $C_{F,rt}$ would be a consumption index of goods produced in any region other than r or abroad.

which in this model is given by $\eta - 1 \geq 0$.

Households maximize utility in (1) subject to the sequence of budget constraints given by

$$\int_0^1 P_{H,rt}(i) C_{H,rt}(i) di + P_{F,rt} C_{F,rt} + E_t [Q_{t,t+1} D_{rt+1}] \leq D_{rt} + W_{rt} N_{rt}$$

for $t = 0, 1, \ldots$ where D_{rt+1} is the nominal payoff in period $t+1$ of the portfolio held at the end of period t.[6] We assume that there are complete international financial markets and that households have access to a complete set of contingent claims that are traded internationally and frictionless.

In what follows, we assume that the period utility function $U(C_{rt}, N_{rt}; Z_{rt})$ takes the form

$$U(C_{rt}, N_{rt}; Z_{rt}) = Z_{rt} \left(\frac{C_{rt}^{1-\sigma} - 1}{1-\sigma} - \frac{N_{rt}^{1+\varphi}}{1+\varphi} \right) \tag{4}$$

where $\sigma \geq 0$ and $\varphi \geq 0$ determine the curvature of the utility of consumption and the disutility of labor, respectively.

2.2 Firms

2.2.1 Technology

There is a continuum of firms in each region, each producing a tradable variety. Varieties can be costlessly traded with the rest of the world, but we assume that these cannot be traded across regions. As in the previous section, a firm producing varity i is indexed by $i \in [0, 1]$. We assume that a typical firm in region r has technology

$$Y_{rt}(i) = A_{rt} N_{rt}(i), \tag{5}$$

where A_{rt} is an exogenous and stochastic productivity shock affecting region r.

We assume that firms set prices in a staggered fashion, as in Calvo (1983). Hence, a measure $1 - \theta$ of firms set new prices each period, with an individual firm's probability of re-optimizing in any given period being independent of the time elapsed since it last reset its price. Firms can sell their goods locally and also export them to the rest of the world. We follow Galí and Monacelli (2005) and assume that these firms engage in producer currency pricing when choosing the price at which they offer their goods.

2.3 Exports

In addition to domestic households demanding goods in region r, there is also a demand by the rest of the world for each variety $i \in [0, 1]$ produced in each region. We assume that the demand for

[6] The portfolio can include shares in local firms.

exports of good $i \in [0,1]$ produced in region r is given by

$$X_{rt}(i) = \left(\frac{P_{H,rt}(i)}{P_{H,rt}}\right)^{-\varepsilon} X_{rt}, \tag{6}$$

where $X_{rt} \equiv \left(\int X_{rt}(i)^{\frac{\varepsilon-1}{\varepsilon}} di\right)^{\frac{\varepsilon}{\varepsilon-1}}$ is an index across varieties, summarizing aggregate exports from region r to the rest of the world. Turning to aggregate exports, we assume that they are given by

$$X_{rt} = \frac{\upsilon^*}{I}\left(\frac{P_{H,rt}}{\mathcal{E}_t P_t^*}\right)^{-\eta} Y_t^* \tag{7}$$

where, similar to the case of a region of the U.S. economy, $\upsilon^* \in [0,1]$ parameterize the degree of openness by the rest of the world against the United States, I is the number of regions that form the U.S. economy, $\mathcal{E}_t$ is the nominal exchange rate expressed in terms of U.S. dollars per rest of the world currency units, P_t^* denotes the price of goods produced abroad expressed in local currency units, and Y_t^* is real GDP in the rest of the world. As will become clearer in the next section, the previous expression implicitly assume that preferences of households in the rest of the world are almost identical to those of domestic households.

2.3.1 Government Policy

The monetary authority conducts a common policy for all region $r = 1, \ldots, I$. We assume that the policy takes the form of the following interest rate rule

$$\hat{r}_t = \phi_\pi(\pi_t - \bar{\pi}_t) - \phi_u(\hat{u}_t - \bar{u}_t) \tag{8}$$

where hats denote deviations from the zero-inflation steady state, and $\bar{\pi}_t$ and $\bar{u}_t$ denote aggregate inflation and unemployment targets by the central bank. Aggregate inflation and unemployment are in turn defined as population-weighted averages across regions:

$$\pi_t = \sum_{r=1}^{I} \nu_{rt}\pi_{rt} \quad \text{and} \quad \hat{u}_t = \sum_{r=1}^{I} \nu_{rt}\hat{u}_{rt}.$$

2.4 Optimality Conditions

2.4.1 Households

From the solution of the households' maximization problem, we obtain that the optimal allocation of expenditures across locally produced varieties is characterized by the conditional demand function

$$C_{H,rt}(i) = \left(\frac{P_{H,rt}(i)}{P_{H,rt}}\right)^{-\varepsilon} C_{H,rt}, \tag{9}$$

where the price index $P_{H,rt}$ is given by

$$P_{H,rt} = \left(\int_0^1 P_{H,rt}\left(i\right)^{1-\varepsilon} di \right)^{\frac{1}{1-\varepsilon}}, \tag{10}$$

and $C_{H,rt}$ denotes the consumption index of locally produced goods. These prices and quantities are such that $\int_0^1 P_{H,rt}\left(i\right) C_{H,rt}\left(i\right) = P_{H,rt} C_{H,rt}$.

The index $C_{H,rt}$, in turn, as well as the non-local final consumption index are determined by

$$C_{H,rt} = \left(1 - \upsilon_r\right) \left(\frac{P_{H,rt}}{P_{rt}} \right)^{-\eta} C_{rt} \quad \text{and} \quad C_{F,rt} = \upsilon_r \left(\frac{P_{F,rt}}{P_{rt}} \right)^{-\eta} C_{rt}, \tag{11}$$

where the price index of the final consumption composite basket is

$$P_{rt} = \left[\left(1 - \upsilon_r\right) \left(P_{H,rt}\right)^{1-\eta} + \upsilon_r \left(P_{F,rt}\right)^{1-\eta} \right]^{\frac{1}{1-\eta}} \tag{12}$$

for the final consumption good in region r.

Given our assumed functional form in (4), we can rewrite the intratemporal optimality condition by the households as

$$C_{rt}^{\sigma} N_{rt}^{\varphi} = \frac{W_{rt}}{P_{rt}}, \tag{13}$$

and the intertemporal optimality conditions as

$$\beta \left(\frac{C_{rt+1}}{C_{rt}} \right)^{-\sigma} \left(\frac{P_{rt}}{P_{rt+1}} \right) = Q_{t,t+1}. \tag{14}$$

These set of conditions can be rewritten to deliver the more usual Euler equation

$$\beta R_t \mathbb{E}_t \left\{ \left(\frac{C_{rt+1}}{C_{rt}} \right)^{-\sigma} \left(\frac{P_{rt}}{P_{rt+1}} \right) \right\} = 1 \tag{15}$$

where $R_t = 1/\mathbb{E}_t \left[Q_{t,t+1} \right]$ denotes the gross return on a riskless one-period bond.

2.4.2 Price Setting by Firms

Let $Y_{rt}(i)$ denote total output by firm i located in region r at time t. This firm's nominal profits at time t are given by

$$\Pi_{rt}(i) = P_{H,rt}(i) Y_{rt}(i) - W_t N_{rt}(i). \tag{16}$$

Given that firms face sticky prices and they can only adjust their price in period t with probability $1-\theta$, if firm i is able to update its price, $P_{H,rt}(i)$, in period t, it will do so to maximize the objective

$$\sum_{k=0}^{\infty} \theta^k \mathbb{E}_t \left\{ Q_{t,t+k} \left(P_{H,rt}(i) Y_{rt+k}(i) - W_{rt+k} N_{rt}(i) \right) \right\} \tag{17}$$

subject to firm i's output satisfying demand given by

$$Y_{rt}(i) = C_{H,rt}(i) + X_{rt}(i) = \left(\frac{P_{H,rt}(i)}{P_{H,rt}} \right)^{-\varepsilon} (C_{H,rt} + X_{rt}) \tag{18}$$

where the second equality follows from equations (6) and (9) and by defining $Y_{H,rt} \equiv C_{H,rt} + X_{rt}$. Let $MC_{rt} \equiv \frac{Wrt}{P_{H,rt} A_{rt}}$ denote the real marginal cost faced by all firms in terms of domestic goods produced in region r at time t. Solving the problem of an updating firm implies that prices will be chosen such that

$$P_{H,rt}(i) = \frac{\varepsilon}{\varepsilon - 1} \frac{\sum_{k=0}^{\infty} (\theta\beta)^k \mathbb{E}_t \left\{ \frac{U'(C_{rt+k})}{P_{rt+k}} \left(MC_{rt+k} P_{H,rt+k}^{1+\varepsilon} Y_{H,rt+k} \right) \right\}}{\sum_{k=0}^{\infty} (\theta\beta)^k \mathbb{E}_t \left\{ \frac{U'(C_{rt+k})}{P_{rt+k}} P_{H,rt+k}^{\varepsilon} Y_{H,rt+k} \right\}}. \tag{19}$$

Given that the right-hand side (19) does not depend on i, all firms resetting prices at time t will choose the same price.

2.5 Equilibrium

In Appendix A we show that a log-linear approximation of the model around a zero inflation steady state delivers a relationship between domestic price inflation, $\pi_{H,rt}$, and real marginal cost given by

$$\pi_{H,rt} = \kappa \widetilde{mc}_{rt} + \beta \mathbb{E}_t \left[\pi_{H,rt+1} \right], \tag{20}$$

where domestic price inflation is defined by $\pi_{H,rt} \equiv p_{H,rt} - p_{H,rt-1}$ where $p_{H,rt} \equiv \log P_{H,rt}$, and $\widetilde{mc}_{rt} = mc_{rt} - mc_r$ where $mc_{rt} = \log MC_{rt}$ and $mc_r = -\log \frac{\varepsilon}{\varepsilon - 1}$ is the log of the real marginal cost in the zero inflation steady state. In (20), κ is a structural parameter given by

$$\kappa \equiv \frac{(1-\theta\beta)(1-\theta)}{\theta}. \tag{21}$$

Note that this parameter only depends on the probability of a firm readjusting its price in any given period, θ, and households' discount factor, β. Hence, the substitutability between domestic and foreign goods does not enter into this relationship. Therefore, according to equation (20), the pass-through from real marginal cost to domestic price inflation does not vary across regions in our model. In particular, the relation between domestic price inflation and the real marginal cost is not

affected by a region's degree of openness. However, as the next lemma shows, trade openness comes into play once we express the real marginal cost in terms of unemployment.

Lemma 1. *In a log-linear approximation of the model around its zero inflation steady state, domestic price inflation in region r can be written in terms of unemployment gaps and expected domestic price inflation as*

$$\pi_{H,rt} = -\kappa_r \hat{u}_{rt} + \beta \mathbb{E}_t \left[\pi_{H,rt+1} \right], \tag{22}$$

where $\hat{u}_{rt} = u_{rt} - u^n_{rt}$ denotes deviations of region r's unemployment rate, defined by $u_{rt} = \log U_{rt}$ where $U_{rt} = 1 - N_{rt}$, from its equilibrium level of unemployment in the absence of nominal rigidities and conditional on y^*_t. The region-specific coefficient, κ_r, is given by $\kappa_r \equiv \kappa(\phi + \sigma^{\upsilon}_r)$ and

$$\sigma^{\upsilon}_r \equiv \frac{\sigma}{(1-\upsilon_r) + \upsilon_r \left[\sigma\eta + (1-\upsilon_r)(\sigma\eta - 1)\frac{1-\phi_r}{\upsilon_r} \right]}, \tag{23}$$

where $\phi_r \equiv \frac{1-\upsilon_r}{(1-\upsilon_r)+\frac{\upsilon^*}{I}}$.

Proof. See Appendix (B) □

Equation (22), which we refer to as the domestic price inflation Phillips curve, shows that the pass-through from regional unemployment gaps into domestic price inflation, κ_r, can vary across regions. More specifically, the slope of this Phillips curve, will be flatter for more open regions—that is, regions with higher values of υ_r—as long as $\sigma\eta > 1$.[7] Under this parameter restriction, more open regions experience a smaller adjustment in their terms of trade—defined as $S_{rt} \equiv \frac{P_{F,rt}}{P_{H,rt}}$—necessary to absorb a change in domestic output (relative to world output) and therefore investment. Hence, more openness dampens the impact of that adjustment on marginal cost and inflation. This effect is pointed out by Clarida et al. (2002) and Galí and Monacelli (2005).

Turning to final consumption prices, in order to derive an expression for regional Phillips curves for final consumption price inflation in region r, $\pi_{rt} \equiv \frac{P_{rt}}{P_{rt-1}} - 1$, consider the share of total final consumption expenditure by region r spent on goods produced abroad:

$$\Lambda_{rt} \equiv \frac{P_{F,rt} C_{F,rt}}{P_{rt} C_{rt}}. \tag{24}$$

The share $1 - \Lambda_{rt}$ can be interpreted as a measure of home bias that provides a sufficient statistic for the welfare gains from trade in a large class of neoclassical models of international trade (Arkolakis

[7] We show in Appendix B that under $\sigma\eta > 1$ and an additional reasonable condition on the relationship between υ_r and υ^*/I, $\frac{\partial \sigma^{\upsilon}_r}{\partial \upsilon_r} < 0$. For the case in which $\upsilon_r = \upsilon^*/I$ (Galí and Monacelli, 2005), it can be easily seen that $\sigma\eta > 1$ is sufficient for $\frac{\partial \sigma^{\upsilon}_r}{\partial \upsilon_r} < 0$.

et al., 2012). This fact is very convenient because (24) can be rewritten as

$$\Lambda_{rt} = \frac{IM_{rt}}{VA_{rt} - (EX_{rt} - IM_{rt})} \tag{25}$$

where $IM_{rt} \equiv P_{F,rt}C_{F,rt}$ denotes imports, $EX_{rt} \equiv P_{H,rt}X_{rt}$ denotes exports, and $VA_{rt} \equiv P_{H,rt}Y_{H,rt}$ denotes value added, all in region r. All these statistics are readily available at the national level for many countries. However, as we discuss in Section 4, computing this statistic at a regional level for the United States carries particular challenges. We will refer to the statistic Λ_{rt} as import penetration from now on. Note that in the model, equation (9) implies that import penetration is given by $\Lambda_{rt} = \upsilon_r \left(\frac{P_{F,rt}}{P_{rt}}\right)^{1-\eta}$, which in a zero inflation steady state of the model with $P_{F,rt} = P_{rt}$ becomes $\Lambda_r = \upsilon_r$.

The next lemma shows how we can rely on changes in import penetration in order to obtain a Phillips curve for final price inflation that incorporates the effects of changes in import prices.

Lemma 2. *Final consumption price inflation in region r can be expressed approximately in terms of domestic price inflation and changes in import penetration as*

$$\pi_{rt} = \pi_{H,rt} - \frac{d\Lambda_{rt}}{\eta - 1}, \tag{26}$$

where $d\Lambda_{rt} = \Lambda_{rt} - \Lambda_{rt-1}$ denotes log changes in import penetration over time.

Proof. Equation (12) implies that $(1+\pi_{rt})^{1-\eta} = (1+\pi_{H,rt})^{1-\eta}\left(\frac{\left(\frac{1-\upsilon_r}{\upsilon_r}\right)+S_{rt}^{1-\eta}}{\left(\frac{1-\upsilon_r}{\upsilon_r}\right)+S_{rt-1}^{1-\eta}}\right)$ and that S_{rt} and Λ_{rt} are such that $S_{rt}^{\eta-1} = \frac{\upsilon_r}{1-\upsilon_r}\frac{1-\Lambda_{rt}}{\Lambda_{rt}}$. Hence, substituting the latter condition into the former implies that

$$(1+\pi_{rt})^{1-\eta} = (1+\pi_{H,rt})^{1-\eta}\left(\frac{1-\Lambda_{rt}}{1-\Lambda_{rt-1}}\right)^{-1},$$

which delivers $\pi_{rt} \approx \pi_{H,rt} - \frac{d\Lambda_{rt}}{\eta-1}$. □

Relying on lemmas 1 and 2, we can derive the regional final consumption price inflation which depends on changes in import penetration, which in turn summarize changes in import prices.

Proposition. *Final consumption price inflation in region r can be expressed in terms of regional unemployment, expected domestic foreign inflation, and changes in import penetration for region r as*

$$\pi_{rt} = -\kappa_r \hat{u}_{rt} + \beta \mathbb{E}_t\left[\pi_{H,rt+1}\right] - \frac{d\Lambda_{rt}}{\eta - 1} \tag{27}$$

where κ_r is as in Lemma (2).

Note that our regional Phillips curves for final consumption price inflation depend on expected future domestic price inflation. We could rewrite (27) in terms of expected future final consumption price inflation and changes in terms of trade as we first did in the proof of Lemma 2. However, we do not want to do this because the empirical analysis that we carry out in the remainder of the paper exploits the fact that we can compute import penetration at the regional level. In the next section we turn to how we can use (27) to discipline our empirical analysis and identification strategy.

3 A Simple Framework to Estimate the Effects of Openness on Regional Phillips Curve

In the previous section, we developed a model of the U.S. economy that can be used to study the effects of trade openness on regional Phillips curves. Our model implies that regional final consumption price inflation Phillips curves are given by equation (27), where $\hat{u}_{rt}$ denotes unemployment deviations from the zero-inflation steady state and Λ_{rt} denotes import penetration in region r.[8]

Consider the United States and its 50 states. In order to estimate equation (27) for this case, we would ideally need data on: (i) state-level CPI inflation, (ii) a measure of expected inflation in locally produced goods at the state level, and (iii) a measure of import penetration by U.S. state. While some of these data are readily available, like (i) above (Hazell et al., 2022), we will exploit the structure of the model in certain dimensions and additional data in order to be able to estimate the structural equation at hand.

There are no data available on measures of domestic price inflation at the state level. Hence, in the spirit of Hazell et al. (2022), we exploit the structure of the model and iterate equation (22) forward in order to obtain the following expression for domestic price inflation:

$$\pi_{H,rt} = -\mathbb{E}_t \sum_{j=0}^{\infty} \beta^j \kappa_r \widetilde{u}_{rt+j} + \mathbb{E}_{t+\infty} \pi_{H,rt+\infty}, \tag{28}$$

where $\widetilde{u}_{rt} = u_{rt} - \mathbb{E}_t[u_{rt+\infty}]$. In line with the literature on regional Phillips curves, we will assume that $\mathbb{E}_{t+\infty}\pi_{H,rt+\infty}$ does not vary across states. This assumption is based on the idea that in the long run, inflation expectations should be equated across regions in a monetary union. Hence, in a panel specification, long-run inflation expectations will be captured by time fixed effects.

Let us now turn to how we compute measures of import penetration at the U.S. state level. Given that these data are not available, we construct such a measure by computing final consumption weights across sectors for a particular year, and then weighting changes in national import penetration measures at the sectoral level. Note that following this procedure implies that all variation across

[8] In Appendix E we present a model that shows that, under certain assumptions, the case of perfectly flexible prices with real rigidities delivers similar relationships.

regions in changes in import penetration will come from differences in sectoral final consumption shares. In Appendix C we show that in a multi-sector version of our model in which regions differ in terms of their sectoral final consumption shares, but sectoral import penetration does not vary across regions, our measure of import penetration is consistent with the model's structural equations. We provide further details on how we construct import penetration measures in Section 4.

In line with the previous discussion on how we construct import penetration measures at the state level, consider an economy with multiple sectors and let Λ_t^j denote national import penetration for sector j at time t. Now, let $\Lambda_{rt} \equiv \sum_j \alpha_r^l \Lambda_t^j$ denote our measure of import penetration at the regional level. In this case, note that in line with (27), the degree of openness in each region has both a direct and an indirect effect on inflation dynamics. Changes in sectoral degrees of openness affect inflation dynamics directly through their effect on changes in Λ_{rt}. After weighting by sectoral expenditure shares, a region that becomes more open experiences $d \log \Lambda_r < 0$, thus dampening inflation. Intuitively, lower import prices lead to expenditure switching towards goods produced by foreign firms which directly affect changes in final consumer prices.

The degree of openness at the time of a shock also affects the pass-through from movements in local unemployment to inflation dynamics. The fact that we derived the Phillips curve in (22) up to a first order approximation implies that κ_r only depends on υ_r rather than on Λ_{rt}, which does vary substantially over time. Hence, in our empirical analysis we will allow for a time-varying slope of the Phillips curve which is a function of Λ_{rt}. We consider a robustness exercise in which we fix regions' openness across time and results are bascially unchanged. Note that, according to our model, more open regions will be associated with a lower κ_r, that is, a higher Λ_{rt}, and a flatter Phillips curve.

We rely on the insights derived from expression (27) above to propose an empirical strategy to quantify the effects of openness on inflation dynamics by estimating regional Phillips curves in the United States in the following section.

4 Empirical Analysis: Exploiting Differences in Openness Across U.S. States

We bring the insights derived from our theoretical framework and specify the following equation to be estimated using quarterly data:

$$\pi_{r,t} = \alpha_r + \gamma_t + \delta u_{r,t-1} + \tau u_{r,t-1} IP_{r,t-1} + \sigma \Delta IP_{r,t} + \delta X_{r,t} + \epsilon_{rt} \tag{29}$$

where $\pi_{r,t}$ is either state-level non-housing CPI inflation (Q4/Q4), or rent inflation; α_r are state fixed effects and γ_t are time fixed effects (which implicitly detrend unemployment); $u_{r,t-1}$ is state unemployment in Q4 of previous year; $IP_{r,t-1}$ is lagged state-level import penetration (import share of consumption), and $X_{r,t}$ is a set of controls that can vary across state and time. This specification

is similar to the one considered by Hazell et al. (2022), except that we have added the the τ and σ terms. The τ term reflects the effects of openness on the slope of regional Phillips curves, while the σ term captures the direct effect of openness on inflation.[9]

4.1 Data

We focus on the period post 1976 and gather the data from multiple sources. To construct our measures of inflation, we rely on state-level non-housing CPI inflation (Q4/Q4) from Hazell et al. (2022). From this source we obtain annual data for 31 states from 1977 to 2017. Figure 2 in the introduction provides a preview of the data on state-level inflation rates. In addition, we collect data on annual rent inflation (only available starting in 1986) for the same states and years from Fair Market Rents from HUD. We collect the data on unemployment from the Quarterly Census of Employment and Wages (QCEW) by the BLS.

The measure of import penetration that is consistent with the model outlined in the previous section should be based on import shares of final consumption in each state. To construct a proxy for this measure, we consider estimates of state-level expenditures at the detailed product level (e.g., cars, men's shirts, jewelry, furniture, etc) for 1994 from the BLS Consumer Expenditure Survey public-use microdata. We also rely on the nominal value of domestic production by NAICS 4-digit industries annually for the period 1976-2017 (for manufacturing sectors, we use the NBER-CES Manufacturing Database, and for agricultural and mining sectors we use BEA detailed GDP-by-Industry data). Lastly, we also collect data on national nominal imports and exports by NAICS 4-digit industry annually from 1976-1989 from Census, 1990 onwards from USITC.

To construct our measures of import penetration at the regional level, we first construct a nationwide measure of import penetration in a given year t for NAICS 4-digit sectors in agriculture, mining, and manufacturing denoted by j as follows:

$$IP_{j,t} = \frac{M_{j,t}}{(Y_{j,t} - X_{i,t}) + M_{j,t}}, \tag{30}$$

where $IP_{j,t}$ is our nationwide measure of import penetration for sector j, $Y_{j,t}$ are national output in sector j, $M_{j,t}$ is national imports in sector j, and $X_{j,t}$ are national imports in sector j, all these measured in period t. Note that this measure can vary from 0 (all consumption is domestic) to 1 (all consumption is foreign-sourced). We then use each state's sectoral expenditure shares from 1994 to form the weighted average across the national sectoral import penetration rates for each year. Let $s_{r,j}$ denote the share of total expenditure on sector j goods by consumers in region r in 1994.

[9] If we assume that we can approximate the dynamics of unemployment and import penetration by AR(1) processes, then it can be shown that the relationship between structural parameters and parameters to be estimated in (29) are given by $\delta = \frac{\kappa_r}{1-\beta\ \rho_u}$, $\tau = \frac{\kappa_r}{1-\beta\ \rho_p}$, and $\sigma = \frac{1}{1-\eta}$ where ρ_u and ρ_i are the AR(1) coefficients on unemployment and the interaction of unemployment and import penetration.

Then, our measure of state-specific import penetration is defined as

$$IP_{r,j,t} = \sum_{j} s_{r,j} IP_{j,t}. \tag{31}$$

We now proceed to estimate different versions of equation (29) with the data that we just described.

4.2 Estimation Results

Following equation (29), we estimate the effects of import penetration on regional Phillips curves in column (1) of Table 1. Importantly, note that in our regressions we have defined import penetration in terms of units of 0.1 percentage points (rather than in terms of 1 ppt.). In column (1), we estimate the effect of the interaction terms between unemployment and import penetration, τ, to be positive and statistically significant. The sign of this estimate is in line with our model and the discussion presented in section 3. Hence, more open states have flatter Phillips curves according to our estimates. Our estimate of σ is negative, but not statistically significant. This point estimate is in line with our model that implies that increases in import penetration should lead to lower inflation rates. Lastly, column (2) includes the lagged level of import penetration as a control in our regression. Our results show that our estimates of δ and τ still align with our model and with the fact that more open regions tend to have flatter Phillips curves.

Table 1: Import Penetration and Non-Housing Inflation Rates: OLS Estimates 1986-2017

Dependent variable: Non-housing CPI annual inflation rate in the fourth quarter (Q4/Q4 in % pts)

	(1)	(2)
$u_{r,t-1}$	-0.34***	-0.49***
	(0.085)	(0.148)
$u_{r,t-1} IP_{r,t-1}$	0.19**	0.35**
	(0.070)	(0.160)
$\Delta IP_{r,t}$	-1.66	-0.87
	(2.067)	(2.594)
$IP_{r,t-1}$		2.63
		(1.614)
State FE	Yes	Yes
Time FE	Yes	Yes

Notes: $N = 889$. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$; standard errors are clustered by state and time.

As Hazell et al. (2022) discuss, while the fixed effects included in the regressions control for important time-varying common factors and time-invariant state factors, they do not completely rule out the possibility of an endogeneity bias. Ultimately, there still could be omitted factors which contribute to movements in both state-level inflation and state-level unemployment (and also state trade exposure). We propose instrumental variables strategies to deal with these potential issues.

First, consider the potential endogeneity bias in the coefficient on state-level unemployment. While Hazell et al. (2022) propose an IV to deal with this issue, we will develop a different IV because the strategy used in Hazell et al. (2022) does not seem as convincing once we consider that states have differential exposure to trade. Specifically, our alternative IV strategy is based on the literature on government spending shocks. In particular, we interact state dummy variables with the lagged value of federal defense spending and use these interactions as instruments for state-level unemployment.

To deal with potential endogeneity of our trade exposure measures, we develop an instrument based on the strategy in Autor et al. (2013). Specifically, we use exports from China to the same non-US countries as in Autor et al. (2013) as an instrument, which should be informative for the level and change in U.S. import penetration. The identifying assumption of this instrument is that it reflects positive productivity shocks in China and not U.S. demand shocks.

Table 2: Import Penetration and Non-Housing Inflation Rates: IV Estimates 1986-2017

Dependent variable: Non-housing CPI annual inflation rate in the fourth quarter (Q4/Q4 in % pts)

	(1)	(2)
$u_{r,t-1}$	-0.56**	-1.03***
	(0.240)	(0.333)
$u_{r,t-1}IP^M_{r,t-1}$	0.40*	0.87**
	(0.225)	(0.318)
$\Delta IP^M_{r,t}$	-2.07	0.22
	(8.772)	(8.554)
$IP^M_{r,t-1}$		5.7**
		(2.667)

Notes: $N = 889$. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$; standard errors are clustered by state and time.

Our IV results, presented in Table 2, are qualitatively similar to our OLS results. The coefficient on the unemployment rate is larger in absolute value, and the coefficient on the interaction term remains positive and statistically significant. While the coefficient in column (1) on the change in import penetration is somewhat more negative than previously, it remains statistically insignificant.

We view the results in column (1) of Table 2 as our preferred non-housing estimates. In order

to understand how taking into account the effects of import penetration affects our estimate of the slope of the Phillips curve, note that according to (29) this slope in period t is given by $\frac{\partial \pi_{r,t}}{\partial u_{r,t-1}} = \delta + \tau \times IP_{r,t-1}$. Hence, according to column (1) of Table 2, we have that the slope of state r's Phillips curve in period t is given by $\kappa_{r,t} = -0.56 + 0.40\times$ each 0.1 ppt. of $IP_{r,t-1}$. For instance, for the typical state, import penetration increased by roughly 0.1 ppt. over our time period. Assuming for simplicity that a hypothetical state started at an import penetration rate of 0, then we would obtain that the slope of the (non-housing) Phillips curve for this hypothetical state would start out at -0.56 and reach -0.16 by the end of our sample period. In addition, suppose this increased import penetration occurred entirely over a single year. Then, the coefficient on the change in import penetration would imply that (non-housing) inflation in that year would be 2.07 ppt. lower due to the increased imports[10].

Table 3: Import Penetration and Rent-Inflation: OLS Estimates 1986-2017

Dependent variable: Rent-inflation rate in the fourth quarter (Q4/Q4 in % pts)

	(1)	(2)
$u_{r,t-1}$	-0.18	-0.89
	(0.541)	(0.614)
$u_{r,t-1}IP_{r,t-1}$	-0.22	0.69
	(0.530)	(0.647)
$\Delta IP_{r,t}$	13.9	18.2
	(9.07)	(13.499)
$IP_{r,t-1}$		15.5***
		(5.177)
State FE	Yes	Yes
Time FE	Yes	Yes

Notes: $N = 992$. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$; standard errors are clustered by state and time.

[10]However, as is well known in the literature on identification through difference-in-difference, the time fixed effects will include any common effect of import penetration on inflation.

Table 4: Import Penetration and Rent-Inflation: IV Estimates 1986-2017

Dependent variable: Rent-inflation rate in the fourth quarter (Q4/Q4 in % pts)

	(1)	(2)
$u_{r,t-1}$	-0.65	-2.00
	(1.141)	(1.784)
$u_{r,t-1}IP_{r,t-1}$	0.18	1.45
	(1.174)	(1.834)
$\Delta IP_{r,t}$	7.48	20.0
	(15.370)	(8.597)
$IP_{r,t-1}$		26.0
		(.)
State FE	Yes	Yes
Time FE	Yes	Yes

Notes: $N = 992$. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$; standard errors are clustered by state and time.

Since the historical CPI data provided by Hazell et al. (2022) cover only non-housing, we have to separately consider rent Phillips curves using the additional rent data we gathered. Table 3 provides the OLS regression results for the rent Phillips curve, while Table 4 reports IV results for the rent regressions. For the OLS results, only the second column of Table 3 reports point estimates that continue to suggest that import exposure has flattened regional Phillips curves, although the coefficients are generally not statistically significant. Although the point estimates from columns 1 and 2 of the IV results suggest a Phillips curve relationship that flattened due to trade, none of those estimates are statistically significant either.

In summary, our estimation results find that greater trade openness is associated with flatter Phillips curves for non-housing inflation. In the next section we investigate how our estimates of regional Phillips curves inform our understanding of the evolution of the national Phillips curve.

5 The Effects of Globalization: The Slope of the Aggregate Phillips Curve and "Missing (dis)inflation"

Given our regression results, we can rely on some further assumptions to recover a national Phillips curve. First, in the spirit of Hazell et al. (2022), we adjust the estimated coefficients of our preferred estimates for the persistence of those terms using AR(1) assumptions[11]. Second, we take a weighted

[11] We assume $\beta = 0.95$ and estimate AR(1) coefficients of 0.75 for the state unemployment rate from 1986-2017, 0.70 from 1977-1990, 0.76 from 1986-1999, and 0.62 from 2003-2017. We estimate an AR(1) coefficient of 0.77 for the

average of these adjusted state Phillips curve slopes, where the weights are 0.6 for non-housing CPI and 0.4 for rent. Finally, we weight each state's Phillips curve slope by it's share in national GDP in 1997 to get the national Phillips curve.

First, we compute the national Phillips curve slopes implied by the early- and late-period subsample IV estimates that allow for different coefficients depending on the degree of openness across states. More specifically, we find the median import penetration, $IP_{r,t}$, and split the set of states in each year depending on their import penetration relative to the median. Hence, we obtain two sets of states, the more- and less-import-exposed states. Columns 2 and 3 from each of the Tables 5 and 8), and columns 2 and 3 from each of the Tables 6 and 7) present these results across time periods and state-types.

Table 5: Non-Housing Phillips Curve: OLS and IV estimates 1977-1990

Dependent variable: Non-housing CPI annual inflation rate in the fourth quarter (Q4/Q4 in % pts)

	(1)	(2)	(3)
$u_{r,t-1}$ from OLS	-0.14**	-0.03	-0.33***
	(0.055)	(0.087)	(0.079)
$u_{r,t-1}$ from IV	-0.49***	-0.53*	-0.39**
	(0.150)	(0.282)	(0.140)
State sample	All states	Less exposed states	More exposed states
State FE	Yes	Yes	Yes
Time FE	Yes	Yes	Yes
N	231	129	102

Notes: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$; standard errors are clustered by state and time.

interaction between lagged state unemployment and the level of import penetration from 1986-2017. We estimate an AR(1) coefficient of -0.11 for the change in import penetration from 1986-2017

Table 6: Rent Phillips Curve: OLS and IV estimates 1986-1999

Dependent variable: Rent inflation in the fourth quarter (Q4/Q4 in % pts)

	(1)	(2)	(3)
$u_{r,t-1}$ from OLS	-0.56	-0.84**	0.14
	(0.348)	(0.289)	(0.462)
$u_{r,t-1}$ from IV	-1.25**	-1.49***	-0.36
	(0.464)	(0.412)	(0.457)
State sample	All states	Less exposed states	More exposed states
State FE	Yes	Yes	Yes
Time FE	Yes	Yes	Yes
N	434	224	210

Notes: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$; standard errors are clustered by state and time.

Table 7: Non-Housing Phillips Curve: OLS and IV estimates 2003-2017

Dependent variable: Non-housing CPI annual inflation rate in the fourth quarter (Q4/Q4 in % pts)

	(1)	(2)	(3)
$u_{r,t-1}$ from OLS	-0.06	-0.03	-0.06
	(0.086)	(0.098)	(0.117)
$u_{r,t-1}$ from IV	-0.01	0.01	-0.00
	(0.071)	(0.047)	(0.160)
State sample	All states	Less exposed states	More exposed states
State FE	Yes	Yes	Yes
Time FE	Yes	Yes	Yes
N	450	225	225

Notes: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$; standard errors are clustered by state and time.

Table 8: Rent Phillips Curve: OLS and IV estimates 2003-2017

Dependent variable: Rent inflation in the fourth quarter (Q4/Q4 in % pts)

	(1)	(2)	(3)
$u_{r,t-1}$ from OLS	-0.01	-0.13	0.10
	(0.328)	(0.438)	(0.274)
$u_{r,t-1}$ from IV	-0.20	-0.38	-0.09
	(.)	(0.279)	(0.330)
State sample	All states	Less exposed states	More exposed states
State FE	Yes	Yes	Yes
Time FE	Yes	Yes	Yes
N	465	240	225

Notes: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$; standard errors are clustered by state and time.

Next, we construct the national Phillips curve slope in each year that is implied by our estimates of the effect of trade. Specifically, for the non-housing results, we use the IV results from the first column of Table 2 [12]. Since we don't find a clear impact of trade on the slope of the rent Phillips curve, we use the constant point estimate from the IV regression that doesn't include any trade terms for the rent Phillips curve slope (column 1 of Table 9).

Table 9: Rent Phillips Curve: OLS and IV estimates 1986-2017

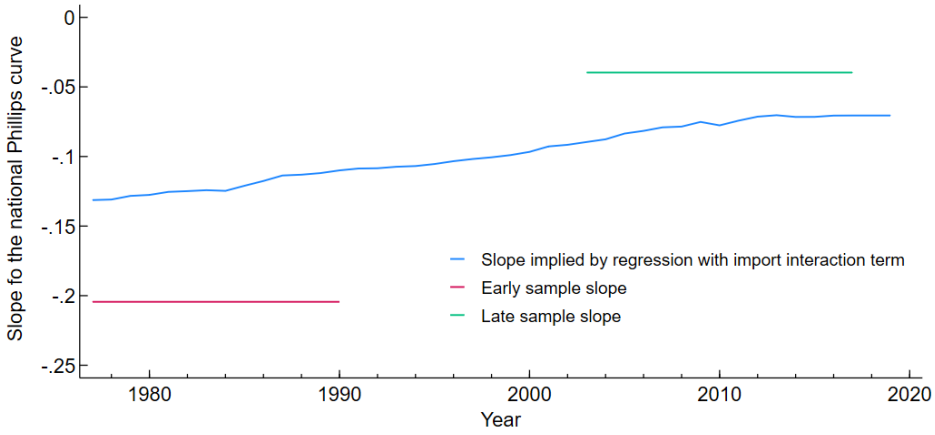
Dependent variable: Rent inflation in the fourth quarter (Q4/Q4 in % pts)

	(1)	(2)	(3)
$u_{r,t-1}$ from OLS	-0.36*	-0.55**	0.00
	(0.207)	(0.213)	(0.199)
$u_{r,t-1}$ from IV	-0.47***	-0.73***	-0.14
	(0.070)	(0.193)	(0.222)
State sample	All states	Less exposed states	More exposed states
State FE	Yes	Yes	Yes
Time FE	Yes	Yes	Yes
N	992	512	480

Notes: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$; standard errors are clustered by state and time.

[12] Note that while maintaining the same estimation period as the rent regression constrained us to an estimation sample starting in the mid 1980s, we can use our estimated coefficients to recover the Phillips curve slope going back to the late 1970s given available trade data.

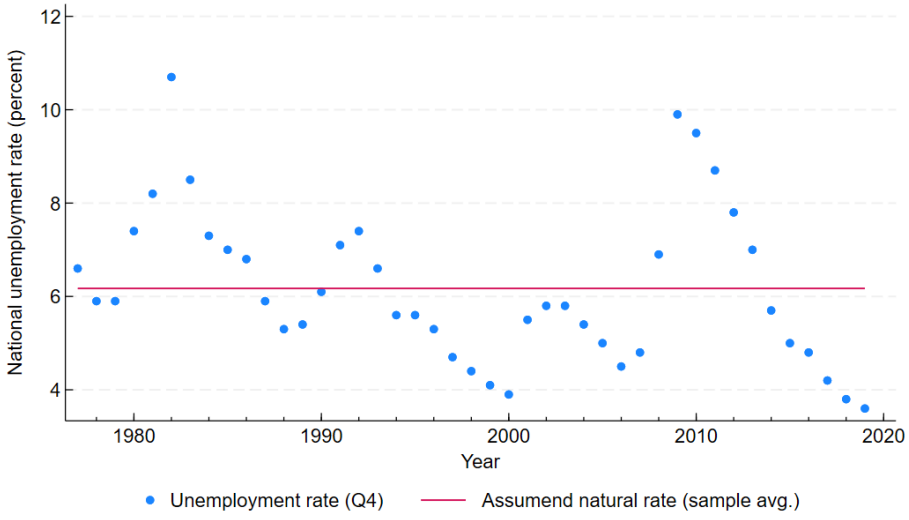
Figure 5: Evolution of the National Phillips Curve Slope Coefficient



The evolution of the slope coefficient of our national Phillips curve can be observed in Figure 5. The slope is expressed in terms of the ratio of annual total CPI inflation (Q4/Q4) in percentage points to the prior year's unemployment rate in percentage points. We estimate that the slope of the Phillips curve declined from about -0.20 in 1977-1990 (the red line) to about -0.04 in 2003-2017 (the green line). Our regression results that include the import interaction term imply a national Phillips curve slope of -0.13 in 1977 that declines to about -0.07 in 2017. This flattening of the Phillips curve due to trade is coming entirely from a flattening of the non-housing inflation Phillips curve. We interpret these results as showing that the increased exposure of the U.S. economy to imports explains a bit less than 40 percent of the flattening of the U.S. Phillips curve that we estimate occurred over the 1977-2017 period.

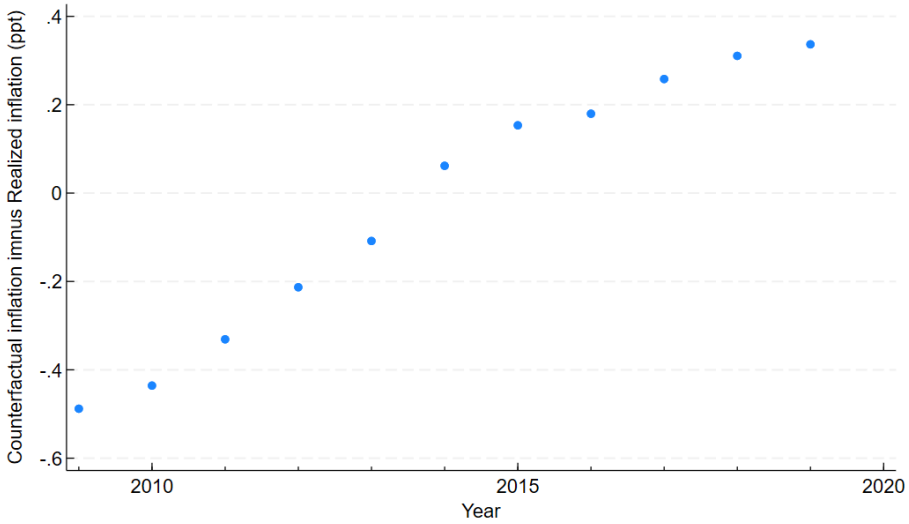
We can compute a simple counterfactual in order to demonstrate the quantitative effect of our estimated decline in the national Phillips curve slope due to trade. Given an estimate of the national unemployment gap over time, we can compute the effect on inflation if the Phillips curve slope hadn't flattened from exposure to trade. For simplicity, we assume the natural rate of unemployment is constant and equal to the sample average of national unemployment from 1977 to 2019, as shown in Figure 6. Using this estimated natural rate of unemployment, we can compute the unemployment gap as the difference between the unemployment rate and this natural rate.

Figure 6: National unemployment



With an estimated unemployment gap in hand, we can compute a simple counterfactual where we hold trade fixed at its 1977 level, and thus the Phillips curve slope doesn't flatten due to trade. The difference between counterfactual inflation and realized inflation in any year, holding all else equal, is just a function of the change in the Phillips curve slope due to trade multiplied by the unemployment gap in that year. The results of this calculation can be seen in Figure 7.

Figure 7: Counterfactual: If Phillips curve hadn't flattened due to trade



The results of this counterfactual are as follows. If the national Phillips curve had not flattened due to trade, then annual headline CPI inflation (Q4/Q4) would have been around 0.5 percentage points lower at the height of the Great Recession, and inflation would have been higher by around

0.3 percentage points in the years just before the global pandemic.

6 Conclusions

We develop a New Keynesian model of an open economy composed of multiple regions that delivers structural equations for regional Phillips curves with slopes that depend on regions' exposure to trade. In line with our model, we construct a new measure of state exposure to international trade in final consumption goods. We exploit variation in this measure across U.S. states to estimate regional Phillips curves.

Our analysis finds that the greater integration of the U.S. economy with the rest of the world contributed to a flattening of state-level Phillips curves over the past four decades. Overall, we estimate that the slope of the national Phillips curve declined from about -0.20 in 1977-1990 to about -0.04 in 2003-2017. We find that about 40 percent of this decline is accounted for by increased exposure to imports.

We use simple counterfactual exercises to study the effect of trade on U.S. inflation dynamics. We find that if the national Phillips curve had not flattened due to trade, then annual inflation would have been about 0.5 percentage points lower at the height of the Great Recession, and inflation would have been higher by about 0.3 percentage points annually in the years just before the global pandemic.

This flattening of the Phillips curve due to trade is a structural change in the U.S. economy that is quantitatively relevant for the conduct of monetary policy. However, the rapid growth in trade between the United States and the rest of the world that occurred over the previous four decades stalled around the late 2000s. Indeed, it's possible that changes in government policies or firm behavior in the coming years could lead to declining openness of the U.S. economy. Our results suggest that a large change in the openness of the U.S. economy would have important effects on the dynamics of U.S. inflation.

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Appendix A Problem of a Firm Resetting Its Price

Nominal profits by firm i in period t are given by

$$\begin{aligned}\Pi_{rt}(i) &= P_{H,rt}(i) Y_{rt}(i) - W_{rt} N_{rt}(i) \\ &= P_{H,rt}(i) Y_{rt}(i) - MC_{rt} P_{H,rt} Y_{rt}(i)\end{aligned}$$

where the second equality follows from our definition of real marginal cost, $MC_{rt} \equiv \frac{W_{rt}}{P_{H,rt} A_{rt}}$. Hence, a firm resetting its price in period t will solve

$$\max_{P_{H,rt}(i)} \sum_{k=0}^{\infty} \theta^k \mathbb{E}_t \left[Q_{t,t+k} \Pi_{rt+k}(i) \right]$$

subject to

$$Y_{rt}(i) = \left(\frac{P_{H,rt}(i)}{P_{H,rt}} \right)^{-\varepsilon} Y_{H,rt}.$$

Substituting the last constraint into $\Pi_{rt+k}(i)$ for any $k > 0$ and differentiating with respect to $P_{H,rt}(i)$ delivers:

$$\begin{aligned}\frac{\partial \Pi_{rt+k}(i)}{\partial P_{H,rt}(i)} &= P_{H,rt+k} Y_{H,rt+k} \frac{\partial}{\partial P_{H,rt}(i)} \left[\frac{P_{H,rt}(i)}{P_{H,rt+k}} \left(\frac{P_{H,rt}(i)}{P_{H,rt+k}} \right)^{-\varepsilon} - MC_{rt+k} \left(\frac{P_{H,rt}(i)}{P_{H,rt+k}} \right)^{-\varepsilon} \right] \\ &= Y_{H,rt+k} \left[(1-\varepsilon) \left(\frac{P_{H,rt}(i)}{P_{H,rt+k}} \right)^{-\varepsilon} + \varepsilon MC_{rt+k} \frac{P_{H,rt+k}}{P_{H,rt}(i)} \left(\frac{P_{H,rt}(i)}{P_{H,rt+k}} \right)^{-\varepsilon} \right] \\ &= P_{H,rt}(i)^{-\varepsilon-1} Y_{H,rt+k} \left[(1-\varepsilon) P_{H,rt+k}^{\varepsilon} P_{H,rt}(i) + \varepsilon MC_{rt+k} P_{H,rt+k}^{1+\varepsilon} \right].\end{aligned}$$

Hence, we have that the first order conditions of a firm resetting prices are given by:

$$\begin{aligned}&\sum_{k=0}^{\infty} \theta^k \mathbb{E}_t \left[Q_{t,t+k} \frac{\partial \Pi_{rt+k}(i)}{\partial P_{H,rt}(i)} \right] \\ =&\sum_{k=0}^{\infty} \theta^k \mathbb{E}_t \left[Q_{t,t+k} P_{H,rt}(i)^{-\varepsilon-1} Y_{H,rt+k} \left\{ (1-\varepsilon) P_{H,rt+k}^{\varepsilon} P_{H,rt}(i) + \varepsilon MC_{rt+k} P_{H,rt+k}^{1+\varepsilon} \right\} \right] = 0,\end{aligned}$$

which implies that the optimal price must be such that

$$\sum_{k=0}^{\infty} (\theta\beta)^k \mathbb{E}_t \left[\frac{U'(C_{rt+k})}{P_{rt+k}} Y_{H,rt+k} \left\{ (1-\varepsilon) P_{H,rt+k}^{\varepsilon} P_{H,rt}(i) + \varepsilon MC_{rt+k} P_{H,rt+k}^{1+\varepsilon} \right\} \right] = 0 \qquad \text{(A.32)}$$

where we have used the fact that $Q_{t,t+k} = \beta^k \frac{U'(C_{rt+k})}{U'(C_{rt})} \frac{P_{rt}}{P_{rt+k}}$.

Solving (A.32) for $P_{H,rt}(i)$ delivers the expression for the optimal price in (19). Note that all

firms resetting prices at t in region r will set the same price. Call this price $P^R_{H,rt}$, and note that $P^R_{H,rt} = \frac{\varepsilon}{\varepsilon-1}\frac{G^1_{rt}}{G^2_{rt}}$ where

$$\begin{aligned} G^1_{rt} &= \sum_{k=0}^{\infty} (\theta\beta)^k \mathbb{E}_t \left\{ \frac{U'(C_{rt+k})}{P_{rt+k}} MC_{rt+k} P^{1+\varepsilon}_{H,rt+k} Y_{H,rt+k} \right\} \\ &= \frac{U'(C_{rt})}{P_{rt}} MC_{rt} P^{1+\varepsilon}_{H,rt} Y_{H,rt+k} + \theta\beta \mathbb{E}_t \left\{ G^1_{rt+1} \right\} \end{aligned}$$

and

$$\begin{aligned} G^2_{rt} &= \sum_{k=0}^{\infty} (\theta\beta)^k \mathbb{E}_t \left\{ \frac{U'(C_{rt+k})}{P_{rt+k}} P^{\varepsilon}_{H,rt+k} Y_{H,rt+k} \right\} \\ &= \frac{U'(C_{rt})}{P_{rt}} P^{\varepsilon}_{H,rt} Y_{H,rt+k} + \theta\beta \mathbb{E}_t \left\{ G^2_{rt+1} \right\}. \end{aligned}$$

Define the following auxiliary variables, $g^1_{rt} \equiv \frac{G^1_{rt}}{P^{1+\varepsilon}_{H,rt}}$ and $g^2_{rt} \equiv \frac{G^2_{rt}}{P^{\varepsilon}_{H,rt}}$, and note that

$$\begin{aligned} g^1_{rt} &= \frac{U'(C_{rt})}{P_{rt}} MC_{rt} Y_{H,rt+k} + \theta\beta \mathbb{E}_t \left\{ g^1_{rt+1} (1+\pi_{H,rt+1})^{1+\varepsilon} \right\}, \\ g^2_{rt} &= \frac{U'(C_{rt})}{P_{rt}} Y_{H,rt+k} + \theta\beta \mathbb{E}_t \left\{ g^2_{rt+1} (1+\pi_{H,rt+1})^{\varepsilon} \right\}, \\ \frac{G^1_{rt}}{G^2_{rt}} &= P_{H,rt} \frac{g^1_{rt}}{g^2_{rt}}. \end{aligned}$$

Hence, we can write the reset price as

$$P^R_{H,rt} = \frac{\varepsilon}{\varepsilon - 1} P_{H,rt} \frac{g^1_{rt}}{g^2_{rt}},$$

which implies that

$$\left(1 + \pi^R_{H,rt}\right) = \frac{\varepsilon}{\varepsilon - 1} \left(1 + \pi_{H,rt}\right) \frac{g^1_{rt}}{g^2_{rt}} \tag{A.33}$$

where $\pi^R_{H,rt} \equiv \frac{P^R_{H,rt}}{P_{H,rt-1}} - 1$ and $\pi_{H,rt} \equiv \frac{P_{H,rt}}{P_{H,rt-1}}$. Moreover, because of our Calvo assumption, we have that reset prices and domestic prices are related by the following equation,

$$P^{1-\varepsilon}_{H,rt} = (1-\theta) P^{R}_{H,rt} + \theta P^{1-\varepsilon}_{H,rt-1},$$

which implies that

$$(1+\pi_{H,rt})^{1-\varepsilon} = (1-\theta)\left(1+\pi^R_{H,rt}\right)^{1-\varepsilon} + \theta. \tag{A.34}$$

Log-linearizing equations (A.33 and (A.34), we obtain

$$\widetilde{\pi}_{H,rt}^{R} = \widetilde{\pi}_{H,rt} + \widetilde{g}_{rt}^{1} - \widetilde{g}_{rt}^{2},$$
$$\widetilde{\pi}_{H,rt}^{R} = \frac{\widetilde{\pi}_{H,rt}}{1-\theta}.$$

implying that

$$\widetilde{\pi}_{H,rt} = \frac{1-\theta}{\theta}\left(\widetilde{g}_{rt}^{1} - \widetilde{g}_{rt}^{2}\right)$$

where $\widetilde{\pi}_{H,rt}^{R} \equiv \pi_{H,rt}^{R} - \pi_{H,r}^{R}$, $\widetilde{\pi}_{H,rt} \equiv \pi_{H,rt} - \pi_{H,r}$, and $\tilde{g}_{rt}^{i} \equiv \log g_{rt}^{i} - \log g_{r}^{i}$ for $i = 1, 2$ denote deviations from steady state variables.

Log-linearizing the auxiliary variables around a zero inflation steady state, we obtain that

$$\widetilde{g}_{rt}^{1} = (1-\sigma)(1-\theta\beta)\,\tilde{c}_{rt} + (\eta-1)(1-\theta\beta)\,\tilde{p}_{rt} + (1-\theta\beta)\,\widetilde{mc}_{rt} + (1+\varepsilon-\eta)\,\theta\beta\mathbb{E}_t\widetilde{\pi}_{H,rt+1} + \theta\beta\mathbb{E}_t\widetilde{g}_{rt+1}^{1},$$

and similarly,

$$\widetilde{g}_{rt}^{2} = (1-\sigma)(1-\theta\beta)\,\tilde{c}_{rt} + (\eta-1)(1-\theta\beta)\,\tilde{p}_{rt} + (\varepsilon-\eta)\,\theta\beta\mathbb{E}_t\widetilde{\pi}_{H,rt+1} + \theta\beta\mathbb{E}_t\widetilde{g}_{rt+1}^{2},$$

where variables defined by small letters refer to the log of variables defined in terms of capital letters, and tilde denotes log deviations from a zero-inflation steady state. Therefore,

$$\begin{aligned}
\frac{\theta}{1-\theta}\widetilde{\pi}_{H,rt} &= \widetilde{g}_{rt}^{1} - \widetilde{g}_{rt+1}^{2} \\
&= (1-\theta\beta)\,\widetilde{mc}_{rt} + \theta\beta\mathbb{E}_t\widetilde{\pi}_{H,rt+1} + \theta\beta\mathbb{E}_t\left(\widetilde{g}_{rt+1}^{1} - \widetilde{g}_{rt+1}^{2}\right) \\
&= (1-\theta\beta)\,\widetilde{mc}_{rt} + \theta\beta\mathbb{E}_t\widetilde{\pi}_{H,rt+1} + \theta\beta\mathbb{E}_t\left(\widetilde{\pi}_{H,rt+1}^{R} - \widetilde{\pi}_{H,rt+1}\right) \\
&= (1-\theta\beta)\,\widetilde{mc}_{rt} + \theta\beta\mathbb{E}_t\widetilde{\pi}_{H,rt+1} + \theta\beta\mathbb{E}_t\left(\frac{\theta}{1-\theta}\widetilde{\pi}_{H,rt+1}\right)
\end{aligned}$$

which implies that

$$\widetilde{\pi}_{H,rt} = \frac{(1-\theta\beta)(1-\theta)}{\theta}\widetilde{mc}_{rt} + \beta\mathbb{E}_t\left[\widetilde{\pi}_{H,rt+1}\right],$$

which delivers equation (20) around a zero-inflation steady state.

Appendix B Proof of Lemma 1

Consider our definition of real marginal cost, $MC_{rt} \equiv \frac{W_{rt}}{A_{rt}P_{H,rt}}$, and note that

$$\begin{aligned} MC_{rt} &= \frac{W_{rt}}{A_{rt}P_{rt}}\frac{P_{rt}}{P_{H,rt}} \\ &= \frac{1}{A_{rt}}C_{rt}^{\sigma}N_{rt}^{\varphi}\frac{P_{rt}}{P_{H,rt}} \\ &= \frac{1}{A_{rt}}C_{rt}^{\sigma}N_{rt}^{\varphi}\left((1-\upsilon_r)+\upsilon_r S_{rt}^{1-\eta}\right)^{\frac{1}{1-\eta}} \end{aligned}$$

where the second equality follows from the intratemporal condition (13) and the third equality follows after rewriting $\frac{P_{rt}}{P_{H,rt}}$ in terms of the terms of trade, S_{rt}.

We start by rewriting C_{rt} and N_{rt} in terms of region r's output and foreign output. From the intertemporal optimality conditions (14) and the assumption of a complete international asset markets, we have that

$$\beta\left(\frac{C_{t+1}^*}{C_t^*}\right)^{-\sigma}\left(\frac{P_t^*}{P_{t+1}^*}\right)\left(\frac{\mathcal{E}_t}{\mathcal{E}_{t+1}}\right) = Q_{t,t+1},$$

and

$$\beta\left(\frac{C_{rt+1}}{C_{rt}}\right)^{-\sigma}\left(\frac{P_{rt}}{P_{rt+1}}\right) = Q_{t,t+1},$$

for every region r, implying that, under suitable normalizations, the following condition must hold for all regions r:

$$C_{rt} = C_t^*\left(Z_{rt}\right)^{\frac{1}{\sigma}}\left(Q_{rt}\right)^{\frac{1}{\sigma}} \tag{B.35}$$

for all t, where $Q_{rt} \equiv \frac{\mathcal{E}_t P_t^*}{P_{rt}} = \frac{P_{F,t}}{P_{rt}}$ denotes the real exchange rate for region r. Moreover, given our assumption of each region r being a small open economy, we have that $C_t^* = Y_t^*$ where Y_t^* denotes foreign output. Hence,

$$C_{rt} = Y_t^*\left(Z_{rt}\right)^{\frac{1}{\sigma}}\left(Q_{rt}\right)^{\frac{1}{\sigma}}.$$

Turning to N_{rt}, note that the labor market clearing condition, $N_{rt} = \int_0^1 N_{rt}(i)\,di$, and market clearing of intermediate goods produced in r imply that

$$A_{rt}\int_0^1 N_{rt}(i)\,di = A_{rt}N_{rt} = \int_0^1 \left(C_{H,rt}(i) + X_{rt}(i)\right)di = Y_{H,rt}\int_0^1\left(\frac{P_{H,rt}(i)}{P_{H,rt}}\right)^{-\varepsilon}di$$

where $Y_{H,rt} \equiv C_{H,rt} + X_{rt}$. Defining the following measure of price dispersion,

$$\varrho_{H,rt} = \int_0^1 \left(\frac{P_{H,rt}(i)}{P_{H,rt}} \right)^{-\varepsilon} di,$$

we obtain the aggregate production function for goods produced domestically in region r:

$$Y_{H,rt} = \frac{A_{rt} N_{rt}}{\varrho_{H,rt}}.$$

Hence, we can rewrite real marginal cost as

$$\begin{aligned} MC_{rt} &= \frac{1}{A_{rt}} C_{rt}^{\sigma} N_{rt}^{\varphi} \left((1-\upsilon_r) + \upsilon_r S_{rt}^{1-\eta} \right)^{\frac{1}{1-\eta}} \\ &= \frac{1}{A_{rt}} (Y_t^*)^{\sigma} Z_{rt} Q_{rt} \left(\frac{\varrho_{H,rt} Y_{H,rt}}{A_{rt}} \right)^{\varphi} \left((1-\upsilon_r) + \upsilon_r S_{rt}^{1-\eta} \right)^{\frac{1}{1-\eta}} \\ &= A_{rt}^{-(1+\varphi)} (Y_t^*)^{\sigma} Z_{rt} S_{rt} (\varrho_{H,rt} Y_{H,rt})^{\varphi}, \end{aligned} \tag{B.36}$$

where the third equality follows from the fact that the real exchange rate, $Q_{rt} \equiv \frac{P_{F,rt}}{P_{rt}}$, can be expressed as

$$Q_{rt} = S_{rt} \frac{P_{H,rt}}{P_{rt}} = S_{rt} \left((1-\upsilon_r) + \upsilon_r S_{rt}^{1-\eta} \right)^{\frac{-1}{1-\eta}}.$$

Consider now the market clearing condition for tradable intermediates. We have that:

$$\begin{aligned} Y_{H,rt} &= C_{H,rt} + X_{rt} \\ &= (1-\upsilon_r) \left(\frac{P_{H,rt}}{P_{rt}} \right)^{-\eta} C_{rt} + \frac{\upsilon^*}{I} S_{rt}^{\eta} Y_t^* \\ &= \left(\frac{P_{H,rt}}{P_{rt}} \right)^{-\eta} C_{rt} \left[(1-\upsilon_r) + \frac{\upsilon^*}{I} \left(\frac{P_{H,rt}}{P_{rt}} \right)^{\eta} S_{rt}^{\eta} \frac{Y_t^*}{C_{rt}} \right] \\ &= \left(\frac{P_{H,rt}}{P_{rt}} \right)^{-\eta} C_{rt} \left[(1-\upsilon_r) + \frac{\upsilon^*}{I} (Z_{rt})^{-\frac{1}{\sigma}} Q_{rt}^{\eta - \frac{1}{\sigma}} \right] \\ &= \left((1-\upsilon_r) + \upsilon_r S_{rt}^{1-\eta} \right)^{\frac{\eta}{1-\eta}} C_{rt} \left[(1-\upsilon_r) + \frac{\upsilon^*}{I} (Z_{rt})^{-\frac{1}{\sigma}} Q_{rt}^{\eta - \frac{1}{\sigma}} \right], \end{aligned}$$

where the second equality follows from (11) and (6), the fourth equality follows from (B.35), and the fifth equality rewrites relative prices in terms of terms of trade relying on equation (12). Define

$$\phi_r \equiv \frac{(1-\upsilon_r)}{(1-\upsilon_r) + \frac{\upsilon^*}{I}}. \tag{B.37}$$

By taking logs and relying on first order approximations, the previous market clearing condition

can be expressed as

$$\begin{aligned} y_{H,rt} &= c_{rt} + \eta \upsilon_r s_{rt} - (1-\phi_r)\frac{1}{\sigma} z_{rt} + (1-\phi_r)\left(\eta - \frac{1}{\sigma}\right) q_{rt} \\ &= c_{rt} + \eta \upsilon_r s_{rt} - (1-\phi_r)\frac{1}{\sigma} z_{rt} + (1-\phi_r)\left(\eta - \frac{1}{\sigma}\right)(1-\upsilon_r)\, s_{rt} \\ &= c_{rt} - (1-\phi_r)\frac{1}{\sigma} z_{rt} + \frac{\upsilon_r\left(\sigma\eta + (1-\upsilon_r)(\sigma\eta - 1)\left(\frac{1-\phi_r}{\upsilon_r}\right)\right)}{\sigma} s_{rt} \\ &= c_{rt} - (1-\phi_r)\frac{1}{\sigma} z_{rt} + \frac{\upsilon_r \omega}{\sigma} s_{rt} \end{aligned}$$

where

$$\omega_r \equiv \sigma\eta + (1-\upsilon_r)(\sigma\eta - 1)\left(\frac{1-\phi_r}{\upsilon_r}\right), \tag{B.38}$$

and where the second equality relies on our definition of real exchange rate, which up to a first order approximation is related to the terms of trade by

$$q_{rt} = (1-\upsilon_r)\, s_{rt}. \tag{B.39}$$

Combining the previous equation with condition (B.35), which in logs is given by

$$c_{rt} = y_t^* + \frac{1}{\sigma} z_{rt} + \frac{1}{\sigma} q_{rt},$$

and with equation (B.39), we obtain that

$$\begin{aligned} y_{H,rt} &= c_{rt} - (1-\phi_r)\frac{1}{\sigma} z_{rt} + \frac{\upsilon_r \omega_r}{\sigma} s_{rt} \\ &= y_t^* + \frac{1}{\sigma} z_{rt} + \frac{1}{\sigma} q_{rt} - (1-\phi_r)\frac{1}{\sigma} z_{rt} + \frac{\upsilon_r \omega_r}{\sigma} s_{rt} \\ &= y_t^* + \frac{\phi_r}{\sigma} z_{rt} + \frac{(1-\upsilon_r) + \upsilon_r \omega_r}{\sigma} s_{rt}. \end{aligned}$$

Hence, we can express the terms of trade in terms of outputs and demand shocks:

$$s_{rt} = \sigma_r^{\upsilon}\left(y_{rt} - y_t^*\right) - \sigma_r^{\upsilon}\frac{\phi_r}{\sigma} z_{rt}, \tag{B.40}$$

where we have defined $y_{rt} \equiv y_{H,rt}$ to simplify notation, and

$$\sigma_r^{\upsilon} \equiv \frac{\sigma}{(1-\upsilon_r) + \upsilon_r \omega_r}. \tag{B.41}$$

Going back to the expression for real marginal cost, equation (B.36), in terms of logs where

$mc_{rt} = \log MC_{rt}$, this equation is given by

$$mc_{rt} = \sigma y_t^* + \varphi y_{rt} + z_{rt} - (1+\varphi)\, a_{rt} + s_{rt},$$

where we have used the fact that $\log[\varrho_{H,rt}] \approx 0$ up to a first order approximation. Substituting (B.40) into this last expression we get that

$$\begin{aligned} mc_{H,rt} &= \sigma y_t^* + \varphi y_{rt} + z_{rt} - (1+\varphi)\, a_{rt} + s_{rt} \\ &= \sigma y_t^* + \varphi y_{rt} + z_{rt} - (1+\varphi)\, a_{rt} + \sigma_r^{\upsilon}\,(y_{rt} - y_t^*) - \sigma_r^{\upsilon}\frac{\phi_r}{\sigma} z_{rt} \\ &= (\sigma - \sigma_r^{\upsilon})\, y_t^* + (\varphi + \sigma_r^{\upsilon})\, y_{rt} - (1+\varphi)\, a_{rt} + \left(1 - \sigma_r^{\upsilon}\frac{\phi_r}{\sigma}\right) z_{rt}. \end{aligned}$$

Let $x_{rt} = y_{rt} - y_{rt}^n$ denote output deviations from its natural level. Note that y_{rt}^n must be such that $mc_{rt} = -\log\frac{\varepsilon}{\varepsilon-1}$. Let $\mu \equiv \log\frac{\varepsilon}{\varepsilon-1}$. Then, the natural level of output must be such that

$$(\varphi + \sigma_r^{\upsilon})\, y_{rt}^n = -\mu - (\sigma - \sigma_r^{\upsilon})\, y_t^* - \left(1 - \sigma_r^{\upsilon}\frac{\phi_r}{\sigma}\right) z_{rt} + (1+\varphi)\, a_{rt},$$

implying that

$$\begin{aligned} y_{rt}^n &= \frac{-\mu}{\varphi + \sigma_r^{\upsilon}} - \left(\frac{\sigma - \sigma_r^{\upsilon}}{\varphi + \sigma_r^{\upsilon}}\right) y_t^* - \frac{1 - \sigma_r^{\upsilon}\frac{\phi_r}{\sigma}}{\varphi + \sigma_r^{\upsilon}} z_{rt} + \frac{1+\varphi}{\varphi + \sigma_{\upsilon}} a_{rt} \\ &= \frac{-\mu}{\varphi + \sigma_{\upsilon}} + \frac{1+\varphi}{\varphi + \sigma_{\upsilon}} a_{rt} + \frac{\sigma_{\upsilon} - \sigma}{\varphi + \sigma_{\upsilon}} y_t^* - \frac{1 - \sigma_r^{\upsilon}\frac{\phi_r}{\sigma}}{\varphi + \sigma_{\upsilon}} z_{rt}, \end{aligned}$$

which delivers the expression for the natural level of output. Moreover, note that

$$\begin{aligned} mc_{rt} - mc_r &= \left((\sigma - \sigma_{\upsilon})\, y_t^* + (\varphi + \sigma_{\upsilon})\, y_{rt} - (1+\varphi)\, a_{rt} + \left(1 - \sigma_r^{\upsilon}\frac{\phi_r}{\sigma}\right) z_{rt}\right) \\ &\quad - \left((\sigma - \sigma_{\upsilon})\, y_t^* + (\varphi + \sigma_{\upsilon})\, y_{rt}^n - (1+\varphi)\, a_{rt} + \left(1 - \sigma_r^{\upsilon}\frac{\phi_r}{\sigma}\right) z_{rt}\right) \\ &= (\varphi + \sigma_{\upsilon})\, x_{rt}, \end{aligned}$$

and that

$$\begin{aligned} x_{rt} &= y_{rt} - y_{rt}^n \\ &= a_{rt} + n_{rt} - \log(\varrho_{H,rt}) - (a_{rt} + n_{rt}^n) \\ &= n_t - \log(\varrho_{H,rt}) - n_t^n \\ &= -(u_{rt} - u_{rt}^n) \end{aligned}$$

Let us consider $\frac{d}{d\upsilon_r}\left[(1-\upsilon_r)+\upsilon_r\omega_r\right] = -1+\left(\omega_r+\upsilon_r\frac{d\omega_r}{d\upsilon_r}\right)$. Start with

$$\begin{aligned}
\upsilon_r\frac{d\omega_r}{d\upsilon_r} &= \upsilon_r\frac{d}{d\upsilon_r}\left[\sigma\eta+(\sigma\eta-1)(1-\phi_r)\left(\frac{1-\phi_r}{\upsilon_r}\right)\right] \\
&= \upsilon_r(\sigma\eta-1)\left[-\frac{d\phi_r}{d\upsilon_r}\left(\frac{1-\phi_r}{\upsilon_r}\right)+(1-\phi_r)\left(\frac{-\frac{d\phi_r}{d\upsilon_r}\upsilon_r-(1-\phi_r)}{\upsilon_r^2}\right)\right] \\
&= (\sigma\eta-1)\left[-\frac{d\phi_r}{d\upsilon_r}(1-\phi_r)+(1-\phi_r)\left(-\frac{d\phi_r}{d\upsilon_r}-\frac{(1-\phi_r)}{\upsilon_r}\right)\right] \\
&= (\sigma\eta-1)\left[-2\frac{d\phi_r}{d\upsilon_r}(1-\phi_r)-\frac{(1-\phi_r)^2}{\upsilon_r}\right] \\
&= -(\sigma\eta-1)\left[2\frac{d\phi_r}{d\upsilon_r}(1-\phi_r)+\frac{(1-\phi_r)^2}{\upsilon_r}\right]
\end{aligned}$$

In addition,

$$\begin{aligned}
\frac{d\phi_r}{d\upsilon_r} &= \frac{d}{d\upsilon_r}\left[\frac{(1-\upsilon_r)}{(1-\upsilon_r)+\frac{\upsilon^*}{I}}\right] \\
&= \frac{-\left((1-\upsilon_r)+\frac{\upsilon^*}{I}\right)+(1-\upsilon_r)}{\left((1-\upsilon_r)+\frac{\upsilon^*}{I}\right)^2} \\
&= \phi_r\frac{1-\left(1+\frac{\upsilon^*}{(1-\upsilon_r)I}\right)}{(1-\upsilon_r)+\frac{\upsilon^*}{I}} \\
&= \phi_r\frac{\frac{\upsilon^*}{(1-\upsilon_r)I}}{(1-\upsilon_r)+\frac{\upsilon^*}{I}} \\
&= \frac{\phi_r(1-\phi_r)}{(1-\upsilon_r)}
\end{aligned}$$

Hence,

$$\begin{aligned}
\upsilon_r\frac{d\omega_r}{d\upsilon_r} &= -(\sigma\eta-1)\left[2\frac{d\phi_r}{d\upsilon_r}(1-\phi_r)+\frac{(1-\phi_r)^2}{\upsilon_r}\right] \\
&= -(\sigma\eta-1)\left[2\frac{\phi_r(1-\phi_r)^2}{(1-\upsilon_r)}+\frac{(1-\phi_r)^2}{\upsilon_r}\right] \\
&= -(\sigma\eta-1)(1-\phi_r)^2\left[2\frac{\phi_r}{(1-\upsilon_r)}+\frac{1}{\upsilon_r}\right]
\end{aligned}$$

and

$$\begin{aligned}\frac{d}{d\upsilon_r}\left[(1-\upsilon_r)+\upsilon_r\omega_r\right] &= -1+\left(\omega_r+\upsilon_r\frac{d\omega_r}{d\upsilon_r}\right)\\ &= \sigma\eta+(\sigma\eta-1)(1-\phi_r)\left(\frac{1-\phi_r}{\upsilon_r}\right)-(\sigma\eta-1)(1-\phi_r)^2\left[2\frac{\phi_r}{(1-\upsilon_r)}+\frac{1}{\upsilon_r}\right]-1\\ &= \sigma\eta+(\sigma\eta-1)\left((1-\phi_r)\left(\frac{1-\phi_r}{\upsilon_r}\right)-(1-\phi_r)^2\left[2\frac{\phi_r}{(1-\upsilon_r)}+\frac{1}{\upsilon_r}\right]\right)-1\\ &= \sigma\eta+(\sigma\eta-1)(1-\phi_r)^2\left(\frac{1}{\upsilon_r}-\left[2\frac{\phi_r}{(1-\upsilon_r)}+\frac{1}{\upsilon_r}\right]\right)-1\\ &= \sigma\eta-(\sigma\eta-1)(1-\phi_r)^2\left(\frac{2\phi_r}{(1-\upsilon_r)}\right)-1\end{aligned}$$

Hence,

$$\sigma\eta\left(1-(1-\phi_r)^2\left(\frac{2\phi_r}{(1-\upsilon_r)}\right)\right)>1-(1-\phi_r)^2\left(\frac{2\phi_r}{(1-\upsilon_r)}\right)$$

which implies that $\sigma\eta>1$ as long as the following holds:

$$\frac{1}{2}>(1-\phi_r)^2\left(\frac{\phi_r}{(1-\upsilon_r)}\right)$$

Consider the case in which $\frac{\upsilon^*}{I}=\upsilon_r$. Then $\phi_r=1-\upsilon_r$ and we require that $\upsilon_r=\frac{\upsilon^*}{I}<\sqrt{\frac{1}{2}}$, which is a reasonable assumption in the data. Now, note that for $\frac{\upsilon^*}{I}\to 1$, we have that

$$\phi_r=\frac{1-\upsilon_r}{2-\upsilon_r}, 1-\phi_r=\frac{1}{2-\upsilon_r}$$

and

$$(1-\phi_r)^2\left(\frac{\phi_r}{(1-\upsilon_r)}\right)=\frac{1}{(2-\upsilon_r)^3}>\frac{1}{2}$$

or

$$\upsilon_r>2-2^{\frac{1}{3}}=0.740\,08$$

If $\frac{\upsilon^*}{I}\to 0$, we have that $\phi_r=1$, $1-\phi_r=0$ and the condition always holds.

Appendix C A Model with Multiple Sectors

TBD

Appendix D A Model with Trade across Regions

Consider the case in which regions can trade with each other. Then, aggregate consumption in region r is given by

$$C_{rt} \equiv \left((1-\upsilon_r)\, C_{L,rt}^{\frac{\eta-1}{\eta}} + \upsilon_r C_{F,rt}^{\frac{\eta-1}{\eta}} \right)^{\frac{\eta}{\eta-1}}$$

where

$$C_{L,rt} \equiv \left(\sum_{u=1}^{I} \left(\frac{1}{I}\right)^{\frac{1}{\gamma}} C_{ru,t}^{\frac{\gamma-1}{\gamma}} \right)^{\frac{\gamma}{\gamma-1}},$$

represents an aggregate of consumption produced across different regions in the home country and

$$C_{rut} = \left(\int_0^1 C_{rut}\,(i)^{\frac{\varepsilon-1}{\varepsilon}}\, di \right)^{\frac{\varepsilon}{\varepsilon-1}}.$$

is consumption of goods produced abroad. Hence, γ provides us with a measure of the trade elasticity in this model.

Following similar steps as in Appendix B, it can be shown that in this model

$$\sigma_r^{\upsilon} \equiv \frac{\sigma}{(1-\upsilon_r) + \upsilon_r \left[\sigma\eta + (1-\upsilon_r)(\sigma\eta - 1)\frac{1-\phi_{L,r}}{\upsilon_r} \right]},$$

where

$$\phi_{L,r} \equiv \frac{\sum_{u=1}^{I} \frac{(1-\upsilon_u)^2}{(1-\upsilon_r)}}{\sum_{u=1}^{I} (1-\upsilon_u) + \upsilon^*}$$

. Hence, there are simple and reasonable conditions on parameters that ensure that mode open regions have flatter Phillips curves.

Appendix E A Multi-region Model with Flexible Prices and Imperfect Competition

Here we propose a multi-sector model of the U.S. economy with flexible prices and imperfect competition. The United States is assumed to be a small open economy composed of multiple regions indexed by r, each composed of J sectors that we index by j. Each sector is composed of multiple industries in which local and foreign firms compete in supplying differentiated goods. We denote by $\mathcal{R}$ the set of regions in the United States and by F the foreign region. Hence, the

universe of regions in the model is given by $\mathcal{R} \cup \{F\}$.

There are two factors of production, labor and capital, both perfectly mobile across firms, but perfectly immobile across regions. In what follows, we follow the environments of Atkeson and Burstein (2008) and Heise et al. (2020) closely, but extend these frameworks to multiple regions. Each sector consists of a unit continuum of industries.

Competitive firms in sector j of region r produce by aggregating the output of a continuum of industries $i \in [1, 0]$ according to

$$Y_{rj,t} = \left(\int_0^1 Y_{rj,t}(i)^{\frac{\eta-1}{\eta}} di \right)^{\frac{\eta}{\eta-1}}. \tag{E.42}$$

Each industry i is populated by a finite number of firms, $N_{rj,t}(i)$, supplying differentiated varieties indexed by k. These firms can be located in any region r or abroad.[13] Industries aggregate firm-specific varieties according to

$$Y_{rj,t}(i) = \left(\sum_{k=1}^{N_{rj,t}(i)} Y_{rj,t}(i,k)^{\frac{\sigma}{\sigma-1}} \right)^{\frac{\sigma-1}{\sigma}}, \tag{E.43}$$

and we assume that the technology available to firms is Cobb-Douglas in labor and capital. Hence, we can express the marginal cost of the firm producing $Y_{rj,t}(i,k)$ as

$$MC_{rj,t}(i,k) = \frac{\left(W_{\tilde{r}(k),t}\right)^{1-\alpha} \left(U_{\tilde{r}(k),t}\right)^{\alpha}}{A_{j,t}(i,k)}, \tag{E.44}$$

where $\tilde{r}(k) \in (\mathcal{R} \cup \{F\})$ is the region where firm k is located, $W_{\tilde{r}(k),t}$ are wages, and $U_{\tilde{r}(k),t}$ is the rental cost of capital. We will focus on the case of perfectly flexible prices and will ignore the time index t to simplify notation.[14] To keep the model as tractable and parsimonious as possible, we make the following assumption.[15]

Assumption 1. *Domestic firms can only sell goods in the region where they are located (no regional trade). Firms within a region and sector are homogeneous in terms of productivity (equal market shares).*

Assumption 2. *Firms within a region and sector are homogeneous in terms of productivity (equal market shares).*

[13] We will make specific assumptions about firms supplying in each region later.

[14] The model can be easily extended to a fully dynamic framework with nominal rigidities. In such environment, we can derive fully specified regional Phillips curves as in Hazell et al. (2022) or Beraja et al. (2019) (for wages). These extensions is currently work in progress.

[15] We have derived a version of the model without imposing this assumption. In that version, there are spillovers from changes in prices across regions. We choose not to do this because of data availability.

Given assumptions 1 and 2, we can derive an expression for prices in industry i. More specifically, we can can split the total number of firms $N_{rj}(i)$ into local firms, $\mathcal{N}_{rj}^{L}(i)$, and foreign firms, $\mathcal{N}_{rj}^{F}(i)$. Then, it can be shown that industry prices are such that

$$P_{rj}(i)^{1-\sigma} = \sum_{k \in \mathcal{N}_{rj}^{L}(i)} P_{rj}(i,k)^{1-\sigma} + (1 - \Lambda_{rj}(i)) P_{rj,t}(i)^{1-\sigma}. \tag{E.45}$$

must hold, where $\Lambda_{rj}(i)$ is the share of total expenditure in industry i of region r on goods produced by local firms. Hence, we obtain that log-changes in prices at the industry level are given by

$$d \log P_{rj}(i) = \sum_{k \in \mathcal{N}_{rj}^{L}(i)} \phi_{rj}(i,k)\, d \log P_{rj}(i,k) + \frac{d \log \Lambda_{rj}(i)}{\sigma - 1}. \tag{E.46}$$

where $\phi_{rj}(i,k)$ is firm k's market share.[16] To derive the previous equation, we have relied on the fact that $\Lambda_{rj}(i)$ is a sufficient statistic for changes in prices abroad, as emphasized in the international trade literature (Arkolakis et al., 2012). Note that if $\sigma > 1$, then increases in domestic expenditure shares should be positively correlated with increases in prices, as emphasized by Comin and Johnson (2020).

Let us now dig deeper into price setting by firms driving $d \log P_{rj}(i,k)$. As in Atkeson and Burstein (2008), we assume that $\sigma > \eta > 1$. Firms compete under Bertrand competition, taking as given prices chosen by other firms when setting their price and input prices. Given the finite number of firms, firms internalize the effects of its price setting on the price index $P_{rj,t}(i)$.

In every period t, firms solve

$$\max_{P} \left(P_{rj}(i,k) - MC_{rj}(i,k)\right) \left(\frac{P_{rj}(i,k)}{P_{rj}(i)}\right)^{-\sigma} \left(\frac{P_{rj}(i)}{P_{rj}}\right)^{-\eta} Y_{rj}. \tag{E.47}$$

The solution to this problem delivers optimal pricing by the firms:

$$P_{rj}(i,k) = \frac{\mathcal{E}_{rj}(i,k)}{\mathcal{E}_{rj}(i,k) - 1} MC_{rj}(i,k), \tag{E.48}$$

implying that the firm's markup is given by

$$\mu_{rj}(i,k) \equiv \frac{\mathcal{E}_{rj}(i,k)}{\mathcal{E}_{rj}(i,k) - 1}, \tag{E.49}$$

where

$$\mathcal{E}_{rj}(i,k) = \sigma - (\sigma - \eta)\phi_{rj}(i,k) = \sigma(1 - \phi_{rj}(i,k)) + \eta \phi_{rj}(i,k) \tag{E.50}$$

[16] We provide more details on this measure later in the paper.

is the elasticity of demand. From these expressions we obatin that

$$d\log P_{rj}(i,k) = d\log \mu_{rj}(i,k) - d\log A_j(i,k) + (1-\alpha)\, d\log W_{\tilde{r}(k)}. \tag{E.51}$$

where we have assumed that the cost of capital is fixed over time. Moreover, it can be shown that

$$d\log \mu_{rj}(i,k) = -\Gamma_{rj}(i,k)\left[d\log P_{rj}(i,k) - d\log P_{rj}(i)\right] \tag{E.52}$$

where

$$\Gamma_{rj}(i,k) \equiv -\frac{\partial \log \mu_{rj}(i,k)}{\partial \log P_{rj}(i,k)} \tag{E.53}$$

is the elasticity of the markup with respect to a firm's own price. Hence, we obtain the following pass-through equation

$$\begin{aligned} d\log P_{rj}(i,k) =& \frac{\Gamma_{rj}(i,k)}{1+\Gamma_{rj}(i,k)} d\log P_{rj}(i) + \frac{1-\alpha}{1+\Gamma_{rj}(i,k)} d\log W_{\tilde{r}(k)} \\ & - \frac{1}{1+\Gamma_{rj}(i,k)} d\log A_j(i,k)\,. \end{aligned} \tag{E.54}$$

Therefore, we obtain that the following two equations determine changes in industry-level prices:

$$d\log P_{rj}(i) = \sum_{k\in\mathcal{N}_{rj}^L(i)} \phi_{rj}(i,k)\, d\log P_{rj}(i,k) + \frac{d\log \Lambda_{rj}(i)}{\sigma-1} \quad \text{and} \tag{E.55}$$

$$\begin{aligned} d\log P_{rj}(i,k) =& \frac{\Gamma_{rj}(i,k)}{1+\Gamma_{rj}(i,k)} d\log P_{rj}(i) + \frac{1-\alpha}{1+\Gamma_{rj}(i,k)} d\log W_r \\ & - \frac{1}{1+\Gamma_{rj}(i,k)} d\log A_j(i,k)\,. \end{aligned} \tag{E.56}$$

Note that, independently of the factors driving price setting by foreign firms supplying goods in industry i of sector j in region r, changes in domestic trade shares, $d\log \Lambda_{rj}(i)$, summarize the effects on foreign prices on industry-level prices. Hence, conditional on these sufficient statistics, we can analyze the pass-through from local-level wages to prices. This is the key results and one of the main contributions of this paper. By exploiting the Armington structure of production, we can summarize the direct effect of foreign prices on domestic prices using trade shares.[17]

At this stage of our analysis, we see no point in making particular assumptions about real rigidities in our model. Instead, we choose to make a simple reduced form assumption regarding the relationship between real wages and output—and therefore unemployment—in our model.

Assumption 3. *Log deviations from optimal pricing by homogeneous firms (flexible prices and no*

[17] Note that the same is true if we were to allow for inter-regional trade. However, computing trade shares for regional trade relies on survey data for which the time dimension is not long enough.

markups) in region r are described by a decreasing function of the local unemployment rate, u_r:

$$(1-\alpha)d\log W_r - d\log A_r - d\log P_r = -\kappa\left(u_r - \bar{u}\right), \tag{E.57}$$

where $\kappa > 0$ $\bar{u}$ denotes a "natural" rate of unemployment and where we have assumed no difference in sectoral productivities.[18]

In order to simplify things even further and to focus on the main mechanism that we have in mind, let's consider the case in which all firms in a given sector and industry have symmetric market shares. Furthermore, suppose that there are $N_{rj}^{L}(i)$ local firms and $N_{rj}^{F}(i)$ foreign firms such that $N_{rj}(i) = N_{rj}^{L}(i) + N_{rj}^{F}(i)$.

Under symmetric market shares, we have that log changes in industry prices are given by

$$d\log P_{rj}(i) = \Lambda_{rj}(i)\, d\log P_{rj}(i,k) + \frac{d\log \Lambda_{rj}(i)}{\sigma - 1} \tag{E.58}$$

where

$$d\log P_{rj}(i,k) = \frac{\Gamma_{rj}(i)}{1+\Gamma_{rj}(i)} d\log P_{rj}(i) - \frac{\kappa}{1+\Gamma_{rj}(i)}\left(u_r - \bar{u}\right) + \frac{1}{1+\Gamma_{rj}(i)} d\log P_r. \tag{E.59}$$

Hence, by relying on the fact that industries enter symmetrically into sectoral output, we obtain that log-changes in sector-level prices are given by

$$d\log P_{rj} = -\Theta_{rj}\kappa\left(u_r - \bar{u}\right) + \Theta_{rj} d\log P_r + \frac{\left(1+\Gamma_{rj}\right)\Theta_{rj}}{\sigma - 1} d\log \Lambda_{rj}$$

where $\Theta_{rj} = \frac{\Lambda_{rj}}{1+(1-\Lambda_{rj})\Gamma_{rj}}$. If we assume that households in all regions aggregate sectoral consumption levels according to fixed consumption weights given by γ_j—in line with Cobb-Douglas preferences for final consumption, then

$$d\log P_r = -\left(u_r - \bar{u}\right) \underbrace{\kappa \frac{\Theta_r}{1-\Theta_r}}_{\text{Slope of PC}} + \underbrace{\frac{\sum_j \gamma_j \left(1+\Gamma_{rj}\right)\Theta_{rj} d\log \Lambda_{rj}}{\left(\sigma-1\right)\left(1-\Theta_r\right)}}_{\text{Direct effect of openness}} \tag{E.60}$$

where $\Theta_r = \sum_j \gamma_j \Theta_{rj}$. Therefore, we have derived that changes in final consumption prices depend on the deviations of region-specific unemployment from its natural rate—that is, the 'slack' of the economy—and changes in foreign conditions summarized by the direct effect of openness of final consumer prices.

If the total number of firms do not vary across regions, but the share of domestic firms does,

[18] There are multiple ways to microfound such a reduced form relationship. Choosing a particular microfoundation should be relevant if we are interested in using our model for counterfactual analysis. This endeavor is currently work in progress.

then note that Γ_{rj} does not vary across regions, but Λ_{rj} does. Moreover, note that

$$\frac{\partial \Theta_{rj}}{\partial \Lambda_{rj}} > 0. \tag{E.61}$$

Therefore, after controlling for *productivity effects* and *direct effects of openness* on changes in prices, more closed regions should have a steeper region-specific Phillips curve. The intuition follows from equation (E.56). After controlling for direct changes in openness, a demand shock in more open regions generates a lower pass-through to final prices as the smaller share of local firm play a less prominent role in aggregate prices. If we did not control for direct changes in openness, then a key identifying assumption would be that changes in prices driven by demand shocks have no sizable effect on changes in openness.