The Geographic Effects of Monetary Policy Shocks *

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Abstract

We estimate the differential effects of monetary policy shocks across US regions. The reaction of prices and employment varies substantially across metropolitan areas in the United States. There is a positive covariance of the price and employment effects of monetary policy across regions. These patterns are consistent with New Keynesian models of a monetary union where regions have different shares of hand-to-mouth consumers. Regions with a higher sensitivity to monetary policy in prices and employment are low-income metropolitan areas. The model predicts that monetary policy shocks create large differences in consumption and real wages across space.

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1 Introduction

This paper estimates how the transmission of monetary policy shocks to prices and employment differs across metropolitan areas in the United States and evaluates plausible drivers of economic heterogeneity that can explain our findings. We use exogenous variation in the stance of monetary policy since 1969, using the Romer and Romer (2004) shocks, extended to 2007 by Wieland and Yang (2020)[1], and a panel of US metropolitan areas.

Studying the differential effects of monetary policy disruptions across regions requires estimates of the effects on both prices and real quantities. Theories that predict heterogeneity in the slope of local Phillips curves predict a negative covariance between price and quantity responses across regions: after a shift in nominal interest rates, prices will adjust *more* and quantities will react *less* in regions with steeper supply curves, since they are closer to monetary neutrality. Theories that predict heterogeneity in the slope of local demand curves predict a positive covariance between price and quantity responses across regions: after a shift in nominal interest rates, prices will adjust *more* and quantities will react *more* in regions where quantities react more to monetary policy keeping prices prices: in these regions monetary policy is more powerful and creates larger changes in real marginal costs, which through the Phillips curve, create larger price effects.

Households and firms in the economy are affected by aggregate fluctuations differentially as a function of their earnings, balance-sheet positions, or ability to access financial instruments, and households of different characteristics are sorted through space.[2] Imperfect mobility of goods and factors, may amplify or dampen the local effects of aggregate shocks. Local labor markets will fence-in local general equilibrium

[1] We consider other shocks developed by Bu et al. (2021) and Miranda-Agrippino and Ricco (2021). These shocks cover different periods and, depending on the case, exclude the Volcker disinflation, including data after the Great Recession and periods in which the zero lower bound was binding.

[2] For the case of exposure to monetary policy, see Coibion et al. (2017) exploring differences in income inequality; Beraja et al. (2019) and Wong (2021) exploring heterogeneity in balance-sheet positions. See also Doepke and Schneider (2006).

effects, using the language of Mian et al. (2022), allowing us to measure the importance of the differential effects.

We conduct our analysis using regionally disaggregated data for employment and consumer prices in the United States. We use Consumer Price Index (CPI) data for the metropolitan areas where the Bureau of Labor Statistics makes data available. We also use employment data from the Quarterly Census of Employment and Wages (QCEW) to generate private employment counts for the same geographical areas as in the price data.

After a contractionary monetary policy shock, inflation and employment decrease at different rates across metropolitan areas. Metro areas that experience larger price declines are the same metropolitan areas that experience larger employment losses. Areas more affected by monetary policy shocks are those with lower household earnings. These results hold for a variety of consumer expenditure categories, different sources of shocks, and are larger for non-tradeable goods.

As a pedagogical device, we present a model that speaks to the patterns in the data. Regions in a monetary union are characterized by a differential fraction of hand-to-mouth households, different degree of price rigidity, and different labor supply elasticities. Our model is a monetary union extension of the Two-Agent New Keynesian (TANK) model in Bilbiie (2008). Regions with different shares of hand-to-mouth households have differential sensitivities of regional consumption to local real interest rates, and non-Ricardian households may only smooth consumption via their labor supply decisions.

We illustrate that this simple model can reproduce the qualitative regional patterns we estimate in the data with variation in the share of hand-to-mouth households, but not with variation in the extent of nominal rigidities. Heterogeneity in demand and supply curve predict a covariance between price and employment responses of opposite signs. In regions with a higher marginal propensity to consume, quantities react by more, and through the Phillips curve, they generate larger price responses since real marginal costs respond by more to the monetary policy shock even when the slope of the Phillips curve is the same across regions.

In the model, monetary policy has relevant distributional effects in the short run. Contractionary monetary policy shocks induce larger drops in price inflation and employment in regions with a higher share of hand-to-mouth consumers. On top of that, it generates an even larger heterogeneity in consumption and real wages across regions. Local areas with more Ricardian agents can smooth their consumption by importing goods produced in areas with a higher share of hand-to-mouth consumers. In areas with a higher percentage of hand-to-mouth consumers, real wages drop by more, which creates a demand amplification that reduces consumption in equilibrium.

To make the model and the data comparable, we use the insight of Patterson (2019), who documents that income is an important covariate to explain marginal propensities to consume using data from the United States. We use the Current Population Survey to compute average metropolitan area-level average income and Patterson (2019) estimates to back out the average marginal propensity to consume at the local level. We use our model to back out a share of hand-to-mouth consumers per metropolitan area consistent with the data.

Since income is an important determinant of MPCs for which we have available data at the local level and frequency, we compute local projections of employment and prices after monetary policy shocks and decompose them into two determinants; an average effect and a heterogeneous effect by income level at the metropolitan area level. This approach is similar to that advocated by Cloyne et al. (2020b). After the same monetary policy shock, low-income metropolitan areas exhibit larger price and larger employment responses. Metropolitan areas in the bottom 10th percentile of the geographical income distribution face peak employment losses of 2.0 percent after a tightening of 100 basis points. Regions in the top 10th percentile suffer negligible effects after the same shock. The differential effects we estimate are persistent; employment stays depressed for four years after the occurrence of the shock.

Concerning prices, a 100-basis point tightening causes cumulative price responses in metropolitan areas in the 10th percentile of the income distribution to be 50 percent larger compared to the average responses and 50 percent smaller compared to the average effect in regions in the 90th percentile of the income distribution. As a validation exercise, we use CPI data disaggregated by expenditure categories and find consistent results. We find that the prices of goods and services of a wide range of narrow categories react less in high-income areas compared to low-income areas. The differential effects are larger for expenditure categories priced locally, like food away from home, and the differential effects on inflation across metropolitan areas are smaller for highly traded, homogeneous goods, like gasoline. The differential price responses for these highly traded categories are statistically insignificant when we use conservative standard errors.

Our findings do not require us to take a strong stance on the structural driver of marginal propensities to consume across regions with different income levels. Households in regions with lower productivity levels may be closer to their subsistence, or industries with differential sensitivity may sort across space. We illustrate the role of industry by controlling for the industrial composition of the metropolitan areas interacted with the monetary policy shock, to illustrate what is the role of income on top of its importance for factors that are correlated with industrial composition. We show that after this control income is still an important driver of the results.

We use the TANK model to evaluate the aggregate effects of having regions with different shares of hand-to-mouth households. We find that heterogeneity in the percentage of hand-to-mouth households exacerbates the aggregate effects of monetary policy shocks. The origin of the amplification effect of demand shocks as a function of the share of hand-to-mouth consumers is similar to that explained in Bilbiie (2020). An increase in inequality across space in the US increases the aggregate impact of shifts in the stance of monetary policy on both prices and employment.

This paper estimates the differential impact of shifts in the stance of monetary policy across metropolitan areas. We illustrate the differential behavior of aggregate local variables to a common monetary policy shock, building on the literature on heterogeneity at the individual-level. The responses of local prices, employment, and consumption illustrate monetary policy transmission across space. The insight we use is that due to the imperfect mobility of labor and local consumption patterns, individual heterogeneity in exposure to monetary policy shocks is aggregated at the local level. A minimal extension of a textbook model predicts that prices and employment react by less in regions with lower marginal propensities to consume, in line with the causal estimates we provide, and predicts that consumption heterogeneity will be even larger due to the amplification of demand shocks at the local level. Moreover, we show that geographic heterogeneity amplifies aggregate responses. A polarized geographic income distribution exacerbates the effects of monetary policy shocks.

Literature Review

This paper is part of a growing literature seeking to understand the distributional effects of monetary policy and its implications. On the empirical front, Carlino and Defina (1998) and Neville et al. (2012) find heterogeneous effects of changes in interest rates across US census regions using VARs. We study the effects of monetary policy on both prices and employment at the metropolitan area level using disruptions in the stance monetary policy recovered using narrative methods.Coibion et al. (2017) show that monetary policy affects the distribution of nominal income distribution, and Furceri et al. (2018) find similar effects for a panel of countries. Cloyne et al. (2020a) document heterogeneous effects of monetary policy shocks at the household level as a function of the financial position of households. Cravino et al. (2018) focus on the heterogeneity of price adjustment as a driver of differential responses of inflation rates across income groups. Andersen et al. (2021) document the effects of monetary policy on several sub-components of income triggered by monetary policy shocks that induce increases in inequality after expansionary shocks. We provide a new moment, the covariance between price and quantity effects at the local level in order to distinguish across competing mechanisms of heterogeneity.

Our work is particularly related to Almgren et al. (2022) who study the heterogeneous effects of monetary policy in the Euro Area on quantities, like output and consumption. They find that countries with a higher share of hand to mouth have a higher cumulative drop in output after a monetary policy shock. Different to their work, we highlight that comparing the differential effects of monetary policy shocks on quantities and prices at the same time is key to distinguish alternative drivers of heterogeneity. We find a positive covariance of the effects of monetary policy shocks in prices and employment, suggesting that heterogeneity in demand effects is a preferred mechanism. Without information about the differential response of prices after a monetary policy shock, it is possible that heterogeneous effects are driven by variation in the slope of the supply curve.

Russ et al. (2023) explore heterogeneous sensitivity to macroeconomic variables at the county level. They find persistent county level differences in unemployment sensitivity to aggregate business cycle fluctuations. Our results are complementary to theirs, as we find heterogeneous effects in prices and employment conditional to monetary policy shocks.

Bergman et al. (2022) look at different demographics affected by a monetary policy shock. They find that groups with lower labor market attachment have higher employment growth after expansionary monetary policy shocks when the market is tighter. Using a New Keynesian model with heterogeneous workers, they show that this effect is plausible when there are differences in workers' productivity. In this paper, we focus on the spatial income heterogeneity of the US. This heterogeneity allows us to evaluate not only the effect on employment but also on price indexes. Having employment and prices allows us to have a complete picture of the effects in terms of real income.

The distributional effects of monetary policy and its consequences have been studied in theoretical models. Auclert (2019) and Kaplan et al. (2018) focus on how heterogeneity may change the average effects of monetary policy. Bilbiie (2008) presents a two-agent New-Keynesian model in which hand-to-mouth consumers introduce frictions in determining aggregate quantities. We use a framework similar to that in Bilbiie (2008), extending it to a monetary union with heterogeneity in the presence of hand-to-mouth consumers, and we show that this class of models can rationalize the cross-regional heterogeneous responses of monetary policy shocks in the US.

This paper adds to this literature by focusing on the geographic distribution of heterogeneous agents. Our empirical findings show that agents in regions with a larger share of poorer consumers face different changes in local aggregates. We also show that the geographic distribution of heterogeneous agents matters for the national economy, making monetary policy more or less powerful. Our findings are informative about the distributional effect on real income of shifts in monetary policy, complementing the work of Bergman et al. (2022), Coibion et al. (2017), and others that study the effect of monetary policy on employment and nominal income.

The rest of the paper proceeds in the following way: Section 2 presents the data. Section 3 shows that regions with larger price responses also face larger employment responses to a monetary policy shock. Section 4 presents a monetary union New Keynesian model to illustrate the effect of different drivers of heterogeneity on the relation between price and employment effects. Section 5 assesses empirically the effect of differences in MPCs through income in driving differential impacts of monetary policy shocks. Section 6 shows the implications of monetary policy for geographic inequality according to the model. Section 7 concludes.

2 Data

To estimate the effects of monetary policy shocks across space, we estimate impulse response functions of inflation and employment at the regional level via local projections after a monetary policy shock. We construct a balanced panel for 28 metropolitan areas containing 12-month inflation rates and indicators of real economic activity. Our dataset starts in 1969 and ends in 2007, a restriction of using the Romer and Romer

(2004) monetary policy shocks.[3] We use headline CPI inflation as our benchmark and present results for various sub-indexes, including CPI for food, food at home, food away from home, gas, and housing.

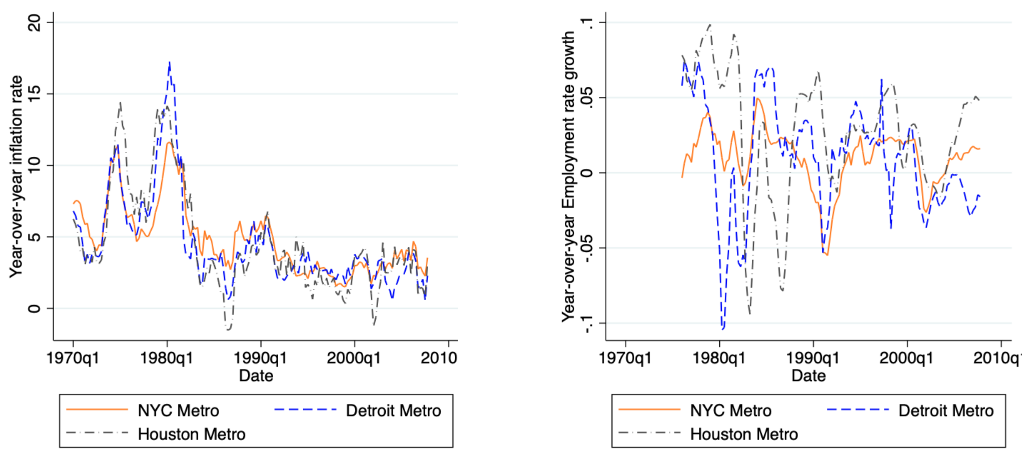
Price index data come directly from the Bureau of Labor Statistics (BLS). For our study, the dispersion of income across space is essential. For that reason, we choose to use city-wide indexes instead of state-wide indexes, such as those produced by Hazell et al. (2022) in order to have more variation in average economic conditions across units of observation. In addition, we will use price indexes for specific consumer categories to illustrate whether our results are driven by changes in degrees of tradeability, product differentiation, or the degree of nominal rigidities.

In our main specification, we will difference away the behavior of prices that is common to every metropolitan area in our dataset. To highlight the variation that we will use, we plot the headline CPI inflation for three selected metropolitan areas in the United States, New York-Newark-Jersey City, NY-NJ-PA (area code S12A in the CPI data), the Detroit-Warren-Dearborn, MI (area code S23B), and Houston-The Woodlands-Sugar Land, TX (area code S37B). Figure 1 presents the data. The main source of variation we will use is the differential inflation rates that metropolitan areas experienced throughout US business cycles. For example, the Houston metro area experienced a higher inflation rate during the Great Inflation of 1974, the Detroit metro area experienced a higher inflation rate during the 1979 inflation, and both had more pronounced changes in inflation during the 2001 recession, compared to New York City.

[3]The metropolitan areas we consider are Boston-Cambridge-Newton (MA-NH), New York-Newark-Jersey City (NY-NJ-PA), Philadelphia-Camden-Wilmington (PA-NJ-DE-MD), Chicago-Naperville-Elgin (IL-IN-WI), Detroit-Warren-Dearborn (MI), Minneapolis-St.Paul-Bloomington (MN-WI), St. Louis (MO-IL), Washington-Arlington-Alexandria (DC-MD-VA-WV), Baltimore-Columbia-Towson (MD), Miami-Fort Lauderdale-West Palm Beach (FL), Atlanta-Sandy Springs-Roswell (GA), Tampa-St. Petersburg-Clearwater (FL), Dallas-Fort Worth-Arlington (TX), Houston-The Woodlands-Sugar Land (TX), Phoenix-Mesa-Scottsdale (AZ), Denver-Aurora-Lakewood (CO), Los Angeles-Long Beach-Anaheim (CA), San Francisco-Oakland-Hayward (CA), Seattle-Tacoma-Bellevue (WA), San Diego-Carlsbad (CA), Urban Hawaii, Urban Alaska, Pittsburgh (PA), Cincinnati-Hamilton (OH-KY-IN), Cleveland-Akron (OH), Milwaukee-Racine (WI), Portland-Salem (OR-WA) and Kansas City (MO-KS).

The employment data come from the Quarterly Census of Employment and Wages (QCEW), which has good geographical coverage. We use county-level data at the quarterly frequency covering private employment since 1975. Since the unit of observation for the employment data is the county, and for prices is the metropolitan area, we create a correspondence between counties in the QCEW and the statistical sampling units created for the CPI, called Primary Sampling Units (PSUs).[4]

Figure 1: Inflation and Employment Across Metropolitan Areas



(a) Inflation

(b) Employment growth

Note: This figure plots the behavior of inflation and employment for three metropolitan areas: New York-Newark-Jersey City, NY-NJ-PA; Detroit-Warren-Dearborn, MI; Houston-The Woodlands-Sugar Land, TX. The top panel shows 12-month headline CPI inflation. The bottom panel shows 12-month employment growth rates at a quarterly frequency.

In a similar way to prices, our main specifications will soak up any effects on symmetric employment responses triggered by the shock. The right panel of Figure 1 illustrates the differential local area business cycles of three metropolitan areas as a matter of example. Houston experienced an employment boom during the early 2000s, and a differential employment loss during the late 1980s. Similarly, the Volcker disinflation

[4]Table A.1 in Appendix A.2 shows the correspondence between PSUs in the Price data and the FIPS codes in the QCEW data.

hit Detroit by more than New York.

We use the Romer and Romer (2004) shocks, extended to 2007 by Wieland and Yang (2020), as our measure of monetary policy shocks. We aggregate monthly shocks at the quarterly frequency. These shocks capture monetary policy changes that are free from the anticipation effects of prices and economic activity inherent to monetary policy decisions. Figure A.1 in the appendix displays the time series of the shock we use. Most of the variation in the Romer and Romer (2004) measure of monetary policy shocks comes from the Volcker disinflation, as pointed out by Coibion (2012). Since the Great Recession, the US policy rule has often been limited by the zero lower bound, which limits the sample period we consider, although we consider robustness to other shocks that use data after the Great Recession.

3 Empirical Strategy and Results

In this section, we present our empirical strategy to estimate the causal effect on prices and employment of a monetary policy shock across US metropolitan areas and our estimation results. Our core identification strategy relies on exogenous shifters to the stance of monetary policy in the United States as measured by the Romer and Romer (2004) shocks. We will identify the dynamic causal effects of monetary policy shocks on both employment and prices using local projections with lagged dependent variables as controls (Jorda, 2005; Montiel Olea and Plagborg-Møller, 2021).

The main result of this section comes from running local projections on prices and employment of each individual metropolitan area in the US, and showing non-parametrically that regions in which prices are more sensitive to monetary policy shocks are the same areas that where employment is more sensitive to the same shocks. Theories that attach heterogeneity in structural parameters to different regions must confront this fact.

3.1 Prices

For a given price index in location i, $\pi_{i,t+h,t-1}$ denotes the cumulative inflation rate between a reference period $t-1$ and $h>0$ periods in the future as

$$\pi_{i,t+h,t-1} = \frac{P_{i,t+h} - P_{i,t-1}}{P_{i,t-1}}.$$

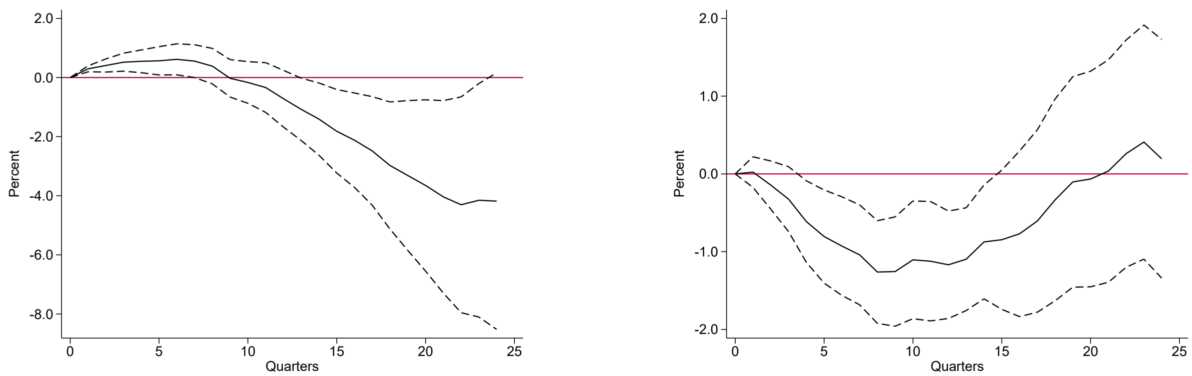
To estimate the effect of a monetary policy shock on prices in the average metropolitan area, we use local projections (Jorda, 2005) method with area fixed effects, formally we run the following set of regressions

$$\pi_{i,t+h,t-1} = \alpha^h_{p,i} + \sum_{j=0}^{J} \beta^{h,j}_p RR_{t-j} + \sum_{k=0}^{K} \gamma^{h,k}_p \pi_{i,t-1,t-1-k} + \varepsilon^h_{p,i,t+h} \;\; \forall h \in [0, H], \tag{1}$$

where i indexes metropolitan areas, t indexes time, h denotes the number of quarters after the shock, and p denotes that these coefficients and error terms belong to a price regression. The coefficient $\beta^{h,j}_p$ accounts for the cumulative effect of a monetary policy shock j periods ago RR_{t-j}, on inflation $\pi_{i,t+h,t-1}$ h periods in the future. $\alpha^h_{p,i}$ is a metropolitan area fixed effect in the price regression, and $\varepsilon^h_{p,i,t+h}$ is the error term. We cluster standard errors at the metro area and time level. This specification is a panel version of the lag-augmented local projections as in Montiel Olea and Plagborg-Møller (2021).

The terms $\beta^{h,0}$ in equation 1 trace the cumulative impulse response function on prices at horizon h after a monetary policy shock, controlling for permanent city-specific inflation differences, past shocks, and differential time-varying inflation dynamics prior to the shock. Figure 2a shows the estimated cumulative impulse response function of overall CPI inflation or, equivalently, the impulse response of prices, after a monetary policy shock that tightens rates by 1 percentage point.

Our results are similar to the original Romer and Romer (2004) results obtained by



(a) CPI (b) Employment

Figure 2: Average Effects of Monetary Policy Shocks on Prices and Employment

Note: The left panel of the figure plots the estimated coefficients of equation (1) for the panel of metropolitan areas. We compute the local projections up to a maximum horizon of $H = 24$, and use eight lags of the dependent variable and the monetary policy shocks as controls ($J = 8$, and $K = 8$). The solid line denotes the estimated coefficients, and the dashed lines represent 90 percent confidence intervals. Standard errors are clustered at the metro area and date level. The right panel of this figure plots the estimated coefficients of equation (2). We use the same values for H, J, K than in the left panel.

running a regression of national CPI inflation on the monetary policy shock and controls at the aggregate level. The effect of a monetary policy shock on prices is positive and close to zero for the first two years, followed by a sharp decline, reaching a value of -6 percentage points after 20 quarters. Both the point estimate and the standard errors are similar to those obtained using aggregate data.

The conceptual difference between the impulse response functions depicted in figure 2a and the results that would arise from a local projection over aggregate inflation numbers is a difference in weights. In order to compute aggregate inflation, the Bureau of Labor Statistics uses population weights over regional inflation indexes. Instead, our calculations use equal weights over regions. In that sense, our results measure the effect of monetary policy shocks for the average city.

By clustering our standard errors by metropolitan areas, our standard errors also contain information about the heterogeneity in the intensity of the effect of the treatment. In subsequent sections of the paper we will exploit differences in observable characteristics across metropolitan areas to document heterogeneity in the effects of monetary policy shocks. Before we do so, we document the average effects on employment growth of monetary policy shocks.

3.2 Economic Activity

Linking the empirical evidence on heterogeneity to economic mechanisms of underlying heterogeneity in the class of New Keynesian models requires to estimate not only the effects on prices, but also the effects on real economic activity. Due to data availability we focus to choose on employment at local level.

To make the case of analyzing employment and prices jointly, let us provide an example. A model in which regions are characterized by Phillips curves with different slopes could in principle create differential price responses in line with those we discussed in the previous section. However, that model would predict that employment would react by *less* in regions where prices react by *more*, since higher price responses would be an indication of economies closer to monetary neutrality.

We run a specification qualitatively similar to equation (1), but with the percentage change of private employment, which we denote by g^e as the dependent variable, given by

$$g^e_{i,t+h,t-1} = \alpha^h_i + \sum_{j=0}^{J} \beta_e^{h,j} RR_{t-j} + \sum_{k=0}^{K} \gamma_e^{h,k} g^e_{i,t,t-k} + \varepsilon^h_{e,i,t+h} \ \ \forall h \in [0, H], \tag{2}$$

where $g^e_{i,t+h,t}$ is the cumulative employment growth in metropolitan area i between time $t-1$ and $t+h$. The rest of the notation is the same than that of equation 1, and the subscript e makes reference to the employment regression.

By estimating $\beta_e^{h,0}$ in equation 2 we trace the average cumulative impulse response function of private employment at different horizons in the average US metropolitan area after a monetary policy shock that tightens rates by one percentage point.

After a monetary policy tightening, there is a negative effect on employment. This effect occurs faster than the effect on prices: After five quarters, we estimate an employment drop that persists for 10 quarters. This effect is significant; the maximum cumulative effect reaches a 1 percent decrease in private employment.

3.3 Metropolitan Area Results

We run local projections for each individual metropolitan area instead of pooling them in a panel specification, with the purpose of illustrating non-parametrically whether there is comovement in the response of inflation and employment across space.

The comovement of employment and price effects will be informative about the nature of the source of heterogeneity. Heterogeneity in the slopes of the supply block of the model will create a negative comovement of inflation and price responses, while heterogeneity in the demand block of the model will create a positive comovement between price and employment responses.

We run local projections at the individual level on local inflation and local employment growth, but allow for arbitrary impulse response functions for each particular city instead of pooling the results together. For prices, the specification we consider takes the form of

$$\pi_{i,t+h,t-1} = \alpha_{0,p} + \sum_{j=0}^{J} \beta_{i,p}^{h,j} RR_{t-j} + \sum_{k=0}^{K} \gamma_{i,p}^{h,k} \pi_{i,t-1,t-1-k} + \varepsilon_{p,i,t+h}^{h} \;\; \forall h \in [0,H], i \in \mathcal{I}, \quad (3)$$

while that of employment takes the following form

$$g_{i,t+h,t-1}^{e} = \alpha_{0,e} + \sum_{j=0}^{J} \beta_{i,e}^{h,j} RR_{t-j} + \sum_{k=0}^{K} \gamma_{i,e}^{h,k} g_{i,t,t-k}^{e} + \varepsilon_{e,i,t+h}^{h} \;\; \forall h \in [0,H] i \in \mathcal{I}, \quad (4)$$

where $\alpha_{0,p}$ and $\alpha_{0,e}$ denote the intercepts of the price and employment equations, respectively; and the β and γ coefficients have the same interpretation as in the previous subsections, with the clarification that they are city-specific coefficients, which we clarify with the i subscript. $\mathcal{I}$ denotes the set of metropolitan areas for which we have data.

The identifying assumption behind equations 3 and 4 is more demanding than the traditional identifying assumption behind local projections with aggregate data. The key added restriction is that the Romer and Romer shocks not only clean anticipation effects of inflation and economic conditions with respect to aggregate variables, but they do so with respect to local variables as well. A violation of this restriction would occur if, for example, the FOMC were more concerned about economic conditions in some regions rather than others. In section 5.2 we run robustness exercises using other sources of shocks.

To present our results, we take the approach suggested by Ramey (2016) of computing ratios of the cumulative responses to summarize the effect of a shock. In particular, we add up the effects on employment 20 quarters after the onset of the shock. For prices, we add up the effects on inflation up until quarter 20.

Figure 3 illustrates the comovement of the impulse responses 20 quarters after the shock for each metropolitan area. The x-axis plots the effects on prices, while the y-axis plots the effects on employment. Each dot corresponds to one metropolitan area. Cities with higher price effect also have higher employment effect. In Appendix A.4, we show that this positive relationship is statistically significant and remains positive after we consider the variation of each point estimate.

We will use the results of Figure 3 in order to inform the magnitude of the margins of economic heterogeneity that rationalize the heterogeneous responses of local economic conditions to a common monetary policy shock.

In Appendix A.4 we conduct a number of exercises to show that the patterns in Figure 3 are statistically significant. We refer the reader to the details of the appendix, but we summarize the highlights here.

First, we use the standard errors associated with each point in 3 to do a simulation-based exercise in which we perturb the points in Figure 3 and re-estimate its slope. Figure A.9 shows that in 99.6 percent of our simulations, the estimated slope is positive.

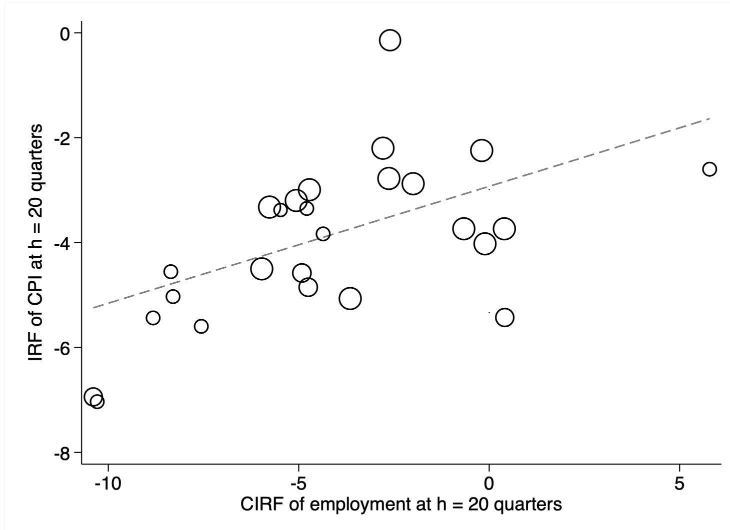


Figure 3: Effect of a Monetary Policy Shock in Employment and Prices for Each City

Note: This figure plots on the y-axis the local projection on local consumer prices of an exogenous monetary policy tightening of 100 basis points 20 quarters after the shock. The x-axis plots the cumulative effect (area under the curve) of local employment 20 quarters after a monetary policy shock of 100 basis points. The units of both axes are percentage points. Each bubble in the scatter plot corresponds to a metropolitan area. The size of each bubble represents the average income per capita of each metropolitan area.

Second, we impose a restriction in the system of local projections in order to estimate the slope that rationalizes the data and estimate this slope directly from the micro data.[5] Our exercise is similar in spirit to estimate a Phillips multiplier in the language of Barnichon and Mesters (2021) in a cross-section of regions. Figure A.10 presents the results for different horizons of the impulse responses. The estimate has the interpretation of the reaction of prices to a one percent cumulative effect on employment growth triggered by a monetary policy shock. We find a positive and significant slope coefficient with standard errors clustered by metropolitan area and time.

[5]We thank Jim Hamilton for suggesting this approach.

4 Monetary Union TANK Model

The purpose of this section is to present a parsimonious New Keynesian model with as few departures from textbook models as possible that is flexible enough to generate heterogeneity in responses across regions after a monetary policy shock in line with those documented in the data.

In the model, regions are local labor markets without any degree of mobility. Households have standard preferences, although the intertemporal elasticity of substitution and the elasticity of labor supply may vary across space. There is a share of hand-to-mouth households in each region, and this share may change across space. There are firms in each region that produce differentiated varieties subject to Calvo (1983). The varieties produced at home and abroad may have in principle differential frequency of price adjustment.

Although the model does not include every possible margin of heterogeneity, it is very general insofar other margins of heterogeneity enter the problem either by changing the sensitivity of local consumption growth to local real interest rates, the sensitivity of producer price inflation to local real marginal costs, or both.

We document that heterogeneity in demand factors, like the differential share of hand to mouth consumers can rationalize our results. Heterogeneity in supply factors, like the heterogeneity in the extent of nominal rigidities cannot.

4.1 Model Environment

We first present a model of a monetary union in which monetary policy shocks induce differential regional responses. The model has a large tradition in macroeconomics; it is an extension of the TANK model (Bilbiie, 2008) to a monetary union.

The model has two regions: Home (H) and Foreign (F). Each region has two types of households: Ricardian (R) and hand-to-mouth (H) households. Each region is characterized by a differential share of each household type. Aguiar et al. (2020), documents the determinants of being a hand to mouth consumer. Heterogeneity in the share of hand to mouth consumers will induce differential sensitivity of consumption growth to changes in local real interest rates.

On the supply side, we assume that in principle, the Calvo (1983) parameter could be heterogeneous across regions. On top of the slope of the Phillips curve being different, the forcing variable itself, local real marginal costs, may behave differently as well due to labor immobility across regions, home bias in consumer preferences, and variation in the share of hand-to-mouth households.

Home and Foreign regions are equal in population, an assumption that is not important but reduces notation. The Home region (H) is populated by both Ricardian (HR) and hand-to-mouth households (HH). The share of hand-to-mouth agents in the Home and Foreign regions is denoted by λ_H and λ_F, respectively. Ricardian and hand-to-mouth households in the same region have the same preferences and supply homogeneous labor. Ricardian households save and own firms, and hand-to-mouth households consume their labor income at every point in time. Labor markets are perfectly integrated within a region, and there is no labor mobility across regions.

We present the setting for the Home region, with the understanding that the problem of the Foreign region is analogous. Households have separable preferences for consumption and leisure that take a standard form,

$$U(C_{j,t}, L_{j,t}) = \frac{C_{j,t}^{1-\gamma_H}}{1-\gamma_H} - \psi \frac{L_{j,t}^{1+\alpha_H}}{1+\alpha_H}, \;\; j = \{HH, HR\}$$

Ricardian households maximize their discounted sum of expected utility

$$\max \sum_{t=0}^{\infty} E_0 \beta^t U(C_{HR,t}, L_{HR,t}),$$

subject to a sequence of budget constraints, given by

$$B_{HR,t+1} + P_{H,t} C_{HR,t} \leq W_{H,t} L_{HR,t} + B_{HR,t}(1+i_t) + \Pi_{H,t},$$

where $B_{HR,t}$ denote nominal bonds holdings. i_t is the national nominal interest rate, common to Home and Foreign regions, and set by the central bank. $P_{H,t}$ is the consumer price index in the Home region, $C_{HR,t}$ is the consumption of the Ricardian agent, and $W_{H,t}$ is the nominal wage of the H region. $L_{HR,t}$ denotes hours of work of Ricardian agents. $\Pi_{H,t}$ are the nominal profits of firms in region H.

Hand-to-mouth households maximize the same utility function, but they are subject to a static budget constraint that links labor income to consumption expenditures,

$$P_{H,t}C_{HH,t} \leq W_{H,t}L_{HH,t}.$$

Regional consumption in the home region $C_{H,t}$ aggregates the consumption of both types of households, weighted by their population shares,

$$C_{H,t} = \lambda_H C_{HH,t} + (1-\lambda_H)C_{HR,t}.$$

Households have CES preferences over varieties produced in the Home and Foreign region with elasticity of substitution ν and potential home bias $\phi \geq 1/2$. Specifically

$$C_{j,t} = \left[\phi^{\frac{1}{\nu}} C_{j,H,t}^{\frac{\nu-1}{\nu}} + (1-\phi)^{\frac{1}{\nu}} C_{j,F,t}^{\frac{\nu-1}{\nu}}\right]^{\frac{\nu}{\nu-1}},$$

with $j = \{HH, HR\}$ and $C_{i,k,t}$ is the consumption of goods produced in region k by agent i , which is a CES aggregate of a continuum of varieties with an elasticity of substitution η,

$$C_{i,k,t} = \left(\int_0^1 C_{i,k,t}(z)^{\frac{\eta-1}{\eta}} dz\right)^{\frac{\eta}{\eta-1}}.$$

The labor supply decisions in the Home region are given by

$$\psi L_{Hj,t}^{\alpha_H} C_{Hj,t}^{\gamma_H} = \frac{W_{Ht}}{P_{Ht}}, \text{ for } j \in [H, R]. \tag{5}$$

For the case of hand-to-mouth households, plugging in the budget constraint, and solving for the labor supply yields

$$L_{HHt} = \left(\frac{1}{\psi}\right)^{\frac{1}{\gamma_H + \alpha_H}} \left(\frac{W_{Ht}}{P_{Ht}}\right)^{\frac{1-\gamma_H}{\gamma_H + \alpha_H}}. \tag{6}$$

Equation 6 makes clear that the co-movement of labor supply decisions of hand-to-mouth households and the real wage depends on whether the intertemporal elasticity of substitution is smaller, equal, or greater than 1, a feature of models with hand-to-mouth households with standard preferences. For the case of log-utility, hand-to-mouth households' labor supply is acyclical. However, for the standard case where $\gamma > 1$ the amount of labor supplied by hand-to-mouth households is countercyclical. In this case, during a recession that lowers the real wage, hand-to-mouth households adjust by supplying more hours of work, the only available means they have to smooth consumption.

There is a continuum of firms in each region producing tradeable varieties. Each firm faces demand coming from Home and Foreign regions. Market clearing in the goods market implies then that production for each variety satisfies consumer demand

$$Y_{H,t}(z) = \lambda_H C_{HH,H,t}(z) + (1 - \lambda_H) C_{HR,H,t}(z) + C_{F,t}(z).$$

Firms produce using a production function linear in local labor and are subject to regional productivity shocks, $Y_{Ht}(z) = A_{Ht} L_{Ht}(z)$. Real marginal costs, denoted MC, expressed in terms of domestic prices are common across firms within a region, and equal to $MC_{Ht} = \frac{W_{Ht}}{P_{Ht}} \frac{1}{A_{Ht}}$.

The price-setting problem of these firms is standard. Firms change their prices freely with probability $(1-\theta_H)$, and must keep their prices unchanged with probability θ_H, as in Calvo (1983). Firms choose to set prices equal to a markup over the weighted discounted sum of nominal marginal costs whenever they have the chance to do so. Up to first-order approximation, the optimal price-setting rule, consists of a price $\bar{p}_{Ht}$ that depends on regional prices, real marginal costs, the discount factor β, and the probability that firms may not adjust their prices θ_H. In particular reset prices can be characterized by

$$\bar{p}_{Ht} = (1-\beta\theta_H)\sum_{k=0}^{\infty}(\beta\theta_H)^k\,\mathbb{E}_t\left[mc_{H,t+k} + p_{H,t+k}\right]. \tag{7}$$

The Phillips curve in the Home and foreign region has a slope κ_H, and κ_F, respectively, given by

$$\pi_{Ht} = \beta\mathbb{E}_t\pi_{H,t+1} + \kappa_H mc_{Ht} \tag{8}$$

$$\pi_{Ft} = \beta\mathbb{E}_t\pi_{F,t+1} + \kappa_F mc_{Ft} \tag{9}$$

where $mc_{j,t}$ is the average marginal cost in region j and $\kappa_H = \frac{(1-\theta_H\beta)(1-\theta_H)}{\theta_H}$ is a coefficient that captures the extent of nominal rigidities. The slope of the Phillips curve for the Foreign region is symmetric as a function of θ_F and the common discount factor β.

The risk-sharing condition states that consumption of the Ricardian househols in the Home and Foreign region obey the following relationship,

$$\left(C_{HR,t}\right)^{\gamma_H}\left(C_{FR,t}\right)^{-\gamma_F}\vartheta_0 = \frac{P_{F,t}}{P_{H,t}}$$

.

where ϑ_0 is a constant that takes the value of 1 in the special case where Home and

Foreign regions are equally productive in the long run. In the general case, ϑ_0 captures the current expectations of price and quantity differentials in the infinite future.

There is a single central bank for the monetary union that sets an interest rate i_t according to a monetary policy reaction function that takes as inputs national inflation and output, and a monetary policy shock ε_t,

$$i_t = \phi_\pi(\pi_{Ht} + \pi_{Ft}) + \phi_y(y_{Ht} + y_{Ft}) + \varepsilon_t.$$

Parameterization

Our benchmark parameterization follows a standard textbook calibration of the standard parameters in the model, which we summarize in Table A.3 in the Appendix. The two parameters not included in the table are λ, the share of hand to mouth consumers, and θ_H, θ_F, the frequency of price changes in the home and foreign regions. We will do comparative statics for these parameters to understand the effects of their heterogeneity in the response to monetary policy shocks across space.

Heterogeneity in λ and positive comovement of inflation and employment responses

To provide intuition on the effect of increasing the difference in the share of hand to mouth consumers, we start by fixing $\theta_H = \theta_F = 0.75$, a common value in the literature, and solve the model for a set of values for $\lambda_H \in [0, 0.5]$, while keeping λ_F fixed at 0. We simulate a 100 basis point interest rate tightening in the model and compute the on-impact responses of employment and prices in each region.

Figure 4 shows the relative effect of a monetary policy shock on prices and employment between the Home and Foreign regions. We will present the result of these alternative models using a series of scatterplots. The x-axis of each scatterplot will show the present value of the impulse response function of prices in the Home region relative to the present value of the impulse response of prices in the Foreign region. The y-axis will be analogous but for the employment responses rather than for prices. Each point in the scatterplot will correspond to a model with a different value for the parameter of interest in the Home region. We keep the calibration for the Foreign region fixed.

The main message of 4 is that heterogeneity in the share of hand-to-mouth consumers will generate, in equilibrium, a positive relation between the causal effects of monetary policy on employment and on prices. Regions with a higher share of hand to mouth consumers will suffer larger employment losses and larger price declines after the same shock.

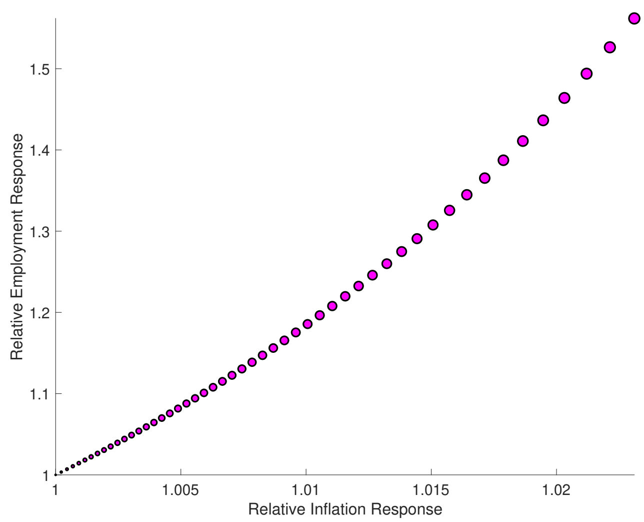


Figure 4: Relative Price and Employment Responses - Fraction of Hand-to-Mouth Consumers

Note: This figure shows the relative behavior of regional prices, on the x-axis, and employment, on the y-axis, after a national monetary policy shock. The source of regional heterogeneity is the share of hand-to-mouth households (λ). Relative inflation and employment are computed as the ratio between the discounted cumulative impulse response functions of each variable in the Home region divided by the analogous object in the Foreign region. A value of 1 means that the Home and Foreign regions have responses of the same magnitude in present value. Each point of the scatterplot represents the solution of a model with a different value of λ. The size of the marker represents how large is the heterogeneity in parameters across regions. The calibrations that underlie the figure are presented in Appendix A.5.

We now move to a model where each region is populated by Ricardian agents ($\lambda = 0$), and there is dispersion between the extent of nominal rigidities across regions, $\kappa_H < \kappa_F$. We focus on this alternative to illustrate the effects of a driver of heterogeneity on the slope of the supply block of the model, the Phillips curve.

Figure 5 shows the results. It makes clear that when regions are heterogeneous due to the steepness of local supply curves, regions with prices that are more sensitive to demand shocks are those with employment being less sensitive to the same demand shock. Intuitively, variation in the slope of the Phillips curve creates differences in the extent of monetary non-neutrality, which in a cross-section of regions generates a negative covariance between the effects of a monetary policy shock on prices and on employment. This finding is the opposite of what we find in the empirical section; regions with larger price responses have larger real responses as well.

We present results from two-region New Keynesian models of an open economy in which geographical heterogeneity arises from different alternative mechanisms, including the elasticity of labor supply, and the intertemporal elasticity of substitution. We set the fraction of hand-to-mouth households λ to zero. We will present the main takeaways of these exercises in this section, although the figures and details on the calibration of the models are relegated to Appendix A.6.

The exercise we will perform will be analogous to our main exercise in the previous section. For each economic mechanism highlighted above, we will compare the impulse response of inflation and employment of Home and Foreign economies to a monetary policy shock. Home and Foreign economies are symmetric except for the one particular dimension (elasticity of labor supply, elasticity of intertemporal substitution) that we will vary. Each of these margins of heterogeneity will induce differential impulse responses across regions.

Figure A.11 in the appendix considers other possibilities. The first alternative we consider is that the driver of heterogeneity is differences in labor supply elasticities. Variation in the elasticity of labor supply across regions induces changes in marginal costs. So although the sensitivity of inflation to real marginal costs is the same across regions with different elasticities of labor supply, the reaction of inflation to demand shifts will be different across regions.

This intuition explains why the left panel of Figure A.11 is qualitatively similar to Figure 5. The frequency of price changes and the elasticity of labor supply affect the

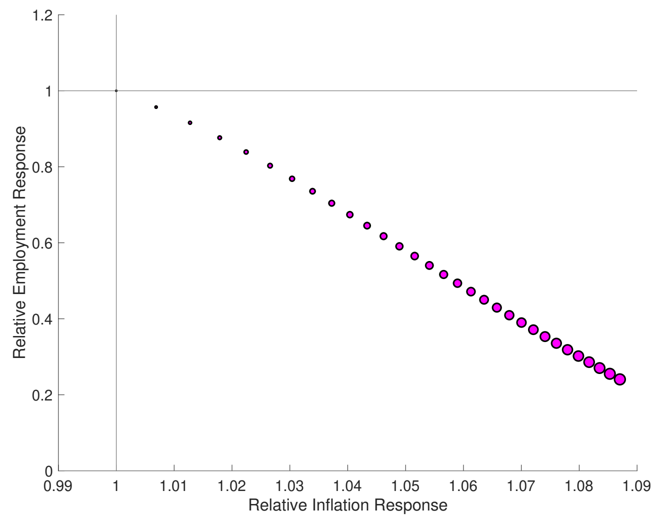


Figure 5: Relative Price and Employment Responses - Phillips curve

Note: This figure shows the relative behavior of regional prices, on the x-axis, and employment, on the y-axis, after a national monetary policy shock. The source of regional heterogeneity is variation in the extent of nominal rigidities. Relative inflation and employment are computed as the ratio between the discounted cumulative impulse response functions of each variable in the Home region divided by the analogous object in the Foreign region. A value of 1 means that Home and Foreign regions have responses of the same magnitude in present value. Each point of the scatterplot represents the solution of a model with different variations in the extent of nominal rigidities. The size of the marker represents how large the heterogeneity in parameters is across regions. The calibrations that underlie the figure are in Appendix A.6.

slope of the Phillips curve. So models in which these margins drive regional heterogeneity imply that economies in which inflation is more sensitive to monetary policy shocks should be closer to monetary neutrality.

A final alternative is that regional heterogeneity is driven by differences in the intertemporal elasticity of substitution. The case of the intertemporal elasticity of substitution is a priori less evident, since variation in this margin will introduce cross-sectional changes in the intertemporal IS curve and in the Phillips curve via changes in the behavior of real marginal costs when using separable preferences.

Figure A.11, right panel, shows that cross-sectional variation in the intertemporal elasticity of substitution creates a pattern counter to the ones we have presented before and in line with those in the data. In fact, the monetary union TANK model we presented before aims to introduce the same variation as reduced-form heterogeneity in intertemporal elasticity of substitution across regions. By placing a fraction of the population out of their Euler equation, the TANK model changes the effective intertemporal elasticity of substitution.

The covariance of the regional response of prices and employment to a monetary policy shock are sufficient to distinguish supply and demand margins of heterogeneity, but are not enough to distinguish across different drivers of demand effects. In that sense, we cannot distinguish whether in the data the variation is driven by the share of hand-to-mouth consumers, or by households with different elasticities of intertemporal substitution. However Aguiar et al. (2020) show that these two margins are correlated in the data.

There are certainly more margins of heterogeneity that one may consider. To the extent that these margins map into either differential elasticities of the Euler equation, or differential elasticities of the Phillips curve our analysis covers those additional margins of heterogeneity. Margins of heterogeneity that create dispersion in the slope of the Euler equation (the sensitivity of local consumption growth to local interest rates) can explain our results. Margins of heterogeneity that create differences in the slope of local Phillips curves (the sensitivity of local inflation to changes in local demand), cannot.

5 Heterogeneous effects of Monetary Policy

To make the connection between the data and the model sharper, We link income and marginal propensities to consume using evidence by Patterson (2019) that documents that income is the most important determinant of variation in marginal propensities to consume (MPC), and our model that makes the argument that differences in MPCs generate variation in the cross-section of metropolitan areas in line with the data.

On top of being an important covariate behind MPCs, income data is available for our sample of metropolitan areas. Other alternative drivers for MPCs such as the stock of liquid assets would also be suitable for this exercise, but we do not have as reliable data as we do for income.

To rank local areas, we use a transformed measure of real personal income per capita. We deflate nominal income per capita using national CPI to avoid a mechanical correlation between regional real income per capita and regional inflation. Then, we regress real personal income per capita on time fixed effects and use the residual as our normalized measure of income. The interpretation of this residual is the difference in income between a specific city with respect to the average income across cities in our sample for a given year.[6]

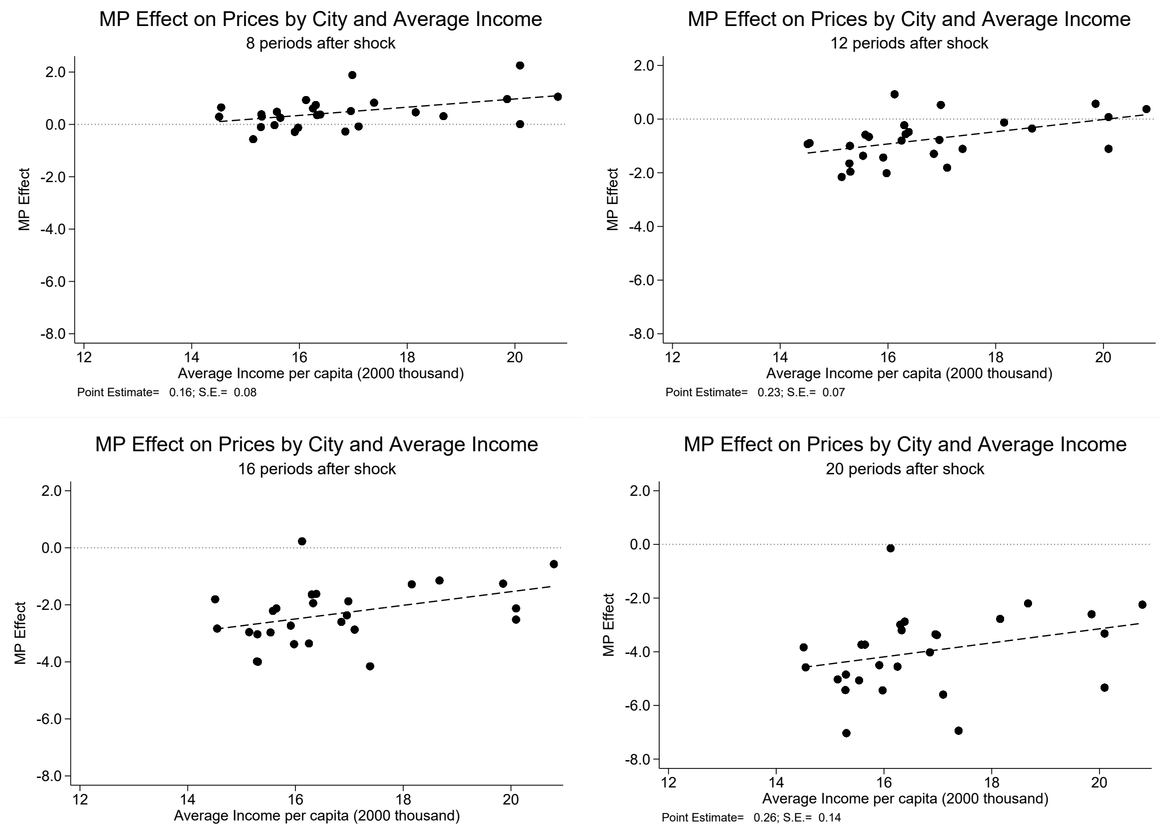
We focus on the heterogeneous effects of monetary policy shocks across local economic areas in the United States. Our first approach is to run local projections for each individual location, computing the cumulative effect on prices of monetary policy shocks 8, 12, 16, and 20 quarters after the onset of the shock. To show our results systematically, we plot our estimated effects in Figure 6, as a function of the income of each city expressed in thousands of dollars of the year 2000.

There is substantial heterogeneity across space and horizons in Figure (6). Two years after the shock (left top panel), the effects on prices of monetary policy shocks are small, and are increasing in income, a manifestation of the price puzzle in the cross-section of metropolitan areas. Three years after the shock (top right panel), poorer cities have accumulated a 2 percent price drop, while cities with higher income levels have experienced none. Four and five years after the shock, peak effects of the shocks materialize, with cumulative declines in prices of 2.5 percentage points after 4 years, and meaningful heterogeneity that correlates with city-average income levels.

Figure (6) presents the heterogeneity of the estimates across regions, but fails to give a sense of their economic size, or their statistical significance. Intuitively, each point in

[6]The decision to deflate income by the CPI avoids introducing heteroskedasticity in the data as the dispersion measured in current values increases through time. Our results are robust to not deflating nominal income by aggregate prices but using the residuals of a regression of nominal income on time fixed effects. Our results are also robust to deflate by local CPI. However, the interpretation of deflating by local CPI is not to make income comparable across regions since local CPIs do not play the role of price parities across space, but to account for differential trends in inflation across metropolitan areas.

Figure 6: Effect of Monetary Policy Shock on Prices - CPI by Cities



Note: The figure shows the results of equation (1) for each individual metropolitan area. We use $J = 8$, and $K = 8$. The upper-left panel plots cumulative effects over 8 quarters, the upper-right panel 12 quarters, the lower-left panel 16 quarters, and the lower-right panel 20 quarters.

the scatter plot above does not transmit information about the standard errors associated with the estimation of each local projection. However, it is reassuring that at each horizon, there is a positive relation between income and the size of price responses after monetary policy shock, which dictates our specification choices going forward.[7]

We extend equation 1 to account for regional heterogeneity in terms of real income per capita, which we estimate by running a regression of local inflation rates on the monetary policy shocks, interactions between the monetary policy shock and real rela-

[7]These results should be interpreted as the effects on the price level, so even if inflation returns to its pre-existing rate, the price level is permanently changed, as predicted by standard theories.

tive income per capita, and local area controls that are included in the information set at time t. Our specification uses the Blinder-Oaxaca decomposition on local projections as in Cloyne et al. (2020b), applied to a panel setting. Formally, we estimate,

$$\pi_{i,t+h,t} = \alpha_{i,p}^{h} + \sum_{j=0}^{J} \beta_p^{h,j} RR_{t-j} + \sum_{j=0}^{J} \gamma_p^{h,j} RR_{t-j} \times RPIPC_{i,t-j-1} + \sum_{j=0}^{J} X_{i,t-j}' \theta_p^{h,j} + \varepsilon_{p,i,t+h}^{h}, \quad (10)$$

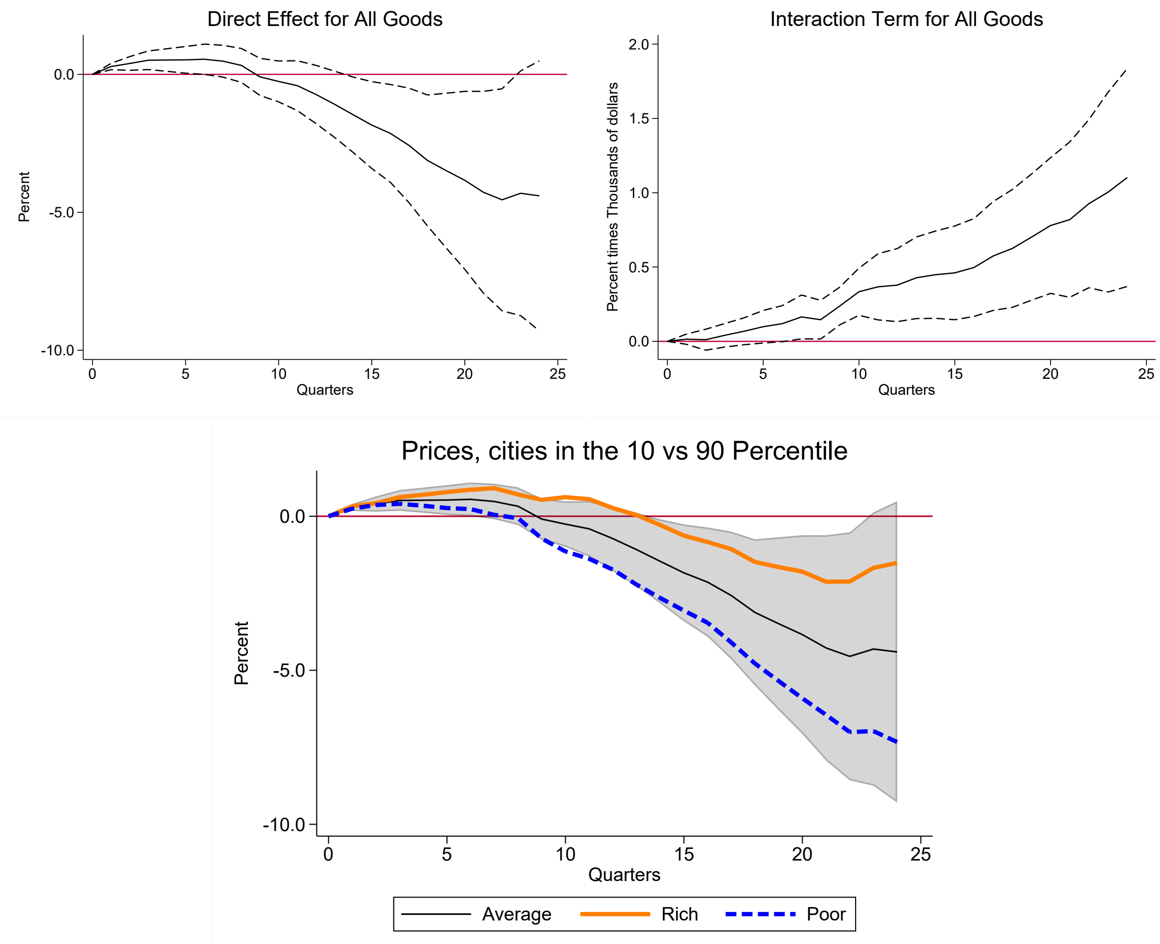
$\forall h \in [0, H]$ with $X_{i,t-j} = [RPIPC_{i,t-j-1} \;\; \pi_{i,t,t-j}]$, where $RPIPC_{i,t}$ is the relative personal income per capita in city i at time t, and π and RR represent the same objects as before.

The marginal effect of a monetary policy shock that occurs in period t on inflation in city i, h periods after the shock is given by $\beta_p^{h,0} + \gamma_p^{h,0} RPIPC_{i,t-1}$. Since our income control does not vary with h, we do not use any variation in real income per capita caused by the monetary policy shock. Instead, we use pre-existing differences across metropolitan areas at the onset of the shock.

The top left panel of Figure 7 shows the impulse response of prices for a city of average income. Due to the normalization of real income per capita, the identity of the average city may change at different points in time. The interpretation of the top interaction term in the right panel is the additional effect on prices experienced by a city with real income that is \$1000 (in the year 2000) higher than average, after a monetary policy shock of 1 percentage point. The main takeaway of the right panel is that a contractionary monetary policy shock causes a smaller decline in prices in high-income metropolitan areas compared to those suffered in low income areas. The differential effects are economically sizable; a city with an income per capita that is \$1000 higher than the average gets one percentage point less cumulative inflation after a monetary policy shock of one hundred basis points after twenty quarters.

To illustrate further the economic relevance of our estimated heterogeneous effects, the bottom panel of Figure 7 shows the effect for cities in the 10th percentile of the income distribution versus cities in the 90th percentile, giving a sense of the quantitative

Figure 7: Effect of Monetary Policy and Income Heterogeneity



Note: The top left and right panel of the figure shows the estimated coefficient $\hat{\beta}_p^h$ and $\hat{\gamma}_p^h$ from equation 10, respectively. We use $H = 24$, $J = 8$, and $K = 8$. Relative income per capita is denominated in 2000 dollars. The dashed lines show 90 percent intervals. Standard errors are clustered at the metropolitan area and time level. The bottom panel shows the point estimates of the impulse response for notional metropolitan areas in the 10th and 90th percentiles of the income distribution, together with the average response coming from the top left panel. The 90th percentile of the distribution is USD 3,060 higher than the average annual income, and the 10th percentile is USD 2,105 lower than the average annual income.

importance of our result throughout the geographical distribution of income. A monetary policy shock of the same size causes an effect on prices almost 50 percent larger for cities in the 10th percentile of the distribution compared to the average, and 50 percent milder in the richer 90th percentile compared to the average. Among cities as rich as those in the 90th percentile of the income distribution, we fail to detect negative effects of monetary policy shocks on prices.

Although the effects for headline CPI are appealing, headline prices are not free of shortcomings. Since regions can vary in their expenditure weights, it could be the case that our results emerge from differences in weights rather than differences in the prices of different categories. The comparison of the sub-components of the CPI allows us to dig deeper into the mechanism behind our main results.

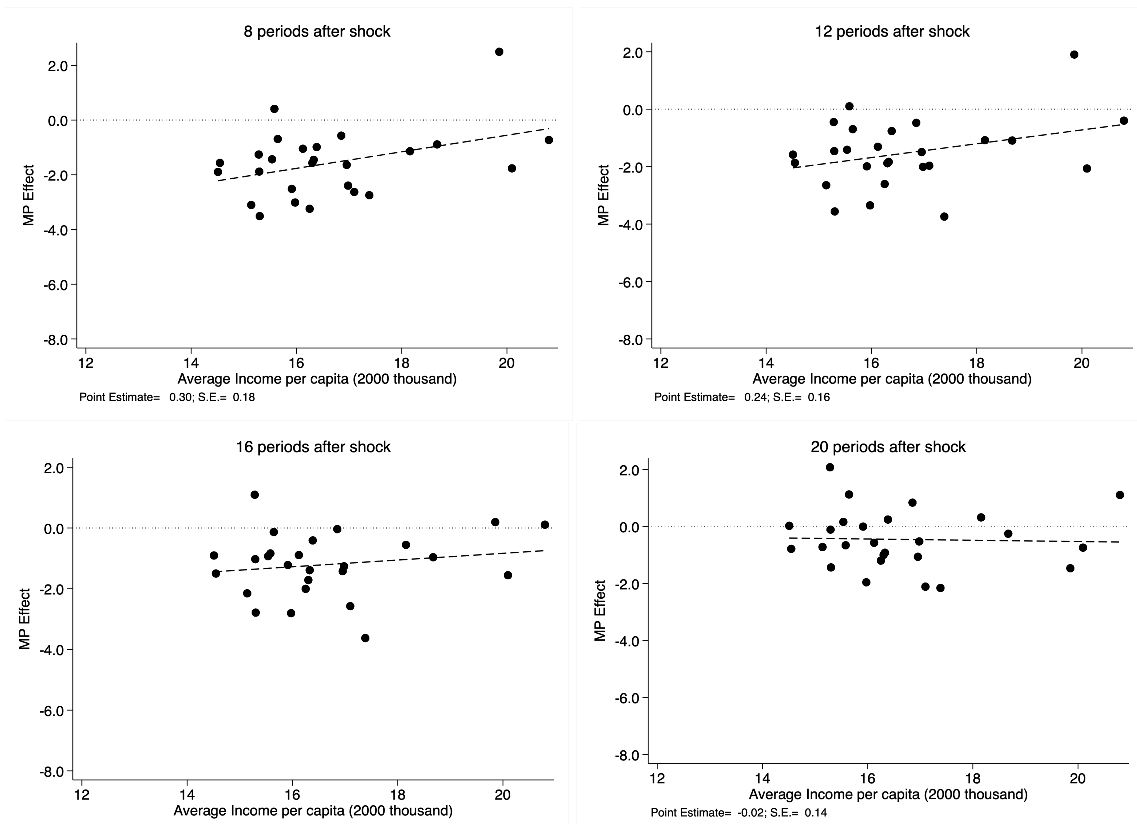
Our results hold across goods with a differential degree of tradeability, with larger differential effects for consumer categories that are closer to being non-traded. Figure A.2 in the Appendix shows our estimated impulse responses for "food at home,", a category with a substantial tradeable component, and "food away from home," a category with a large non-tradeable component. In Appendix A.1, Figure A.4 shows similar results for "housing," which also has a large non-tradeable component due to the relevance of shelter in that consumption category. Figure A.2 is in line with the intuition that the relative effects in the right panel should be larger for consumption categories that have a larger non-tradeable component to them, since intuitively, consumption and pricing of those goods depends on local economic conditions more than for the case of tradeable goods.

We provide results for gasoline, a highly tradeable, homogeneous, flexible-price good, which we show in Figure A.3. Gasoline has very flexible prices (see Nakamura and Steinsson (2008)), with a frequency of price change of once every month. Its price change behavior is dominated by national and world events, implying that our heterogeneous results as a share of the average results must be smaller. This is what we find, prices react less in regions with higher average income, and using conservative standard errors the effects are insignificant. We take these results as indicative that our findings are not driven by particular regional differences in particular aspects of a small set of consumer expenditure categories.

5.1 Economic Activity

We now present analogous results for employment at the local level. We start by running local projections for each city, and sorting these cities by their average income levels. Figure 8 plots the results 8, 12, 16, and 20 quarters after a shock that tightens rates by 1 percent.

Figure 8: Effect of Monetary Policy Shock on Employment by Metropolitan Area



Note: The figure shows the results of equation (1) for each individual metropolitan area and employment growth as the dependent variable. We use $J = 8$, and $K = 8$. The upper-left panel plots cumulative effects over 8 quarters, the upper-right panel 12 quarters, the lower-left panel 16 quarters and the lower-right panel 20 quarters.

Qualitatively similar to in Section 3, the effect in most of local markets is faster compared to the behavior of the impulse response for prices. Negative effects kick in

8 quarters after the shock. Lower income areas have, on average, larger negative employment effects. We can see that this pattern stays there after 12 quarters, but starts to dissipate after. The real effects of monetary policy dissipate 20 quarters after the shock, meaning that metropolitan areas return to their employment level prior to the shock.[8]

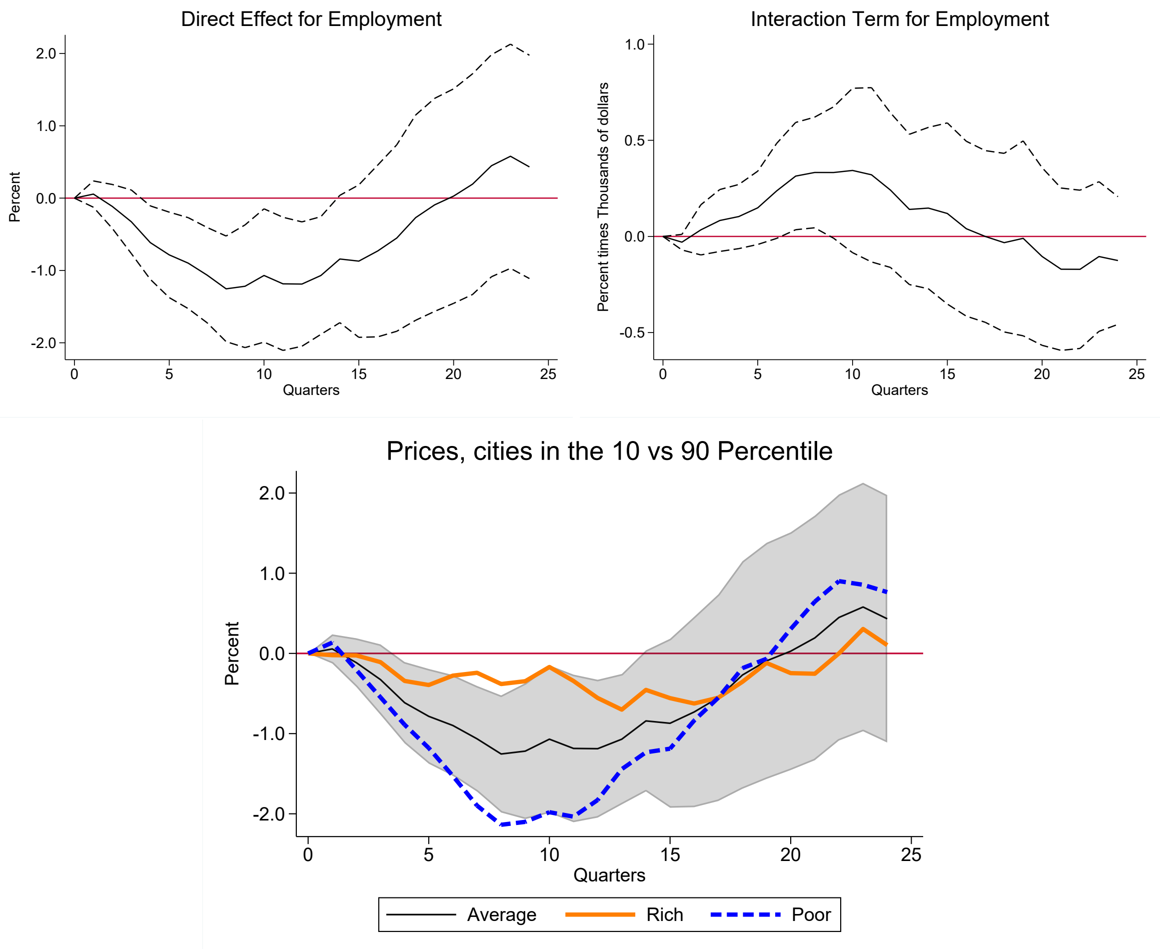
We estimate local projections with heterogeneous effects on the panel of metropolitan areas, following our approach of interacting the Romer and Romer (2004) shock with the pre-existing metro area real personal income per capita. The upper panel of Figure 9 presents the direct and interaction effects. We estimate a significant effect of the interaction term that dampens the negative effects for richer cities. The interaction term goes in the opposite direction of the direct effect; higher-income areas have smaller relative employment declines when the direct effect is negative. When employment starts to recover on average, high income metropolitan areas experience smaller improvements. These results together imply smaller causal effects on employment to monetary policy shocks in high-income areas.

The lower panel of Figure 9 shows the effect for a city in the 10th percentile of real relative income versus a city in the 90th percentile. Our results indicate that poor cities shape the national profile of employment effects. We do not find significant employment effects for areas with income as high as those in the 90th percentile of the geographic income distribution. Metro areas with income as low as those in the 10th percentile of the distribution have employment losses two times as large as those observed on average.

Figure 9 shows that the effects of monetary policy shocks during the first 15 quarters are negligible in high-income areas, while the peak response for a low-income area is roughly 2 percent, which reverts after 15 quarters. Low income metropolitan areas drive the national effects: the effects of metropolitan areas with higher income are small throughout the horizon of the impulse response function.

[8]That the slope of the effect of employment as a function of income reaches zero means that employment goes back to their pre-shock value in levels.

Figure 9: Effect of Monetary Policy Shock and Income Heterogeneity for Employment



Note: The top left and right panel show the estimated coefficients $\hat{beta}^h$ $\hat{gamma}^h$, respectively when the left-hand side variable in equation (10) for private employment. We use $H = 24$, $J = 8$ and $K = 8$. The dashed lines show 90 percent intervals. Standard errors are clustered at the city and time level. The lower panel shows the point estimates $\beta^h + \gamma^h RPIPC_{i,t+h}$ of equation (10) for metropolitan areas in the 90th and 10th percentiles of the geographic income distribution along with the average effects from the top left panel. The 90th percentile of the employment distribution is 4,755 USD (in 2000 dollars) higher than the average annual income, while the 10th is 3,596 USD (in 2000) lower than the average annual income.

5.2 Robustness

The main heterogeneous results use the Romer and Romer (2004) shock and heterogeneous results by relative personal income per capital of a given metropolitan area. In this section, we explore robustness of these results to other forms of heterogeneity and other sources of monetary policy shocks.

A natural candidate as a source of heterogeneity is to include differences in industrial composition across local areas. Sectors might be heterogeneous in their exposure to interest rate changes, or changes in aggregate demand within the set of metropolitan areas from which the price data comes, which are large, urban areas. A natural question is whether focusing on sectoral heterogeneity is sufficient to understand the differential effects of monetary policy we documented.

Even if cities might have a distinct industrial composition, it is unclear whether average income is a function of industrial composition or the other way around. Industries might sort across cities due to the demographic characteristics of the population, or workers might migrate to a city due to its industrial composition. That discussion is beyond the scope of this paper. It is important to highlight that the metropolitan areas that the BLS samples are large, complex, and financially developed. We do not include any data on small cities or rural areas.

As the role of industrial composition is not clear, we extend our main regression 10 by including as a control time-fixed effect interacted with lagged local sectoral employment shares. Figure A.6 presents the results. The heterogeneous effects are qualitatively similar to our benchmark specification and still significant, highlighting the relevance of the regional dimension of the data. To unpack the employment shares that are important in generating our result, Figure A.5 in Appendix A.1 shows the results of including one sector shares at a time.

Another potential concern is that the shock in Romer and Romer (2004) identification assumption relies on the Greenbook forecast capturing anticipation effects on inflation and output. A reasonable concern to have is that the FOMC, at the same time, reacts differentially to future expected trends in some regions relative to others, and that *aggregate* Greenbook forecasts do not appropriately capture these *differential* expected future trends at the local level.

The concern is that while the Romer and Romer (2004) shock controls for information about the expected future trends of the national economy included in the information set of the FOMC, this shock might not clean anticipation effects about local economies. We test for this possibility and we find that the Romer and Romer (2004) is not predictable by local inflation rates. We also use other shocks related to monetary policy surprises. One is the series developed by Bu et al. (2021) and the second by Miranda-Agrippino and Ricco (2021). Results are presented in Appendix A.3. The direct effects of monetary policy shocks are lower for richer cities, which is the same we found using the Romer and Romer (2004) shock.

Using these shocks also allows us to evaluate our main effect on a sample size that covers the period after the Great Recession. We see that the results are robust to that extension of the period. In addition, these results are obtained with data from the 90s, excluding the Volcker disinflation period, which is one of the main sources of variation of the Romer and Romer (2004) shock according to Coibion (2012).

6 Aggregate Implications

In Section 5, we showed that the average relative income of a city is a relevant margin of heterogeneity for the local effects of monetary policy shocks on employment and prices. We showed our results are consistent with a model of a monetary union where regions differ in their share of hand-to-mouth (HtM) households. Aguiar et al. (2020) and Patterson (2019) show a large negative correlation of HtM (or high MPC consumers) with income at the individual level.

We use estimates of the relationship between income and MPCs produced by Patterson (2019) to characterize the average MPCs across cities in the US. Figure A.7 shows the evolution of MPCs for US cities since 1986 and their distribution. The median of the distribution has been relatively stable over time, with a slight decrease in recent years, but there is substantial heterogeneity across US cities.

This section explores the implications of the heterogeneity of regional MPCs to the transmission of monetary policy shocks across regions and their relevance to understanding the aggregate effects of shifts in the stance of monetary policy. We will run counterfactuals that vary the dispersion in the share of HtM households across locations keeping the national share of HtM households constant. We will use the model presented in Section 4.1 to back out the relevance of geographical heterogeneity in determining aggregate outcomes.

We impute the relationship between MPCs and income to individual earnings data from the CPS using estimates by Patterson (2019). We have a panel of MPCs for 177 metropolitan areas from 1986 to 2020.[9] We extend our model to include share of hand-to-mouth in both regions (λ_i), and compute the 90th and 10th percentiles of the distribution of hand-to-mouth to each region using the MPC estimates. In particular, the MPC out of transitory income shock for hand-to-mouth consumers is equal to 1, since the consume all their income. In the case of Ricardians consumers, such a shock would induce a direct effect equal to $(1-\beta)$. Then, after taking a stance on the time-preference parameter β, we can obtain a share of HtM λ_i. Specifically, $MPC_i = \lambda_i + (1-\lambda_i) * (1-\beta)$ or $\lambda_i = \frac{MPC_i - (1-\beta)}{\beta}$.

We use the parameter values summarized in table A.3. We simulate the model using two regions keeping the national average λ constant, but varying its geographical dispersion. Table 1 shows the results of the simulations.

[9] The start date is determined by changes in the geographical sampling of the CPS and our intention to have a balanced panel of metropolitan areas.

Table 1: Simulation of Heterogeneous and Homogeneous Monetary Union

	Heterogeneity			Homogeneity		
	Region 1	Region 2	Aggregate	Region 1	Region 2	Aggregate
Share of HtM	70.2	57.9	64.0	64.0	64.0	64.0
Employment	-1.739	-0.440	-1.090	-0.799	-0.799	-0.799
Consumption	-2.174	-0.005	-1.090	-0.799	-0.799	-0.799
Real Wage	-3.334	-0.298	-1.816	-1.331	-1.331	-1.331
Inflation	-0.197	-0.097	-0.147	-0.114	-0.114	-0.114

Note: This table shows the effect on impact of a monetary policy shock of 1 percentage points on employment, inflation, consumption, and the real wage. We introduce the same experiment for economies with heterogeneity in the share of hand-to-mouth consumers, and without heterogeneity in hand-to-mouth consumers. Both economies have an average share of hand-to-mouth consumers of 64%. Columns 2 to 4 (heterogeneity) show the effect of the shock in an economy with heterogeneous values of HtM across regions. We show the results for each region (columns 2 and 3) and the aggregate economy (column 4). Columns 5 to 7 show the same effects, but for an economy where regions have the same share of hand-to-mouth consumers. All the numbers are shown in percentage points.

Table 1 contains two main messages. The first one, is that heterogeneity is very important to understand the transmission of monetary policy to different aggregates. In standard textbook models, the reaction of employment and consumption to a monetary policy shock are equivalent, and that equivalence still holds in our economy at the aggregate level (the second and third row of the *Aggregate* columns contain the same numbers). However, the heterogeneity in hand-to-mouth consumers we use, generates significant dispersion in the responses of consumption relative to production at the local level. After a common monetary policy shock, consumption for households in Region 2 is almost neutral, while consumption in region 1 contracts more than their production. The response of real wages in Region 1 is more than 10 times higher than that in region 1. There is an important disparity of inflation across space.

Hand-to-mouth consumers use their labor supply as their only available means to smooth consumption. In our parameterization, HtM households do not adjust their labor supply, while Ricardian agents reduce their hours worked as the real wage falls. Declines in economic activity introduce additional downward pressure on the real wage in regions with a higher share of hand-to-mouth consumers in equilibrium.

Since consumption falls more than production in Region 1, there is a reallocation of consumption from Region 1 into Region 2. The effect on prices are relatively smaller, which is a result of our assumption of having only tradable goods that are relatively substitutable.

The second message of Table 1 is that heterogeneity in MPCs amplifies the response of the aggregate economy to monetary policy. Amplification arises due to the non-linear effects of the share of hand-to-mouth consumers described in Bilbiie (2020). After a contractionary monetary policy shock, Ricardian agents reduce consumption and labor supply, reducing real wages in the local region. The effect on real wages makes hand-to-mouth (HtM) consumers reduce their spending as they consume exclusively from their labor income. The reduction in local wages, common for a given region by our assumption of integrated local labor markets, produces an additional decrease in demand in the local economy that depends on the share of hand-to-mouth households. This additional effect reduces marginal costs, increasing profits and producing an income effect.[10]

This effect depends critically on the labor supply elasticity (determined by α in our model), and it is non-linear in the share of hand-to-mouth consumers. The higher the share of HtM, the higher the effect in absolute value and at an increasing rate. Because of this non-linearity, the average effect is also larger in absolute value when there is a region with a higher share of HtM compared to the average. Therefore, the higher the dispersion of HtM, the higher the effect will be. Heterogeneity across regions amplifies the effect of monetary policy on both employment and prices.

7 Conclusions

This paper documents the differential regional effects on real and nominal variables of monetary policy shocks in the US. We find that cities that experience larger price effects also experience larger employment effects. The positive covariance of price and

[10]See Bilbiie (2008) for details on the conditions for this equilibrium.

employment effects is significant and robust to include the variation of individual estimates. We evaluate a set of economic mechanisms typically discussed in the New Keynesian literature to document which are consistent with our results. We propose a model in which a different fraction of hand-to-mouth consumers characterizes regions. By affecting the sensitivity of consumption to real interest rates, the model rationalizes the larger employment and price responses we estimate in the data. Models with variation in intertemporal elasticities of substitution can also explain our results. On the contrary, models in which differential slopes of the Phillips curve characterize regions fail to rationalize our findings since they would imply lower employment responses in areas with higher price responses.

More sensitive regions tend to have lower income, and income is a key covariate behind MPC variation. We estimate that monetary policy shocks induce larger effects on prices and employment in low-income metropolitan areas. The price results hold for overall prices and a wide range of consumer expenditure categories.

The effects we estimate are economically large and suggest an important challenge for the monetary authority since the power of its main tool varies across regions. This challenge is compounded for the case in which regions have differential exposure to the underlying shocks, as in trade shocks (Autor et al. (2016)), or government spending shocks (Nakamura and Steinsson (2014)).

Our results highlight the potential role of fiscal policy in generating the same aggregate effects as those induced by monetary policy, but with different local effects, as studied in the literature on equivalence results between monetary and fiscal policies (Wolf (2021)). Along that same line, the results of this paper highlight the potential complementary role of fiscal policy in correcting undesirable distributional effects of monetary policy.

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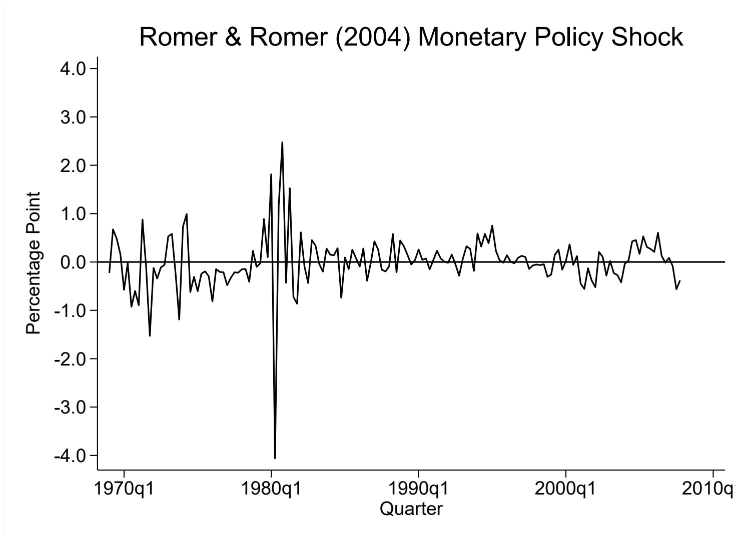
A Appendix

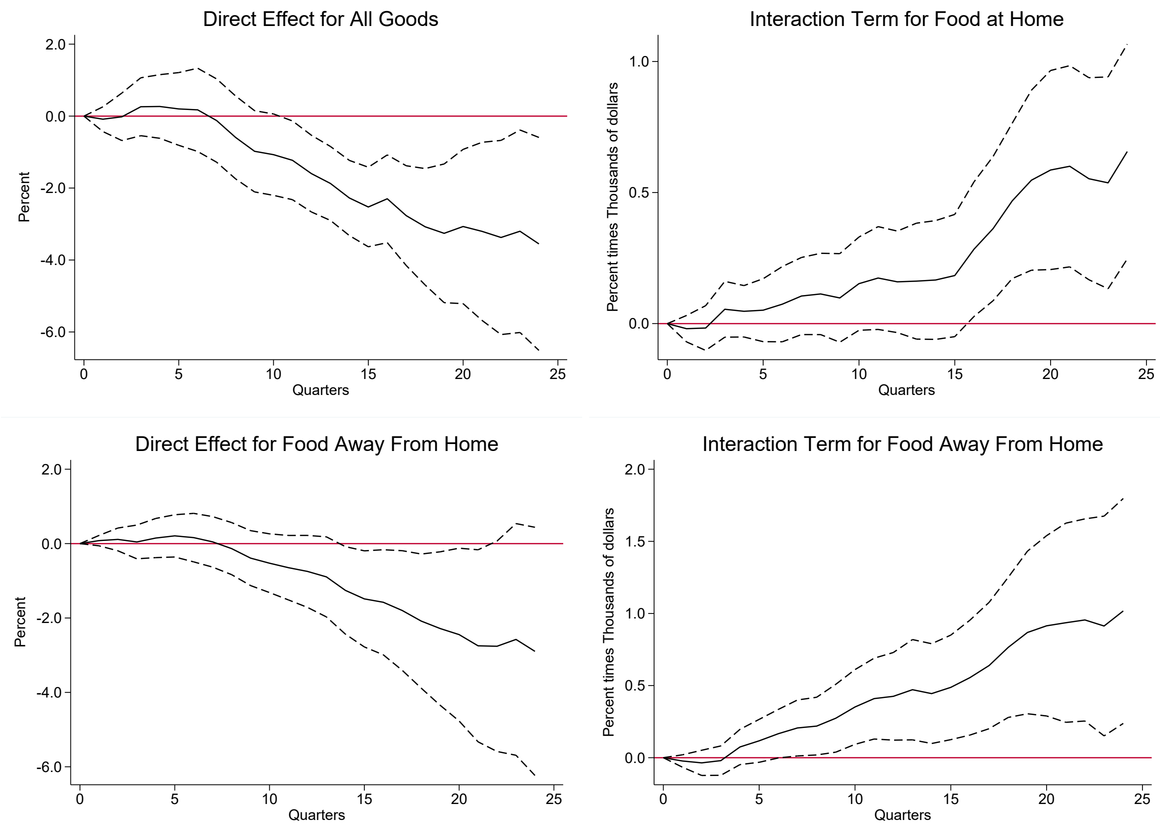
A.1 Additional Figures

Figure A.1: Romer and Romer (2004) Monetary Policy Shock



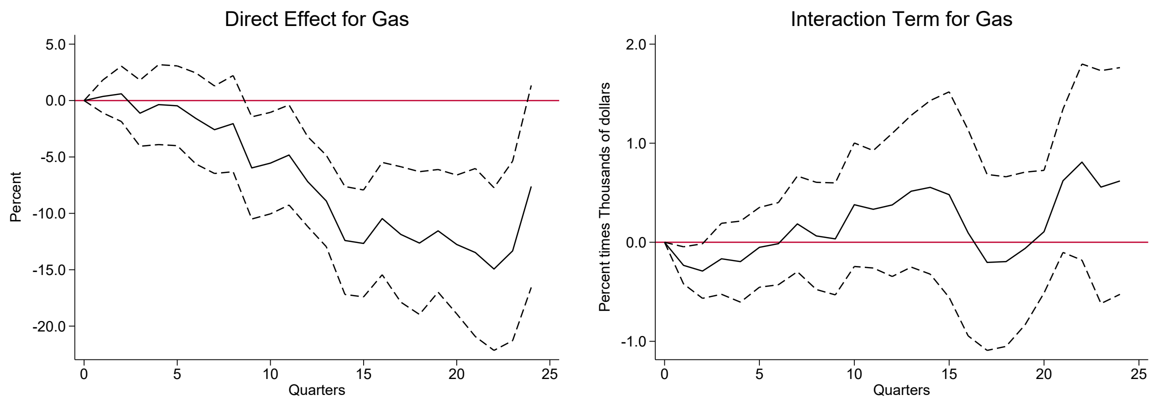
Note: This figure plots the Romer and Romer (2004) monetary policy shocks extended by Wieland and Yang (2020) aggregated at a quarterly level. We aggregate monetary policy shocks at a quarterly frequency by computing a sum of the monthly-level shocks.

Figure A.2: Monetary Policy Shocks and Income Heterogeneity - By Tradeability



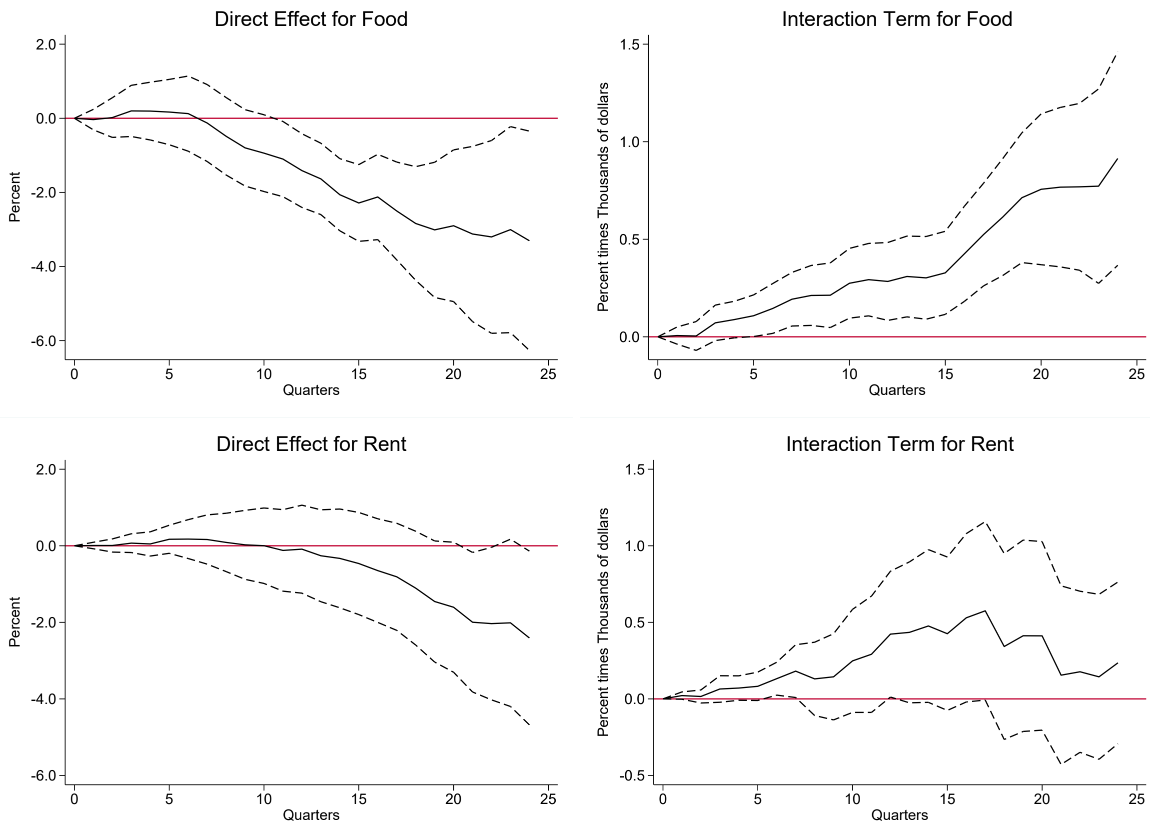
Note: The left panel shows the β^h coefficient and the right panel shows the γ^h coefficient of equation (10) for Food Away From Home. We use $H = 24$, $J = 8$, and $K = 8$. The dashed lines show 90 percent intervals. Standard errors are clustered at the city level.

Figure A.3: Effect of Monetary Policy Shock and Income Heterogeneity for Gas



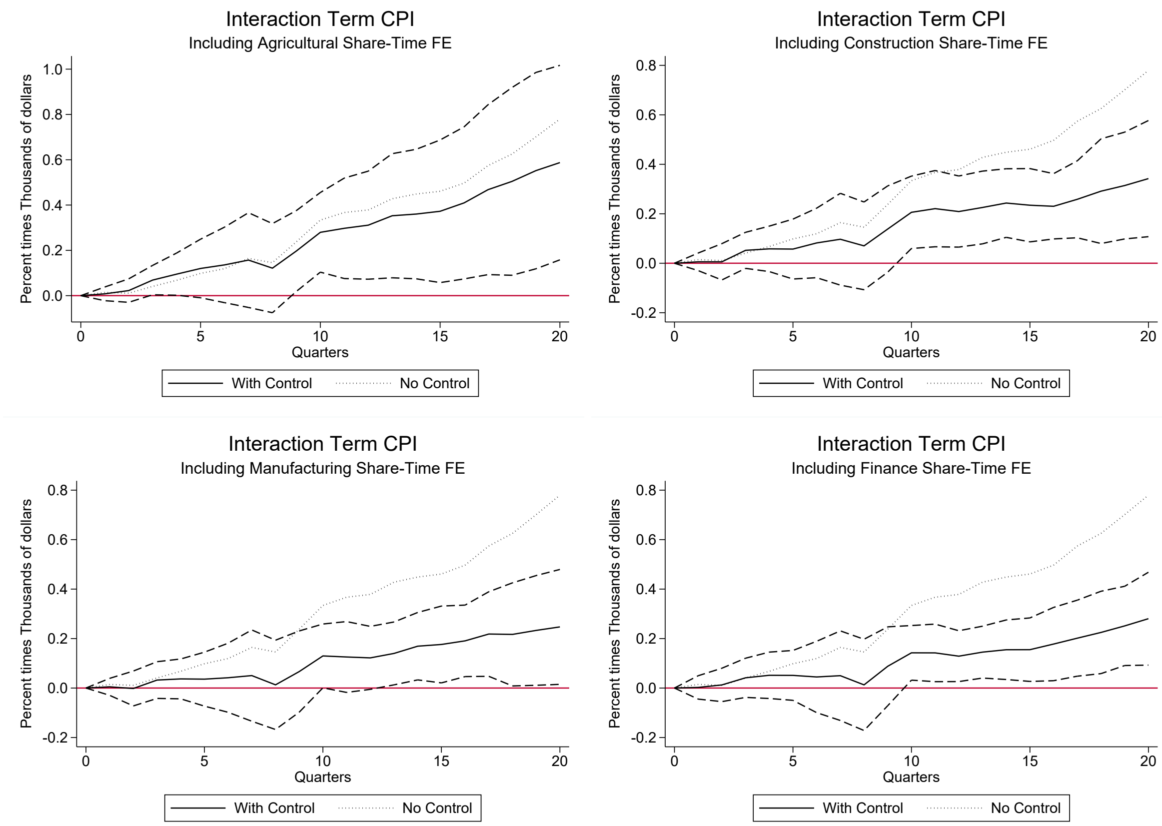
Note: The left panel shows the β^h coefficient and the right panel shows the γ^h coefficient of equation (10) for gasoline (regular).We use $H = 24$, $J = 8$, and $K = 8$. The dashed lines show 90 percent intervals. Standard errors are clustered at the city level.

Figure A.4: Effect on Narrow Price Indexes



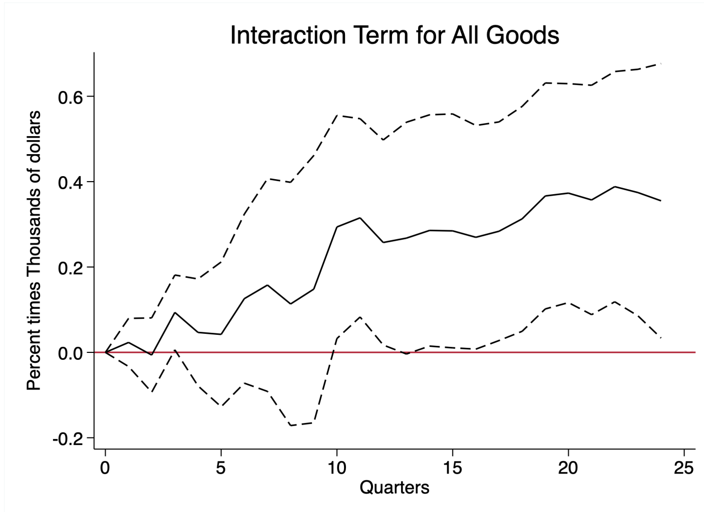
Note: The left panel shows the β^h coefficient and the right panel shows the γ^h coefficient of equation (10) for different price indexes. We use $H = 20$, $J = 8$ and $K = 8$. The dashed lines show 90 percent intervals. Standard errors are clustered at the city level.

Figure A.5: Effect on Narrow Price Indexes



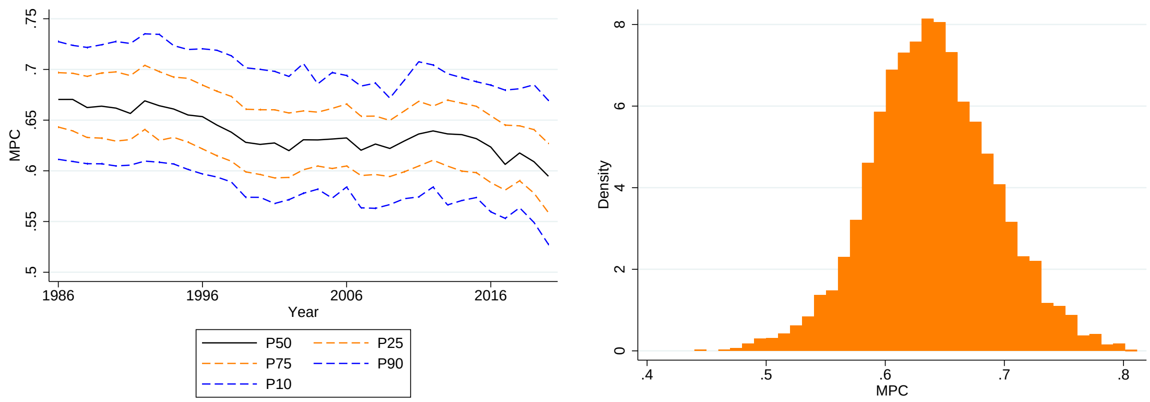
Note: Each figure shows the baseline regression for CPI inflation, controlling by a time fixed effect interacted by the share of employment in the sector indicated in each graph for each city. Agriculture is sector SIC A. Construction is sector SIC C. Manufacturing is sector SIC D and Finance is sector SIC H. We use $H = 20$, $J = 8$ and $K = 8$. The dashed lines show 90 percent intervals. Standard errors are clustered at the city and time level. The dot line shows the baseline regression result.

Figure A.6: Effect with Controls



Note: The figure shows the baseline regression for CPI inflation, controlling by a time fixed effect interacted by the share of employment in agriculture (sector SIC A), construction (sector SIC C), manufacturing is sector (SIC D), and the finance is sector (SIC H). We use $H = 20$, $J = 8$ and $K = 8$. The dashed lines show 90 percent intervals. Standard errors are clustered at the city and time level. The dot line shows the baseline regression result.

Figure A.7: Distribution of MPCs in the US over Time



Note: These figures show the distribution of the marginal propensity to consume across US metropolitan areas and over time. We use the estimates from Patterson (2019) and compute them for each metropolitan area at every period of time. The left panel shows the evolution over time for the mean (solid black), 25th and 75th percentile (orange dashed) and 10th and 90th percentile (blue dashed) between 1986 and 2020. The right panel is a histogram that shows the complete distribution of values and their density for all periods of time and year.

A.2 Correspondence CPI and QCEW

To merge the CPI and employment data, we get the counties according to the FIPS code that match the PSU zones. The PSU zones have changed over time, so we take the larger set of counties, as adding or removing counties would change employment as well. We keep the numbers of counties constant over the sample. Table A.1 shows the correspondence, with the PSU codes and name and FIPS codes.

Table A.1: Commuting zone and equivalent FIPS codes

PSU 18	PSU 98	Name	FIPS			
S11A	A103	Boston-Cambridge-Newton (MA-NH)	25009	25025	25013	23031
			25017	33015	25027	9015
			25021	33017	33011	
			25023	25005	33013	
S12A	A101	New York-Newark-Jersey City (NY-NJ-PA)	34003	34031	36061	42103
			34013	34035	36071	34021
			34017	34037	36079	34041
			34019	34039	36081	9001
			34023	36005	36085	9005
			34025	36027	36087	9007
			34027	36047	36103	9009
			34029	36059	36119	
S12B	A102	Philadelphia-Camden-Wilmington(PA-NJ-DE-MD)	10003	34015	42045	34009
			24015	34033	42091	34011
			34005	42017	42101	
			34007	42029	34001	
S23A	A207	Chicago-Naperville-Elgin (IL-IN-WI)	17031	17089	17197	18127
			17037	17093	18073	55059
			17043	17097	18089	17091
			17063	17111	18111	
S23B	A208	Detroit-Warren-Dearborn, (MI)	26087	26125	26049	26161
			26093	26147	26091	
			26099	26163	26115	
S24A	A211	Minneapolis-St. Paul-Bloomington (MN-WI)	27003	27053	27123	27163
			27019	27059	27139	27171
			27025	27079	27141	55093
			27037	27095	27143	55109
S24B	A209	St. Louis (MO-IL)	17005	17117	29071	29189
			17013	17119	29099	29510
			17027	17133	29113	28149
			17083	17163	29183	29055
S35A		Washington-Arlington-Alexandria (DC-MD-VA-WV)	11000	51510	51061	51179
			24009	51013	51630	51187
			24017	51043	51107	51685
			24021	51047	51153	54037
			24031	51600	51157	
			24033	51610	51177	
S35E		Baltimore-Columbia-Towson (MD)	24003	24510	24025	24035
			24005	24013	24027	

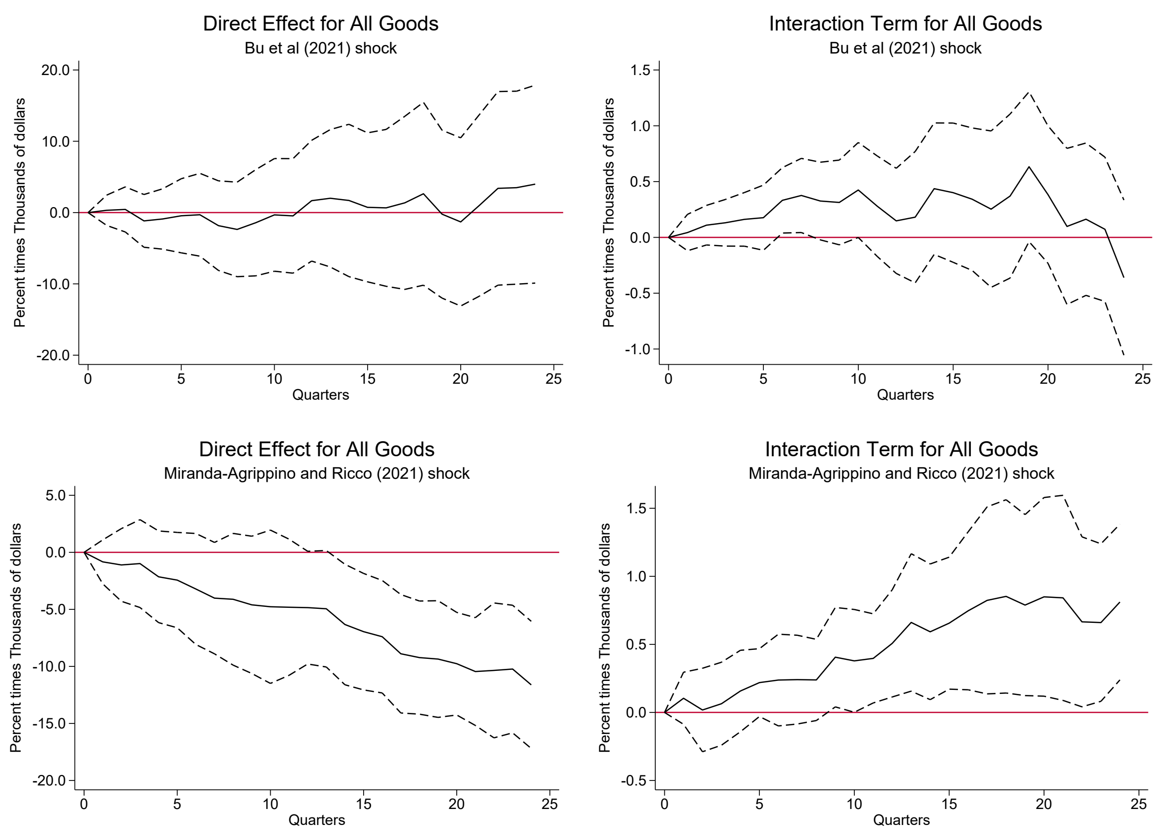
Table A.2: Commuting zone and equivalent FIPS codes (cont)

PSU 18	PSU 98	Name	FIPS			
S35B	A320	Miami-Fort Lauderdale-West Palm Beach (FL)	12011	12025	12086	
S35C	A319	Atlanta-Sandy Springs-Roswell (GA)	13013	13085	13149	13227
			13015	13089	13151	13231
			13035	13097	13159	13247
			13045	13113	13171	13255
			13057	13117	13199	13297
			13063	13121	13211	
			13067	13135	13217	
			13077	13143	13223	
S35D	A321	Tampa-St. Petersburg-Clearwater (FL)	12053	12057	12101	12103
S37A	A316	Dallas-Fort Worth-Arlington (TX)	48085	48221	48367	48497
			48113	48231	48397	
			48121	48251	48425	
			48139	48257	48439	
S37B	A318	Houston-The Woodlands-Sugar Land (TX)	48015	48157	48291	
			48039	48167	48339	
			48071	48201	48473	
S48A	A429	Phoenix-Mesa-Scottsdale (AZ)	4013	4021		
S48B	A433	Denver-Aurora-Lakewood (CO)	8001	8019	8039	8093
			8005	8031	8047	8013
			8014	8035	8059	8123
S49A		Los Angeles-Long Beach-Anaheim (CA)	6037	6059		
S49C		Riverside-San Bernardino-Ontario(CA)	6065	6071		
S49B	A422	San Francisco-Oakland-Hayward (CA)	6001	6075	6085	6097
			6013	6081	6087	
			6041	6055	6095	
S49D	A423	Seattle-Tacoma-Bellevue (WA)	53033	53061	53035	
			53053	53029	53067	
S49E	A424	San Diego-Carlsbad (CA)	6073			
S49F	A426	Urban Hawaii	15003			
S49G	A427	Urban Alaska	2020	2170		
	A104	Pittsburgh (PA)	42003	42019	42125	
			42007	42051	42129	
	A213	Cincinnati-Hamilton (OH-KY-IN)	18029	21077	39015	39165
			18115	21081	39017	
			21015	21117	39025	
			21037	21191	39061	
	A210	Cleveland-Akron (OH)	39007	39055	39093	39133
			39035	39085	39103	39153
	A212	Milwaukee-Racine (WI)	55079	55101	55133	
			55089	55131		
	A425	Portland-Salem (OR-WA)	41005	41047	41053	41071
			41009	41051	41067	53011
	A214	Kansas City (MO-KS)	20091	20209	29049	29165
			20103	29037	29095	29177
			20121	29047	29107	

A.3 Other Shocks

In this Appendix, we run regression (10) for prices, with the interaction on income using different sources of shock. We use the Bu et al. (2021) shock and the Miranda-Agrippino and Ricco (2021) shock. The Bu et al. (2021) is available from 1994 to 2017 in the case of our sample and the Miranda-Agrippino and Ricco (2021) from 1990 to 2015. We plot the direct and indirect effect.

Figure A.8: Effect of Monetary Policy and Income Heterogeneity with Alternative Shocks



Note: The top left and right panel of the figure shows the estimated coefficient $\hat{\beta}^h$ and $\hat{\gamma}^h$ from equation 10, respectively using the Bu et al. (2021) shock. The bottom left and righ panel use the Miranda-Agrippino and Ricco (2021) shock. We use $H = 24$, $J = 8$, and $K = 8$. The relative income per capita numbers are year 2000 dollars. The dashed lines show 90 percent intervals. Standard errors are clustered at the metropolitan area and time level.

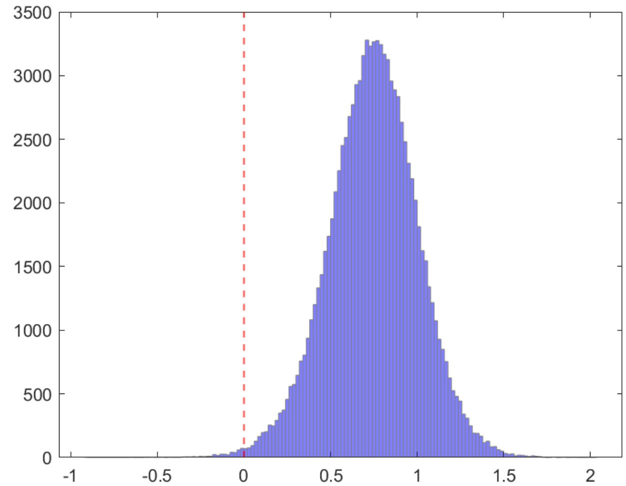
We can see that, despite the direct effect, the interaction term shocks that the effect is milder or more positive for the richer cities, as with the Romer and Romer (2004) shock.

A.4 Robustness Positive Relationship Between Price and Employment result

Figure 3 uses point estimate results of equations 4 and 3. However, Figure 3 does not take into account that each point in the scatter plot is estimated with uncertainty. In this section, we perform robustness exercises to confirm the positive slope, considering the uncertainty around the coefficients.

The plot is built with 26 coefficients for CPI and employment. We assume normal distributions for each coefficient and independence across coefficients. We simulate 100,000 random draws of the coefficients using the standard errors underlying each estimate. For each draw, we run the same regression as in Figure 3 and collect the slope coefficient analogous to the dotted line in Figure 3. Figure A.9 shows the histogram of the estimated slopes. We find that 99.6 percent of the draws give as a result a positive relationship between price and employment effects.

Figure A.9: Result of a Regression for Simulated Coefficients of City Employment and Price Regressions



Note: The figure is an histogram of the coefficients from 100,000 regressions of the city level effect of a monetary policy shock on prices and employment, where those coefficients are built using the all sample point estimate, and the standard deviation of those coefficients. Then, we simulate coefficients independently, using random draws assuming a normal distribution.

Additionally, in this section we formally test the slope of Figure 3 by estimating the relative effect of a monetary policy on inflation relative to the effect on employment.

The local projection of local cumulative inflation on a monetary policy shock takes the form of

$$\pi_{i,t+h,t-1} = \alpha^{h}_{p,i} + \sum_{j=0}^{J} \beta^{h,j}_{p,i} RR_{t-j} + \sum_{k=0}^{K} \gamma^{h,k}_{p} \pi_{i,t-1,t-1-k} + \varepsilon^{h}_{p,i,t+h} \ \ \forall h \in [0, H], \tag{11}$$

where we allow for the effect of the monetary policy shocks on prices to be different for each metropolitan area, see the notation $\beta^{h,j}_{p,i}$.

Similarly the local projection of cumulative employment growth on the monetary policy shock is given by

$$\sum_{\tau=0}^{h} g^{e}_{i,t+\tau,t-1} = \alpha^{h}_{i,e} + \sum_{j=0}^{J} \beta^{h,j}_{e,i} RR_{t-j} + \sum_{k=0}^{K} \gamma^{h,k}_{e} g^{e}_{i,t,t-k} + \varepsilon^{h}_{e,i,t+h} \;\; \forall h \in [0, H], \tag{12}$$

where again, we allow the impact of a monetary policy shock on employment to be different across regions, and notice that the left hand side variable is the area below the curve of the cumulative employment changes.

We add the additional constraint that we want to estimate, a linear relation between the causal effects of the monetary policy shock on prices relative to the causal effect of those same shocks on employment. Formally, we want to estimate for the coefficient φ such that,

$$\sum_{j=0}^{J} \beta^{h,j}_{p,i} RR_{t-j} = \varphi_h \times \left(\sum_{j=0}^{J} \beta^{h,j}_{e,i} RR_{t-j} \right). \tag{13}$$

By replacing equation 13 on equation 11, and replacing equation 12, we find

$\pi_{i,t+h,t-1} = \alpha^{h}_{p,i} + + \varphi_h \alpha^{h}_{i,e} + \varphi_h \sum_{\tau=0}^{h} g^{e}_{i,t+\tau,t-1} - \varphi_h \sum_{k=0}^{K} \gamma^{h,k}_{e} g^{e}_{i,t,t-k} + \sum_{k=0}^{K} \gamma^{h,k}_{p} \pi_{i,t-1,t-1-k} + \varepsilon^{h}_{p,i,t+h} - \varphi_h \varepsilon^{h}_{e,i,t+h} \;\; \forall h \in [0, H]$,

which we can represent in a more concise way as

$$\pi_{i,t+h,t-1} = \alpha^{h}_{2s,i} + \varphi_h \sum_{\tau=0}^{h} g^{e}_{i,t+\tau,t-1} - \sum_{k=0}^{K} \gamma^{h,k}_{e,2s} g^{e}_{i,t,t-k} + \sum_{k=0}^{K} \gamma^{h,k}_{2s,p} \pi_{i,t-1,t-1-k} + \varepsilon^{h}_{2s,i,t+h} \;\; \forall h \in [0, H], \tag{14}$$

and we can estimate using the monetary policy shocks as instruments for $\sum_{\tau=0}^{h} g^{e}_{i,t+\tau,t-1}$.

The results for the estimation are in Figure A.10. The figure shows in the y-axis estimates of φ_h for each horizon h between 1 and $H = 20$. In other words, each point represents a slope for a given horizon in a plot similar to Figure 3. The orange area shows the 95% confidence interval. Standard errors are clustered at the city and time dimension.

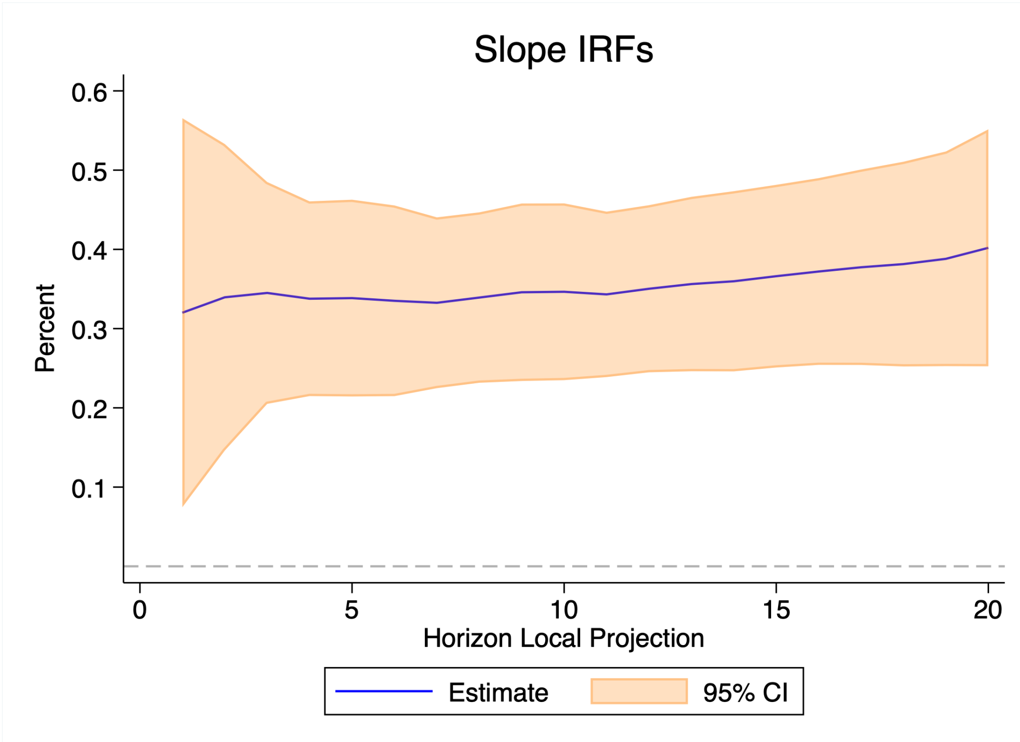


Figure A.10: Slope between the impulse responses of inflation and employment

A.5 TANK Monetary Union

In this appendix we present the log-linearized equations that characterize the model explained in Section 4.1. In the following equations, lower case represents deviation from the steady state, other than for the case of the price index $P_{j,t}$ and the inflation of the price index $\Pi_{j,t}$, to differentiate it from the price of the good produced in j, $p_{j,t}$ and the price inflation $\pi_{j,t}$.

$$\pi_{H,t} = \kappa mc_{H,t} + \beta \pi_{H,t+1}$$

$$\pi_{F,t} = \kappa mc_{F,t} + \beta \pi_{F,t+1}$$

$$c_{HR,t} = -\frac{1}{\gamma}(i_t - \Pi_{H,t+1}) + c_{HR,t}$$

$$c_{HH,t} = w_{H,t} - P_{H,t} + l_{HH,t}$$

$$-\gamma c_{HR,t} + \gamma c_{F,t} = P_{H,t} - P_{F,t}$$

$$i_t = \phi_\pi(\Pi_{H,t} + \Pi_{F,t}) + \phi_y(y_{H,t} + y_{F,t}) + e_t$$

$$P_{H,t} = \phi p_{H,t} + (1-\phi) p_{F,t}$$

$$P_{F,t} = \phi p_{F,t} + (1-\phi) p_{H,t}$$

$$\Pi_{H,t} = P_{H,t} - P_{H,t-1}$$

$$\Pi_{F,t} = P_{F,t} - P_{F,t-1}$$

$$\pi_{H,t} = p_{H,t} - p_{H,t-1}$$

$$\pi_{F,t} = p_{F,t} - p_{F,t-1}$$

$$mc_{H,t} = \alpha y_{H,t} + (\gamma - (1/\nu)) c_{H,t} + (1/\nu)(\lambda c_{HH,H,t} + (1-\lambda) c_{HR,H})$$

$$mc_{F,t} = \alpha y_{F,t} + (\gamma - (1/\nu)) c_{F,t} + (1/\nu) c_{FF,t}$$

$$y_{H,t} = \lambda l_{HH,t} + (1-\lambda) l_{HR,t}$$

$$\gamma c_{HR,t} + \alpha l_{HR,t} = w_{H,t} - P_{H,t}$$

$$\gamma c_{HH,t} + \alpha l_{HH,t} = w_{H,t} - P_{H,t}$$

$$-c_{FF,t} + c_{FH,t} = \nu(p_{F,t} - p_{H,t})$$

$$-c_{HH,H,t} + c_{HH,F,t} = \nu(p_{H,t} - p_{F,t})$$

$$-c_{HR,H,t} + c_{HR,F,t} = \nu(p_{H,t} - p_{F,t})$$

$$c_{H,t} = \lambda c_{HH,t} + (1-\lambda) c_{HR,t}$$

$$c_{HH,t} = \phi c_{HH,H,t} + (1-\phi) c_{HH,F,t}$$

$$c_{HR,t} = \phi c_{HR,H,t} + (1-\phi) c_{HR,F,t}$$

$$c_{F,t} = \phi c_{FF,t} + (1-\phi) c_{FH,t}$$

Table A.3: Parameterization

Parameter	Explanation	Value
β	Discount factor	0.99
γ	Intertemporal elasticity of substitution	1
α	Inverse labor supply elasticity	2/3
η	Elasticity of substitution among local varieties	4
ν	Elasticity of substitution between Home and Foreign varieties	3
θ	Price stickiness	0.75
π_π	Taylor rule coefficient on inflation	1.5
π_y	Taylor rule coefficient on output	0.5
ϕ	Home bias coefficient	0.85
ρ	Monetary policy shock persistence	0

Note: This table presents the calibration of our model for every parameter except for θ and λ, which we vary in our main exercise.

$$y_{H,t} = \lambda\phi c_{HH,H,t} + (1-\lambda)\phi c_{HR,H,t} + (1-\phi)c_{FH,t}$$

$$y_{F,t} = \phi c_{FF,t} + \lambda(1-\phi)c_{HH,F,t} + (1-\lambda)(1-\phi)c_{HR,F,t}$$

$$\varepsilon_t = \rho\varepsilon_{t-1} + e_t$$

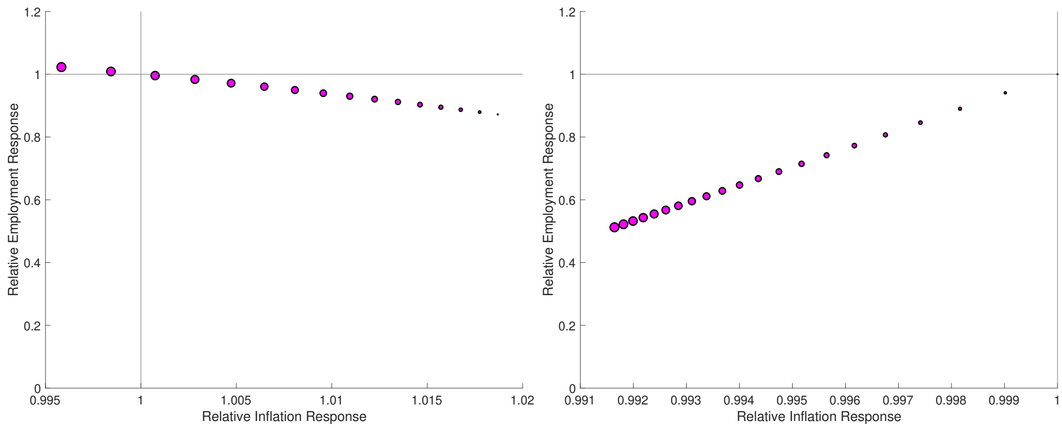


Figure A.11: Relative Price and Employment Responses - Labor Supply and IES

Note: These figures show the relative behavior of regional prices, on the x-axis, and employment, on the y-axis, after a national monetary policy shock. The source of regional heterogeneity is variation in the elasticity of labor supply (left panel) and the intertemporal elasticity of substitution (right panel). Relative inflation and employment are computed as the ratio between the discounted cumulative impulse response functions of each variable in the Home region divided by the analogous object in the Foreign region. A value of 1 means that Home and Foreign regions have responses of the same magnitude in present value. Each point of the scatterplot represents the solution of a model with different variations in the extent of nominal rigidities, labor supply or intertemporal elasticity of substitution. The calibrations that underlie the figure are in Appendix A.6.

A.6 Alternative New Keynesian Models

We simplify the model used in Section 4. In this case, we assume $\lambda = 0$, but we allow for regional heterogeneity in the parameters of the model. The model is characterized by the following equations:

$$\pi_{Ht} = \beta \mathbb{E}_t \pi_{H,t+1} + \kappa_H mc_{Ht} \tag{15}$$

$$\pi_{Ft} = \beta \mathbb{E}_t \pi_{F,t+1} + \kappa_F mc_{Ft} \tag{16}$$

with

$$mc_{Ht} = \alpha_H y_{H,t} + \left(\gamma_H - \frac{1}{\nu}\right) C_{H,t} + \left(\frac{1}{\nu}\right) C_{H,H,t} \quad (17)$$

$$mc_{Ft} = \alpha_F y_{F,t} + \left(\gamma_F - \frac{1}{\nu}\right) C_{F,t} + \left(\frac{1}{\nu}\right) C_{F,F,t} \quad (18)$$

where $C_{k,j,t}$ is the consumption of region k on region j good in time t. Since here $\lambda = 0$, there are only Ricardian agents; then the IS curve is characterized by:

$$C_{H,t} = -\frac{1}{\gamma_H} \left(i_t - E_t \Pi_{H,t+1}\right) + E_t C_{H,t+1} \quad (19)$$

For region F, we replace that condition with the risk-sharing condition (does not really matter which one we replace).

$$\gamma_H C_{H,t} - \gamma_F C_{F,t} = P_{F,t} - P_{H,t} \quad (20)$$

Finally, we have a national monetary policy rule that symmetrically weights both regions:

$$i_t = \phi_\pi (\pi_{Ht} + \pi_{Ft}) + \phi_y (y_{Ht} + y_{Ft}) + \varepsilon_t.$$

In Section 4, we allow for differences in the intertemporal elasticity of substitution γ_i, extent of nominal rigidities κ_i and the elasticity of labor supply α_i.

The values for α and γ we consider are values between 1 and 3. The values for θ that we consider are between 0.6 and 0.9. The benchmark values for these parameters for the Foreign region, which we keep fixed, are $\alpha = 1$, $\gamma = 1$, and $\theta = 0.75$.