Monetary Policy, Fiscal Federalism, and Capital Intensity

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February 2017

Abstract

Does monetary policy play a role in fiscal federalism? This paper presents a novel implication of monetary policy shocks by studying their heterogeneous effects across federal-states and their consequent connection to fiscal equalization. A two-region monetary union DSGE model with a federal equalization mechanism shows that capital intensive states experience a relatively larger contraction following a positive monetary policy shock, due to the greater share that capital takes in their production process. This, in turn, brings them greater inflows of federal grants. We show that state-heterogeneity in capital intensity is explained by levels of natural resource abundance over large periods, and hence by pre-determined geographical characteristics. Based on this identification strategy, we test the model's predictions using a panel of U.S. states over the period 1969-2007 and find that following a one standard deviation monetary policy shock, output growth (output share of federal transfers) in capital intensive states contemporaneously decreases (increases) by 1% relative to their counterparts, on average. In addition, we find no differential effects on other state-level economic indicators, consistent with the model.

JEL classifications: E52, H77

Keywords: Monetary policy, Fiscal federalism, Capital intensity

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1 Introduction

Over at least the past 30 years there has been a significant effort in macroeconomics to identify the causal effects of monetary policy on economic activity by studying the impact of shocks to central bank rate decisions.[1] Recently, research has begun to focus on the distributional implications of monetary policy by looking into the effects of monetary policy on economic inequality (see, e.g., Ledoit (2011), Brunnermeier and Sannikov (2013), Doepke et al. (2015), Gornemann et al. (2016), and Coibion et al. (2016)), in conjunction with a shift in policymakers' attention to the relation between monetary policy and economic inequality (see, e.g., Mersch (2014), Bullard (2014), Bernanke (2015), and Forbes (2015)).

It is, therefore, surprising that such a transition has not followed suit in the context of the relation between monetary policy and fiscal federalism, particularly in light of the recent big debate about the merits of fiscal equalization in the European Union (see, e.g., Obstfeld (2013) and Tabellini (2015)), and more generally, the major efforts of federal governments to fiscally equalize their nations using redistributive means.[2] This paper makes, to our best knowledge, a first attempt to fill this gap in the literature by addressing the following question: does monetary policy play a role in fiscal federalism? While the standard disconnect between policies of governments and central banks may render an institutionally-entrenched elusive direct link, we unravel a potential market-based nexus by focusing on the heterogeneous effects of monetary policy shocks across states in a federation, and the consequences thereof for fiscal equalization.

While a federation may provide a relatively homogenous environment, states within a federation nonetheless differ in virtually any economic indicator, ranging from prices to wages and productivity. One of those indicators relate to the extent to which states' production processes are dependent on capital. Some states are highly capital intensive, while others less so. As we show in the empirical part, in the case of the U.S. cross-state differences in the Gross State Product (GSP) share of capital compensation can be larger than 50% (for example, in the cases of Wyoming vs. Massachusetts). These significant cross-state differences in the capital share in production may lead to heterogeneous effects of monetary policy shocks across states. A monetary shock has a direct implication on the price of capital; hence, while it is uniform across the federation, its effects may differ across states' level of

[1] See Ramey (2016) for a detailed overview.

[2] Fiscal equalization is an issue of first order importance for federal governments. See discussions in Boadway and Shah (2009), and Qiao (1999) on the motivation for equalization. Martinez-Vazquez and Searle (2007) provide a summary of the related literature.

capital dependency in production. Our main hypothesis is that the output of states with a relatively high share of capital in production is more sensitive to monetary policy shocks compared to that of the remaining states; in turn, if an equity-based equalizing fiscal rule is implemented, an intra-federal monetary-fiscal nexus may be observed.[3]

We study the role of monetary policy shocks in fiscal federalism in two steps. First, we lay out a medium-scale two-region monetary union DSGE model with an equity-based fiscal equality transfer mechanism to study the theoretical implications that monetary policy shocks may have for fiscal equalization. The main result supports our conjecture. Monetary policy shocks affect output more strongly in the region that has a higher capital share in production, without creating a differential effect on investment and consumption. This outcome follows the abovementioned intuition: the region with the higher capital share in production is relatively more affected by a given change in capital due to a monetary policy shock. An important implication of this is that monetary policy shocks have the potential of inducing cross-regional fiscal inequality or equality, depending on the initial level of the income distribution and the nature of the monetary policy shock (i.e., contractionary or expansionary). Given an equity-based equalization rule, if the high capital share region is also the richer one then a contractionary (expansionary) monetary policy shock may reduce (increase) regional fiscal inequality.

Second, we put the model's predictions under empirical testing by adopting the case of the U.S. to estimate the heterogeneous effects of monetary policy shocks across U.S. states' level of capital share in production. We interact the annualized series of plausibly exogenous monetary policy shocks of Romer and Romer (2004), as updated by Tenyero and Thwaites (2016) for the period 1969-2007,[4] with the balance of the GSP share of labor compensation

[3]While we are the first to examine the role of monetary policy shocks in fiscal federalism, we are not the first to study potential heterogeneity in the regional effects of monetary policy shocks. Hurst et al. (2016) study regional heterogeneity and monetary policy in a quantitative spatial model of the U.S. housing and mortgage markets. Rubio (2014) and Sim et al. (2015) incorporate regional heterogeneity within a monetary union; the former allows for heterogeneous regional housing markets, and the latter include heterogeneous financial market frictions. Closer to our analysis are Carlino and DeFina (1998, 1999). They looked into the regional effects of monetary policy shocks, generally finding larger effects in regions in which the construction and manufacturing industries are more prevalent. We improve upon their work along two dimensions. First, their analysis focused on industry mix, rather than on capital intensity directly. This makes a potentially key distinction because they emphasize the interest rate channel which affects capital, yet capital intensity changes across time within industries. In contrast, we consider the role of capital shares, hence addressing time variations in within-industry capital intensities. Second, their identification strategy for estimating the effects of monetary policy shocks is subject to various econometric concerns; conversely, we make use of the state-of-the-art, plausibly exogenous, Tenyero and Thwaites (2016) shock series, which was not available at the time of their work.

[4]We annualize the raw quarterly series of Tenyero and Thwaites (2016) by summing up the corresponding

in the preceding period, and estimate its contemporaneous effect on a multitude of state-level outcome variables. Importantly, we show that state-heterogeneity in capital intensity is explained by levels of natural resource abundance over large periods, and hence by predetermined geographical characteristics. This forms the basis of our identification strategy, applied via an instrumental variable approach.

We find that following a one standard deviation monetary policy shock, output growth (GSP share of federal transfers) in capital intensive states contemporaneously decreases (increases) by 1% relative to their counterparts, on average; the similar (absolute value) magnitudes suggest an equity-based fiscal transfer rule, consistent with the model. In addition, we find no differential effects on other state-level economic indicators. Taken together, these results corroborate those of the theoretical analysis, indicating that monetary policy may affect federal redistribution via states' differences in capital share in production.

Our results are broadly consistent with those of the empirical work by Coibion et al. (2016), in the sense that monetary policymakers are not merely 'innocent bystanders' (as phrased by Coibion et al. (2016)) when it comes to the implications of their actions on important issues such as economic inequality. While Coibion et al. (2016) focus on the effects of monetary policy shocks on aggregate distributional measures of inequality in consumption and income, we take an entirely different approach in focusing on fiscal inequality across states within the U.S. using cross-sectional variation in U.S. states to identify cross-state heterogenous effects of monetary policy shocks. Interestingly, we find that contractionary monetary policy shocks reduce regional inequality because high capital intensive states are richer to begin with. Coibion et al. (2016), in contrast, find that contractionary policy shocks raise economic inequality in the U.S. This contrast, however, should be interpreted carefully because the direction with which contractionary policy shocks affect regional inequality in our setting depends on the initial level of regional income distribution.

The paper is related to three additional strands of literature. First is the literature on the nonlinear effects of monetary policy on the economy. The main aspect of the nonlinearity that was studied in this literature is whether monetary policy shocks have effects that vary over the business cycle (see Tenyero and Thwaites (2016) and references therein).[5] We contribute to this literature by putting forward a novel mechanism by which monetary policy shocks

quarterly observations.

[5]In the context of fiscal policy shocks, the last few years have seen quite a lot of work on the nonlinear effects of policy shocks. The focus has mainly been on whether fiscal policy has different effects at the zero lower bound and/or over the business cycle (see, e.g., Christiano et al. (2011), Auerbach and Gorodnichenko (2012), Sims and Wolff (2015, 2016), and Ramey and Zubairy (2014)).

may have nonlinear effects: the higher the level of capital share in production is, the stronger is the output effect induced by monetary policy shocks. Our use of the cross-section of U.S. states to identify this mechanism demonstrates that there can be merit in utilizing cross-sectional variation across U.S. states to identify potentially nonlinear effects of monetary policy shocks.

Second is the literature that studies the interaction between monetary unions and fiscal federalism. This literature has its roots in the pioneering works of Mundell (1961) and McKinnon (1963) on the classical theory of Optimum Currency Areas (OCA). OCA stresses the potential role of federal fiscal transfer systems as a policy tool that can ameliorate the effects of negative regional shocks in a Currency Union. More recently, this view has received more formal support from work based on micro-founded macroeconomic models (see, e.g., Evers (2012, 2015), Farhi and Werning (2014), and Verstegen and Meijdam (2016)). While these studies looked into the potential welfare gains resulting from federal fiscal transfer systems within a currency union, we emphasize the implications of monetary policy shocks for currency unions that operate alongside a fiscal union with a federal fiscal transfer system. Our results can be seen as providing support for the more general view that federal fiscal transfer systems can act as a stabilization tool in the face of asymmetric idiosyncratic regional shocks, since we find that monetary policy shocks can have effects that are not symmetric across the currency union, notwithstanding their aggregate nature.

Third is the literature on the feasibility of fiscal equalization and the consequences thereof. While being a primary objective, federal governments face major political challenges to fiscally equalize. Lockwood (2002) looks into the challenges related to distributive politics. Boadway (2006) discusses this in the Canadian context. Perez-Sebastian and Raveh (2016) illustrate that sufficient fiscal inequality may lead to secessions, and Albouy (2009) estimates the inefficiencies arising from partial equalization. We contribute to this literature by showing that monetary policy affects fiscal equalization, via its heterogeneous effects across states, and hence can correct or distort inter-state fiscal inequalities irrespective of the aforementioned politics related to federal redistribution.[6]

The paper is structured as follows. Section 2 elaborates on the issue of fiscal equalization in the U.S. Section 3 lays out the details of the model and the theoretical analysis. Section

[6]Nonetheless, given that monetary policy shocks are not shocks that affect the economy in the long-run, their role as a driver of regional redistribution is likely to be limited to short- to medium-run horizons. Long-run fiscal inequality is likely to be driven by other long-run factors such as technology and taxes; that said, we show that short to medium run fluctuations in fiscal inequality caused by monetary policy shocks can still be significant.

4 presents the empirical analysis. Section 5 concludes.

2 Fiscal Equalization in the U.S.

We start with a discussion on some of the relevant aspects of fiscal equalization in the U.S., being our primary focus in the analysis. Despite having large fiscal disparities across U.S. states (Yilmaz et al. (2006)), the federal U.S. government does not adopt a formal equalization mechanism. Nonetheless, equalization is undertaken indirectly via formula-based grant programs, which together with unequal burdens of federal taxation point at equity-based methods of equalization.

More specifically, the U.S. federal transfers system includes more than 900 specific grant programs, out of which approximately 15% distribute federal grant money by formula. Within the latter group, various programs employ an income-based formula, including Community Development, Medicaid, Vocational Education, and the (expired) General Revenue Sharing program, among others. Out of these programs Medicaid is by far the largest, most dominant one, accounting for approximately a third of total federal transfers. Importantly, its grants are allocated based on state differences in per capita income,[7] making it in effect a major equity-based redistributive tool.

However, beyond redistribution, these grants are in fact fiscally equalizing. To see this, consider the unequal burdens of federal taxation across the U.S. While being a uniform policy across the nation, federal taxation has heterogamous effects based on various factors, including for instance, the cost of living.[8] Albouy (2009) illustrates that individuals living in high income areas pay relatively more federal taxes in real terms, yet get back relatively less, given the aforementioned equity-based federal redistribution. He estimates that each year approximately $270 billion are transferred horizontally from low to high wage areas via this mechanism.

Hence, while the literature on fiscal federalism stresses both equity and efficiency motives for fiscal equalization (Boadway (2004)), the case of the U.S. points at an equity-based approach, which we therefore adopt in the analyses to follow.

[7] Grants under the Medicaid system are allocated to the states in accordance with the Federal Medicaid Assistance Percentages (FMAP) formula, where: $FMAP = 1 - (\frac{[state\_per\_capita\_income]^2}{[U.S.\_per\_capita\_income]^2}) * 0.45$.

[8] For instance, Wildasin (1980) finds that federal taxes have heterogeneous effects on labor, causing mobile workers to locate inefficiently across cities offering different wages.

3 Theoretical Motivation

We lay out a medium-scale DSGE model with two regions, home and foreign, that belong to a monetary union. The model's structure builds on Auray and Eyquem (2014) in that it models each region a'la Smets and Wouters (2003) and Wouters and Smets (2005), while allowing for trade to take place between the two regions. Our framework extends that of Auray and Eyquem (2014) along two dimensions. First, we focus on the implications of monetary policy shocks for the fiscal inequality across regions and therefore incorporate monetary policy shocks into the model. Second, we include an equity-based fiscal transfer rule that follows the aforementioned characteristics of this feature in the U.S.[9]

Given that the general setup for both the home and foreign economies in our model is identical, below we describe the model for the home economy only.

3.1 Households

There is a continuum of optimizing households, indexed by $j \in [0,1]$, that choose consumption bundle $C_t(j)$, hours worked $L_t(j)$, one-period securities bonds $B_{t+1}(j)$ with price equal to the inverse of next period's risk-free interest rate $(1/R_{t+1})$, investment bundle $I_t(j)$, next period's capital K_{t+1}, and capital utilization $u_t(j)$, so as to maximise their lifetime utility subject to their inter-temporal budget constraint and the capital accumulation contraint. Formally, this maximization problem can be written as

$$\begin{aligned}
&\max_{\{C_t(j),L_t(j),B_t(j)\}_{t=0}^{\infty}} \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{(C_t(j) - hC_{t-1})^{1-\sigma_c}}{1-\sigma_c} - \frac{L_t(j)^{1+\sigma_l}}{1+\sigma_l} \right] \\
&s.t \ \ C_t(j) + I_t(j) + \frac{B_{t+1}(j)}{R_{t+1}P_t} - T_t \leq \frac{B_t(j)}{P_t} + \frac{W_t^h L_t(j)}{P_t} + \\
&\quad + \frac{R_t^k u_t(j) K_t(j)}{P_t} - \psi(u_t(j))K_t(j) + \frac{Div_t}{P_t}, \\
&\quad K_{t+1} = (1-\delta)K_t - \left[1 - \Upsilon\left(\frac{I_t}{I_{t-1}}\right)\right] I_t,
\end{aligned} \tag{1}$$

where h is the external habit formation parameter; σ_c is the elasticity of inter-temporal substitution; σ_l is the elasticity of labor supply; T_t are lump-sum taxes; W_t^h is the hourly wage paid to households; $K_t^s(j) = u_t(j)K_t(j)$ is capital services used in production, where $u_t(j)$ is the capital utilization rate, $K_t(j)$ is installed capital, $\frac{R_t^k u_t(j) K_t(j)}{P_t}$ is income earned

[9] In effect, our transfer mechanism is similar to the one used in Verstegen and Meijdam (2016), who develop and estimate a two-region monetary union DSGE model for the Euro Area.

from renting capital with R_t^k denoting the rental rate of capital services, and $\psi(u_t(j))K_t(j)$ is the resource cost of increasing the rate of capital utilization;[10] Div_t denotes dividends distributed by imperfectly competitive retail firms and labour unions; P_t is the price of Consumption bundle $C_t(j)$; Υ is the adjustment cost function, with $\Upsilon(\gamma) = \Upsilon'(\gamma) = 0$ and $\Upsilon''(\cdot) > 0$; and δ is the capital depreciation rate.[11]

We define the consumption bundle $C_t(j)$ and its corresponding price index P_t, respectively, as the following Dixit and Stiglitz (1977) type aggregators:

$$C_t(j) = \left[(1-\eta)^{\frac{1}{\theta}} C_t^d(j)^{\frac{\theta-1}{\theta}} + \eta^{\frac{1}{\theta}} C_t^f(j)^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}}, \tag{2}$$

and

$$P_t = \left\{(1-\eta) P_t^{h\,1-\theta} + \eta P_t^{f\,1-\theta}\right\}^{\frac{1}{1-\theta}}, \tag{3}$$

where $C^d(j)$ represents domestic consumption of the domestically produced good for household j, $C^f(j)$ domestic consumption of the foreign-produced good for household j, P^d the domestic price of $C^d(j)$, P^f the price of foreign good $C^f(j)$, $\theta > 1$ the elasticity of substitution among the different goods, and η the import share (fraction of consumed goods that are foreign-produced).

Similarly, we define the investment bundle $I_t(j)$ and the resource cost of capital utilization $\psi(u_t(j))$ as the following Dixit and Stiglitz (1977) type aggregators:

$$I_t(j) = \left[(1-\eta)^{\frac{1}{\theta}} I_t^d(j)^{\frac{\theta-1}{\theta}} + \eta^{\frac{1}{\theta}} I_t^f(j)^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}}, \tag{4}$$

and

$$\psi(u_t(j)) = \left[(1-\eta)^{\frac{1}{\theta}} \psi^d(u_t(j))^{\frac{\theta-1}{\theta}} + \eta^{\frac{1}{\theta}} \psi^f(u_t(j))^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}}, \tag{5}$$

Accordingly, the optimal allocations of expenditure between each type of good are given by

$$C_t^d(j) = \eta C_t(j)\left(\frac{P_t^h}{P_t}\right)^{-\theta}, \;\; C_t^f(j) = (1-\eta) C_t(j)\left(\frac{P_t^f}{P_t}\right)^{-\theta}, \tag{6}$$

$$I_t^d(j) = \eta I_t(j)\left(\frac{P_t^h}{P_t}\right)^{-\theta}, \;\; I_t^f(j) = (1-\eta) I_t(j)\left(\frac{P_t^f}{P_t}\right)^{-\theta}, \tag{7}$$

$$\psi^d(u_t(j)) = \eta \psi(u_t(j))\left(\frac{P_t^h}{P_t}\right)^{-\theta}, \;\; \psi^f(u_t(j)) = (1-\eta)\psi(u_t(j))\left(\frac{P_t^f}{P_t}\right)^{-\theta}. \tag{8}$$

[10] We assume the following capital utilization cost function: $\psi(u_t(j)) = \frac{\omega}{2}(u_t(j)-1)^2$.

[11] We assume the following capital adjustment cost function: $\Upsilon\left(\frac{I_t}{I_{t-1}}\right) = \frac{\varpi}{2}\left(\frac{I_t(j)}{I_{t-1}(j)} - 1\right)^2$.

In equilibrium households will make the same choices for consumption, hours worked, bonds, investment, capital, and capital utilization, resulting in the following first-order conditions (omitting the j index):

$$(\partial C_t): \quad \Xi_t = (C_t - hC_{t-1})^{-\sigma_c} \tag{9}$$

$$(\partial L_t): \quad {L_t}^{\sigma_l} = -\Xi_t \frac{W_t^h}{P_t} \tag{10}$$

$$(\partial B_{t+1}): \quad \Xi_t = \beta R_{t+1} \mathbb{E}_t \left[\frac{\Xi_{t+1}}{\pi_{t+1}} \right] \quad , \tag{11}$$

$$(\partial I_t): \quad \Xi_t \left[1 - \Upsilon \left(\frac{I_t}{I_{t-1}} \right) \right] = \Xi_t \Upsilon' \left(\frac{I_t}{I_{t-1}} \right) \frac{I_t}{I_{t-1}} - \tag{12}$$

$$- \beta \mathbb{E}_t \left[\Xi_{t+1}^k \Upsilon' \left(\frac{I_{t+1}}{I_t} \right) \left(\frac{I_{t+1}}{I_t} \right)^2 \right] + \Xi_t \quad ,$$

$$(\partial K_{t+1}): \quad \Xi_t^k = \beta \mathbb{E}_t \left[\Xi_{t+1} \left(\frac{R_{t+1}^k}{P_{t+1}} u_{t+1} - \psi(u_t) \right) + (1-\delta) \Xi_{t+1}^k \right] \quad , \tag{13}$$

$$(\partial u_t): \quad \frac{R_{t+1}^k}{P_{t+1}} = \Upsilon'(u_t), \tag{14}$$

where Ξ_t and Ξ_t^k are the Lagrange multipliers associated with the budget and capital accumulation constraints, respectively. Tobin's Q can be defined as $Q_t = \frac{\Xi_t^k}{\Xi_t}$ and equals one in the absence of investment adjustment costs.

3.2 Intermediate Labor Union Sector and Labor Packers

There is a continuum of intermediate labor unions that differentiate the labor services supplied by households and sell them to *labor packers* who then package and resell them to intermediate goods producers. It is assumed that each labor union represents a different labor service; we index the continuum of these labor services by $l \in [0, 1]$. The labour packers maximize profits subject to a Dixit and Stiglitz (1977) aggregator:

$$\begin{gathered} \max_{L_t, L_t(l)} W_t L_t - \int_0^1 W_t(l) L_t(l) dl \\ s.t \;\; L_t = \left[\int_0^1 L_t(l)^{\frac{\vartheta^w - 1}{\phi^w}} dl \right]^{\frac{\phi^w}{\phi^w - 1}} \quad , \end{gathered} \tag{15}$$

where W_t and $W_t(l)$ are the prices of the composite and intermediate labor services, respectively, and $\phi^w > 1$ the elasticity of substitution among the different labor services.

Combining the FOCs of Problem (15) gives

$$L_t(l) = L_t\left(\frac{W_t(l)}{W_t}\right)^{-\phi}. \tag{16}$$

Nominal wage rigidities are introduced into the model via a Calvo (1983) pricing scheme with partial indexation: unions have market power and can readjust wages with probability $1-\xi_w$ in each period; for those unions that cannot readjust, $W_t(l)$ will get partially indexed to last period's inflation π_{t-1}. The optimal wage set by the union that is allowed to re-optimize its wage is obtained from solving the following optimization problem:

$$\begin{aligned} &\max_{\widetilde{W}_t(l)} \mathbb{E}_t \sum_{s=0}^{\infty} \xi_w^{t+s} \frac{\beta^{t+s}\Xi_{t+s}P_t}{\Xi_t P_{t+s}} \left[W_t(l) - W_{t+s}^h\right] L_{t+s}(l) \\ s.t\ \ & L_t(l) = L_t\left(\frac{W_t(l)}{W_t}\right)^{-\phi} \\ & W_t(l) = \widetilde{W}_0(l)\prod_0^t \pi_t^{\iota_w}, \end{aligned} \tag{17}$$

where $\widetilde{W}_t(l)$ is the newly set wage, ξ_w is the Calvo (1983) probability of being allowed to optimize one's wage, $\frac{\beta^{t+s}\Xi_{t+s}}{\Xi_t P_{t+s}}$ is the nominal discount factor for households, and $0 \leq \iota_w < 1$ is the parameter governing the partial indexation mechanism. The first order condition of Problem (17) is given by:

$$\mathbb{E}_t \sum_{s=0}^{\infty} \xi_w^{t+s} \frac{\beta^{t+s}\Xi_{t+s}P_t}{\Xi_t P_{t+s}} \left[L_{t+s}(l)\left(\frac{\phi}{\phi-1}\frac{W_{t+s}^h}{P_{t+s}} + \frac{\widetilde{W}_t(l)}{P_{t+s}}\left(\frac{P_{t+s-1}}{P_{t-1}}\right)^{\iota}_{w}\right)\right] = 0.$$

Finally, the aggregate wage expression is

$$W_t^{(1-\phi^w)} = (1-\xi_w)\widetilde{W}_t^{(1-\phi^w)} + \xi_w(\pi_{t-1}^{\iota_w} W_{t-1})^{(1-\phi^w)}.$$

3.3 Final Good Firms

The final good Y_t is produced by final good firms as a composite made of a continuum of intermediate goods, indexed by $i \in [0,1]$. The final good is supplied to consumers, investors, and the government, and is purchased in a monopolistically competitive market from the intermediate goods firms, at monopolistic price $P^d(i)$.

All final good firms have access to a technology that allows them to transform intermediate goods into final goods via a Dixit and Stiglitz (1977) aggregator, leading to the following maximization problem facing final good firms:

$$
\begin{aligned}
&\max_{Y_t, Y_t(i)} P_t^d Y_t - \int_0^1 P_t^d(i) Y_t(i) di \\
&s.t \;\; Y_t = \left[\int_0^1 Y_t(i)^{\frac{\phi^p - 1}{\phi^p}} dl \right]^{\frac{\phi^p}{\phi^p - 1}} \qquad ,
\end{aligned} \tag{18}
$$

where P_t^d and $P_t^d(i)$ are the prices of the composite and intermediate domestically produced goods, respectively, and $\phi^p > 1$ the elasticity of substitution among the different goods. Combining the FOCs of Problem (18) gives

$$
Y_t(i) = Y_t \left(\frac{P_t^d(i)}{P_t^d} \right)^{-\phi^p}. \tag{19}
$$

3.4 Intermediate Goods Producers

There is a continuum of intermediate goods producers that produce good $Y_t(i)$ using the following technology:

$$
Y_t(\omega) = A_t K_t^s(i)^\alpha L_t(i)^{1-\alpha}, \tag{20}
$$

where A_t represent total factor productivity in the economy; $K_t^s(i) = u_t(i) K_t(i)$ is capital services used in production, where $u_t(i)$ is the capital utilization rate and $K_t(i)$ is installed capital; and $L_t(i)$ is the labour input. We assume that intermediate goods producers are perfectly competitive in the input markets; they minimize costs by choosing L_t and R_t^k, taking wages and capital services rental rates as given, subject to the production function (20):

$$
\begin{aligned}
&\min_{L_t, K_t} W_t L_t - R_t^k K_t^s \\
&s.t \;\; Y_t^\omega = A_t K_t^{s\alpha} [\gamma^t L_t]^{1-\alpha},
\end{aligned} \tag{21}
$$

which yields the following FOCs:

$$
(\partial L_t): \qquad \Theta_t(i)(1-\alpha) A_t K_t^s(i)^\alpha L_t(i)^{-\alpha} = W_t, \tag{22}
$$

$$
(\partial K_t^s): \qquad \Theta_t(i) \alpha A_t K_t^s(i)^{(\alpha-1)} L_t(i)^{(1-\alpha)} = R_t^k, \tag{23}
$$

where Θ_t is the Lagrange multiplier associated with the production function and equals marginal cost MC_t, which is the same for all firms and whose expression can be written as

$$
MC_t = \frac{1}{A_t} W_t^{1-\alpha} (R_t^k)^\alpha \alpha^{-\alpha} (1-\alpha)^{(-1-\alpha)}. \tag{24}
$$

Nominal price rigidities are introduced into the model via a Calvo (1983) pricing scheme with partial indexation: retail firms can readjust prices with probability $1-\xi_p$ in each period; for those firms that cannot readjust, $P_t(i)$ will get partially indexed to last period's domestic inflation π^d_{t-1}. The optimal price set by the firm that is allowed to re-optimise its price is obtained from solving the following optimization problem:

$$\begin{aligned}
&\max_{\widetilde{P}_t(i)} \mathbb{E}_t \sum_{s=0}^{\infty} \xi_p^{t+s} \frac{\beta^{t+s}\Xi_{t+s}P_t}{\Xi_t P_{t+s}} \left[P^d_t(i) - MC_{t+s}\right] Y_{t+s}(i) \\
s.t\ \ & Y_t(i) = Y_t \left(\frac{P^d_t(i)}{P^d_t}\right)^{-\phi^p} \qquad (25)\\
& P_t(i) = \widetilde{P}_0(i) \prod_0^t \pi_t^{d^{\iota_p}},
\end{aligned}$$

where $\widetilde{P}^d_t(i)$ is the newly set price, ξ_p is the Calvo (1983) probability of being allowed to optimize one's price, $\frac{\beta^{t+s}\Xi_t}{\Xi_{t+s}P_{t+s}}$ is the nominal discount factor for households, $0 \leq \iota_p < 1$ is the parameter governing the partial indexation mechanism, and MC is the firm's nominal marginal cost. The first order condition of Problem (25) is given by:

$$\mathbb{E}_t \sum_{s=0}^{\infty} \xi_p^{t+s} \frac{\beta^{t+s}\Xi_{t+s}P_t}{\Xi_t P_{t+s}} \left[Y_{t+s}(i) \left(\frac{\phi^p}{\phi^p - 1} MC^d_{t+s} + \frac{\widetilde{P}^d_t(i)}{P^d_{t+s}} \left(\frac{P^d_{t+s-1}}{P^d_{t-1}} \right)^{\iota_p} \right) \right] = 0. \qquad (26)$$

Finally, the aggregate wage expression is Finally, the aggregate wage expression is

$$P_t^{d(1-\phi^p)} = (1-\xi_p)\widetilde{P}_t^{d(1-\phi^p)} + \xi_p((\pi^d_{t-1})^{\iota_p} P^d_{t-1})^{(1-\phi^p)}. \qquad (27)$$

3.5 Aggregate Resource Constraint

Final output may either be transformed into a single type of consumption good that is consumed by households and intermediate goods producers, invested, consumed by the government, or used up through capital utilization costs. In particular, accounting for trade between the domestic and foreign economy, the domestic economy-wide resource constraint is given by

$$Y_t = C^d_t + I^d_t + \psi^d(u_t)K_t + \tilde{C}^f_t + \tilde{I}^f_t + \tilde{\psi}^f(u_t)K_t + G_t \qquad (28)$$

where variables marked with tilde (~) represent the foreign economy counterparts to imports of consumption, investment, and capital utilization costs. G_t represents government spending in the domestic economy and is assumed to consist of domestically produced goods only (i.e., $G_t = G^d_t$).

3.6 Monetary Policy

Prior to presenting how monetary policy is conducted, it is helpful to define union-wide output Y_t^u and gross inflation π_t^u as the following geometric averages of their region-specific counterparts:

$$Y_t^u = (Y_t^d)^{\lambda}(Y_t^f)^{(1-\lambda)}, \tag{29}$$

$$\pi_t^u = (\pi_t^d)^{\lambda}(\pi_t^f)^{(1-\lambda)}, \tag{30}$$

$$\tag{31}$$

where λ is the population share of the domestic economy in the monetary union.

The central bank of the monetary union follows a nominal interest rate rule by adjusting its instrument in response to union-wide inflation and deviations of union-wide output from its respective natural level:

$$\frac{R_{t+1}}{R^*} = \left(\frac{R_t}{R^*}\right)^{\rho}\left[(\pi_t^u)^{r_\pi}\left(\frac{Y_t}{Y_t^{u*}}\right)^{r_y}\right]^{1-\rho}\left(\frac{\frac{Y_t^u}{Y_{t-1}^u}}{\frac{Y_t^{u*}}{Y_{t-1}^{u*}}}\right)^{r_{\Delta y}}\left(\frac{\pi_t^u}{\pi_{t-1}^u}\right)^{r_{\Delta\pi}} exp(\epsilon_t^r), \tag{32}$$

where R^* is the steady state nominal gross rate; Y_t^{u*} is natural union-wide output, defined as the output in the flexible price and wage economy; parameter ρ determines the degree of interest rate smoothing; parameters r_π and r_y govern the strength of the responses of monetary policy to deviations of inflation and output from their target levels, respectively; parameters $r_{\Delta\pi}$ and $r_{\Delta y}$ govern the strength of the responses of monetary policy to deviations of the change in inflation and output growth from their target levels, respectively; and ϵ_r is a white noise monetary policy shock, i.e., $\epsilon_t^r \sim iid(0, \sigma_r)$.

3.7 Fiscal Policy

The government budget constraint is of the form

$$P_t G_t + B_t = \frac{B_{t+1}}{R_{t+1}} + T_t + 0.5\varrho(\tilde{Y}_t - Y_t), \tag{33}$$

where T_t are nominal lump-sum taxes that also appear in the households' budget constraint and $0.5\kappa(\tilde{Y}_t - Y_t)$ is the transfer payment from the other region, to be explained below.

We incorporate into the model an automatic fiscal transfer mechanism that ensures that government spending per capita is always equalized. Specifically, we assume the following fiscal rule:

$$G_t = \varrho Y^{ss} + 0.5\kappa(\tilde{Y}_t - Y_t), \tag{34}$$

$$G_t^f = \kappa \tilde{Y}^{ss} + 0.5\kappa(Y_t - \tilde{Y}_t), \tag{35}$$

where Y^{ss} and $\tilde{Y}^{ss}$ are the steady state output levels in the domestic and foreign regions, respectively; Y_t and $\tilde{Y}_t$ are the actual output levels in the domestic and foreign regions, respectively; and κ is steady state share of government spending in output in both regions and, therefore, in the economy-wide union. This transfer rule ensures equalization of government spending across the two regions at all times as transfers produce a zero-sum game where resources from a region that is doing better output-wise are transferred to the one doing less well.

In effect, this is a simplified version of an equity-based equalization rule that follows the case of the U.S., discussed in the previous section. In addition, we further substantiate this in the empirical part, illustrating this choice of fiscal rule is supported by the data.

3.8 Calibration

We solve the model by log-linearizing its system of equilibrium equations about the steady state values of the variables. Table 1 presents the calibration we use for model's parameters. Our calibration largely follows the estimated parameter values obtained in Wouters and Smets (2005), who estimated a closed economy version of this model for the U.S. The trade elasticity parameter, θ, and the domestic consumption share in total consumption parameter, η, are calibrated in accordance with the values used in Auray and Eyquem (2014). Lastly, we calibrate the population share parameter, λ, to 0.88 in accordance with the population share of resource-poor states in the U.S.

All parameters are calibrated identically for the two regions apart from the capital share parameter, α, which differs across the two regions equaling 0.1 in the domestic (low capital share region) economy and 0.25 in the foreign (high capital share region) one. These capital shares were obtained by using data on the average non-labor share in income across resource-rich and resource-poor states while accounting for the fact that our model implies a 50% price markup. Specifically, we computed the regional capital share as $1 - (non\_labor\_share \times 1.5)$.

3.9 Monetary Policy Shocks and Fiscal Inequality

Figure 1 shows the response of the model economy to a contractionary monetary policy shock. The solid line depicts the response of the region with the lower capital share region and the dashed line shows the response of the higher capital share region. The impulse responses clearly demonstrate that the capital intensive economy's output responds more strongly to the monetary policy shock. This stronger response seems to be mainly driven by the fact that, for a given capital movement, there is a stronger induced output change due the higher capital share.

Specifically, it is evident that the both the timing and the magnitude of the hours response are inconsistent with an hours-based explanation for the stronger output response. Furthermore, the difference in the investment response is quite negligible, as is the difference between the capital services responses. Hence, we can infer that it is mainly the capital share parameter that is driving the observed output response difference.

Importantly, the impulse responses shown in Figure 1 are broadly consistent with previous results on monetary policy shocks (e.g., Christiano et al. (2005)): monetary policy shocks induce business cycle comovement and produce hump-shaped declines in output, consumption, and investment. It is worthwhile noting that the positive responses of hours taking place after about 6 quarters can be explained by the strong decline in consumption that peaks at roughly the time at which the hours' rise begins. In particular, it seems that the wealth effect produced by the consumption decline becomes dominant after about 6 quarters, leading to the observed (albeit moderate) rise in hours.

The fiscal payment variable, whose objective is fiscal equalization, behaves as expected. As the output response is stronger in the capital intensive region, this region also transfers a fiscal payment to the less capital intensive region so as to ensure fiscal equalization. This illustrates that monetary policy shocks induce fiscal inequality in the monetary union which in turn produces a fiscal transfer mechanism whose aim is to overturn this effect. The main takeaway from these results is that standard theory predicts that monetary policy shocks may have potentially important implications for fiscal federalism and its objective of fiscal equalization.

We end this section with a discussion on the issue of factor mobility. Our model assumes region-specific labor and capital markets; hence, it does not allow for a formal mechanism by which production factors can freely move from one region to another. One may argue that the inclusion of such a factor mobility mechanism can alter our results. We think this concern can be ameliorated by looking at the responses of real wages and real rental rates of capital services, shown in Figure 1. It is clear that both real wages and capital real rental rates decline more in the capital intensive region (albeit less so for the latter). This effectively causes hours and capital services in the capital intensive region to be higher than its low capital share region counterpart. I.e., any factor mobility mechanism that pushes towards factor price equalization would actually enlarge the gap between the output responses in the two regions. It is therefore reasonable to ascertain that our results are not driven by or dependent upon the abstraction we make from factor mobility.[12]

4 Empirical Evidence

The theoretical analysis outlined a monetary transmission channel affecting federal redistribution. In addition, it illustrated this channel operates via differences in the output elasticity of capital, with marginal differential effects in other state-level indicators. In this section we seek to provide empirical evidence for these predictions, following an identification strategy that links variations in states' output elasticity of capital to geographical characteristics observed via natural resource endowments. We elaborate on the latter issue in the following sub-section.

Our focus in the empirical part is on the U.S. economy, which presents several merits for our purpose. First, it is a federalized economy, operating under a currency union with an equalization mechanism, consistent with the framework of the model. Second, it presents vast cross-state heterogeneity in the share of capital in production, which we proxy for through the balance of the GSP share of labor compensation (a measure we describe further in the following sub-section), as illustrated in Figure 2. Third, as we discuss later when outlining the details of the data used, it provides state-level measures, as well as data on plausibly exogenous monetary policy shocks, over a relatively long period of four decades. Last, adopting it for the empirical analysis contributes to making a more effective comparison to the calibration exercise, which was parameterized based primarily on values derived from the U.S. economy.

4.1 Capital Intensity and Natural Resource Abundance

The theoretical analysis suggested that the state-output elasticity of capital represents the key parameter through which monetary policy connects to fiscal equalization. A key question is, however, which states have systematically and persistently higher share of capital in production? In this sub-section we attempt to identify these states, as we provide some

[12]Importantly, we show empirically that neither labor nor capital flows across states significantly change in response to monetary policy shocks. This constitutes a reassurance that the existence of factor flows is not the explanation for the main results of the paper.

suggestive evidence that link between capital-biased production processes and abundance in pre-determined, geographically based, natural resource endowments. Establishing this link will serve as the basis of our identification strategy in the main empirical analysis.

Three points motivate our conjecture. First, industries that extract point-source resources are immobile, due to the inherent geographical characteristics of these resources, which can be extracted from specific locations. Second, extractive industries are highly capital intensive.[13] Third, point-source resources offer significant rents, which in turn provide major incentives to extract them. Put together, these points suggest that states that are endowed with major reserves of natural riches, to the extent that they represent a significant source of income for these states over extended periods of time, are expected to base a relatively higher portion of their production process on capital, compared to their counterparts. Given the incentives to extract the natural wealth, and the capital immobility of the related industries, this capital intensity is expected to be persistent over time, even at periods of high capital prices.

To test these hypotheses we employ a panel of 48 U.S. states, for the period 2000-2007, through which we estimate the following standard logarithmic production function, for state i and year t:

$$\ln(yN)_{i,t} = \alpha + \beta \ln(kN)_{i,t} + \gamma \ln(hoursN)_{i,t} + \delta R_{i,t} + \theta(\ln(kN) * R)_{i,t} + \eta_i + \nu_t + \epsilon_{i,t}, \quad (36)$$

where yN, $hoursN$, kN, R, η, and ν denote real GSP per capita, hours worked per capita, real capital stock per capita, a resource abundance proxy, state fixed effect, and year fixed effect, respectively. All data is derived from the U.S. Census Bureau and the Bureau of Economic Analysis, with the exception of state capital stocks, derived from Garofalo and Yamarik (2002),[14] and the measure of hours worked, derived from IPUMS-USA; the latter is available annually starting in the year 2000, and exlcludes Alaska and Arizona, whereas the former is available annually up to 2007, hence limiting our sample for the mentioned period and state coverage. All variables are outlined in the Data Appendix; descriptive statistics are presented in the Appendix Table A1.

We test three measures of state resource abundance. The first measure (*resource income*) is the share of severance tax revenues in states' total tax revenues. Severance taxes are levied by U.S. states on the exploitation of natural resources located in their territories. In addition

[13]For instance, data from O'Mahony and Timmer (2009) indicate that the mining sector has the largest average share of capital compensation in total compensation among the major NAICS industries, over the period of 1970-2007.

[14]In effect, we exploit extensions of this data set, available from the second author's homepage.

to providing an indication for the level of natural wealth, this measure also gives a direct observation over the fiscal asymmetry across U.S. states, a feature that we exploit throughout the analysis. The second measure (*mining share*) is the conventional resource-proxy of the GSP share of the mining sector.

As for the third measure, given the potential endogeneity of the first two measures (see, for example, van der Ploeg (2011)), we consider an additional, plausibly exogenous, one (*price measure*). This measure is the product of the international price of oil and a dummy variable that captures the states that have an average share of mining output in GSP of at least 10% over the more general sample period of 1969-2007 (corresponding to the one used in the main analysis); these include Alaska, Louisiana, New Mexico, Oklahoma, Texas, and Wyoming. Having a large share of mining output in total output over a prolonged period of time suggests that resource abundance in these states are based on pre-determined geographical characteristics.[15] Thus, assuming variations in the international price of oil are determined by global shocks, this interaction provides a measure with plausibly exogenous variations across sections and time.

As kN and $hoursN$ serve as our proxies for the capital and labor inputs in production, β and γ thus represent the capital and labor shares of production, respectively. Our focus in this exercise is on θ, which measures the systematic difference in the capital share in production across state levels of resource abundance. Results appear in Table 2. In Column 1 we exclude the resource measure and the interaction term. The estimated β and γ are positive and significant, as expected, with the magnitude suggesting that the labor share in production is approximately 40%; the balance includes the capital share together with additional TFP changes that we consider part of the former for consistency with the empirical counterpart of this measure, outlined in the next section.

In Columns 2-4 we consider the three resource measures, in the order outlined above, together with their interaction with the capital input in production. Results on β and γ are similar to the benchmark estimation in all cases. Interestingly, θ is positive and significant in all cases, providing some support that the output elasticity of capital is indeed higher, to some considerable extent, in natural resource rich states. The third, *price measure* based, case further suggests this systematic difference in the capital elasticity parameter is plausibly exogenous.

[15] To illustrate this differently: on top of the overall average, the six states included in the resource abundant group have also the highest GSP share of mining output in each of the sample years, 1969-2007, separately.

To better illustrate this let us examine this using the empirical counterpart of the capital share in production. Given there is no direct data on state-level capital compensation for our sample period, we measure the capital share in production (*capital_share*) as one minus the GSP share of labor compensation, as mentioned in Section 2. We make two simple illustrations with this measure, both being based on the prolonged period of 1969-2007, further supporting the persistence of the correlation and hence its potentially pre-determined, plausibly exogenous, nature.

The first illustration is presented in Figure 3, which graphs the residuals from regressing *capital_share* on year and state fixed effects and the residuals from regressing *resource income* on year and state fixed effects.[16] The fitted line has a slope of 1.36, with a p-value of 0.00, and r-squared of approximately 0.18. The second illustration is presented in Figure 4 which graphs the cross-sectional relation between *capital_share* and *resource income*, averaged over the period 1969-2007; the correlation is 0.65. Both cases further establish the observation that our parameter of interest and states' natural endowment comove over prolonged periods, supporting the initial conjecture that capital share differences are related to cross-state geographical characteristics. We exploit this feature in the main analysis, presented in the next section.

4.2 Monetary Policy Shocks and Capital Share

In this sub-section we provide empirical evidence for the model's predictions, as per illustrated in Figure 1 – focusing on the contemporaneous effects (quarters 1-4 in the theoretical analysis), which represent the main features of the divergent paths we aim to observe empirically. Specifically, we seek to examine the heterogeneous contemporaneous effects of monetary policy shocks across states' levels of *capital_share*. To that end, we employ a panel of the 50 U.S. states that covers the period 1969-2007, to estimate the following model, for state i and year t:

$$\begin{aligned}\Delta \ln(outcome)_{i,\Delta(t-1,t)} &= \alpha + \beta \ln(outcome)_{i,t-1} + \gamma(capital\_share)_{i,t-1} + \\ &+ \delta(monetary)_t + \theta[(capital\_share_{i,t-1}) * (monetary)_t] + \eta_i + \nu_t + \epsilon_{i,t}, \quad (37)\end{aligned}$$

where *outcome* denotes one of the following variables (all in their natural logarithm form): real GSP per capita, GSP share of federal transfers, hours worked normalized by GSP, GSP

[16] In effect it graphs the estimated β in the regression: $capital\_share = \alpha + \beta(resource\_income)_{i,t} + \eta_i + \nu_t + \epsilon_t$, for state i at time t, state fixed effect (η), and year fixed effect (ν), for the sample period 1969-2007.

share of investment, GSP share of consumption, GSP share of capital stock, and population – all of which follow the factors presented in Figure 1, with the latter two proxying for cross-state capital and labor movements, under assumptions that we outline below.[17] η and ν denote the state and year fixed effects, respectively, as before. The dependent variable is in changes, consistent with the dynamic setting of the model, with its level version in $t-1$ added as a regressor to control for potential convergence.

The variable *capital_share* denotes our proxy for the capital share in production, measured as outlined above. Based on the discussion in the previous sub-section, we consider its cross-sectional variation to be plausibly exogenous, based on geographical determinants leading to natural resource wealth. To address the within-state, across time, variation we consider its level in the previous period $(t-1)$ in the analysis.[18] The second key variable is *monetary*, denoting the monetary policy shocks we examine. These are derived from Tenyero and Thwaites (2016), which are in effect, based on the plausibly exogenous narrative-based monetary policy shocks of Romer and Romer (2004), extended to the period 1969-2007, hence limiting our analysis to it. All the remaining variables are derived from the U.S. Census Bureau and the Bureau of Economic Analysis, with the exception of investment and capital stocks (derived from Garofalo and Yamarik (2002)), as well as hours worked (derived from IPUMS-USA). As mentioned, the latter case excludes the states of Alaska and Arizona, due to data sampling limitations. As for the sample period, while it corresponds to 1969-2007 in the majority of cases, it is limited to 1997-2007 (2000-2007) in the cases related to consumption (hours worked) due to data availability. The Data Appendix outlines the variables and their sources; the Appendix Table A1 presents descriptive statistics.

Following the exogeneity assumptions over our two main variables of interest, namely *capital_share* and *monetary*, we estimate Equation (37) using OLS, for each of the mentioned outcome variables, and focus on interpreting θ. The latter indicates how monetary policy shocks affect the outcome variable differentially across levels of *capital_share* in the preceding period, hence touching on our hypotheses, via Figure 1, directly.

Results appear in Table 3. Columns 1-7 test each of the outcome variables in the order they appear above. In Column 1, the negative and significant θ indicates that a contractionary monetary shock is more contractionary for states with high capital share in produc-

[17]With the exception of GSP (normalized by population), and population (not normalized), all dependent variables are normalized by GSP. This is done for consistency. Examining other alternatives, such as normalizing by population or not normalizing at all, yields qualitatively similar results.

[18]Nonetheless, we note that results remain qualitatively similar if we instead consider its contemporaneous level.

tion. Moreover, the positive and significant θ of Column 2 indicates that the latter states receive more federal transfers following such a shock. Conversely, the results of the remaining cases suggest there are no differential effects in the remaining variables. These results are consistent with the patterns observed in Figure 1, pointing at differential effects on changes in output and federal transfers, with close comovements in the remaining variables.[19] Empirically observing the latter patterns supports the model's assertion that the underlying mechanism leading to the differential effects on output (and consequently, transfers) is the inherent, plausibly exogenous, differences in the capital share in production, rather than differential effects on various state-level macroeconomic indicators.

To interpret the magnitudes, let us consider capital intensive states to have capital share in production of approximately 0.5, and the remaining ones to have a share of 0.4, consistent with the levels presented in Figure 2.[20] Under such values, the results in Columns 1 and 2 indicate that following a one standard deviation monetary policy shock, output growth (GSP share of federal transfers) in capital intensive states contemporaneously decreases (increases) by approximately 1% relative to their counterparts, on average. The similar magnitude suggests an equity-based transfer mechanism is at work, consistent with the analytical framework.

The two latter cases in Table 3, appearing in Columns 6 and 7, deserve further comment. The first (second) case examines changes in the GSP share of capital (population). Assuming relatively similar birth, mortality, and capital depreciation rates across states, within the framework of our model (reminiscent of a closed economy), the two cases may proxy for inter-state capital and labor flows, respectively. Observing these do not react to a monetary shock further motivates our choice to abstract from explicitly modelling factor flows in the theoretical framework. The observation that inter-state labor movements are relatively inelastic in the short term is consistent with findings of previous studies;[21] conversely, the observed immobility patterns over capital can be potentially due to the specificity of it to the immobile extractive industries, making its movements less reactive to the monetary policy shocks. Importantly, these results further support our specific focus on the *capital_share* in the proposed underlying mechanism.

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[19] An exception is the case of hours worked. Figure 1 presents mild differences between the two types of states. Note that while the result in the empirical analysis is not statistically significant, the sign and relatively small standard errors of the estimated coefficient of interest appear to point as well at the weak differential effect suggested by the model.

[20] Similar results are yielded if the model's parameterized values are adopted instead.

[21] See, for instance, Hauser (2014), and Perez-Sebastian and Raveh (2015).

4.2.1 IV Estimation

The key heterogeneity we look into is that in the output elasticity of capital. Previously, we pointed at the potential cross-sectional exogeneity of it, given its systematic relation to geographic characteristics related to natural endowments. Nonetheless, the time variation remained susceptible to potential endogeneity, which we attempted addressing by examining *capital_share* in the preceding period. While mitigating this econometric concern, it nevertheless remains applicable in case *capital_share* is sufficiently persistent.

To address this more effectively we undertake an instrumental variable approach, focusing on the two cases of interest: output growth and changes in federal transfers. The IV we adopt is the *price measure* introduced in the previous sub-section, with which we instrument the *capital_share*. On the one hand, the results of the analysis presented in the previous subsection indicated that *capital_share* is expected to correlate strongly with the *price measure*. On the other hand, given the geographically-based cross-sectional variation of it –derived from the mentioned resource dummy that includes the resource abundant states– and the plausibly exogenous time variation –derived from the international oil price– we assume it does not affect the outcome variables once *capital_share* in controlled for. This forms the basis of our identification assumption.

To motivate this assumption through the data, we first present estimations following a reduced form approach with the IV included in Equation (37) in lieu of *capital_share*. Results for the cases of output growth and changes in federal transfers appear in Columns 1 and 3 of Table 4, respectively. In both cases θ is similar in sign and significance to that estimated in the benchmark cases using *capital_share*. This changes when we add *capital_share* (in $t-1$, as before), together with its interaction with monetary policy shocks. Both estimations, which appear in Columns 2 and 4 of Table 4 for the output and transfers case, respectively, show that θ now becomes statistically insignificant, unlike the coefficient on the additional interaction, using *capital_share*, which bears the expected sign and is precise, in both cases. This, in turn, lends support to the underlying identification assumption that our proposed IV affects the outcome variable via its effect on the endogenous variable, *capital_share*.

Thus, we proceed to estimate Equation (37) by 2SLS. As the endogenous variable appears in the interaction term, we follow the methodology set by Wooldridge (2002) to instrumentation of endogenous interaction terms. In the first stage, we predict *capital_share* using the instrument with the remaining controls in Equation (37) and the interaction term excluded. In both cases the coefficient on the IV is positive and statistically significant at the 0% level, with the F-statistic surpassing 1000, hence validating the strength of the first stage. We then interact the predicted variable, in the preceding period (following the initial specification), with the outcome variable, and use it in the second stage of the 2SLS procedure.

Second stage results appear in Columns 5 and 6 of Table 4, for the output and transfers cases, respectively. The results on θ are similar to those estimated under the OLS cases, with the difference of having larger magnitudes in each. A positive monetary shock leads to relatively larger contraction and inflows of federal grants in states with high capital share in production. Hence, the patterns reported are robust to using a different estimation technique.

4.2.2 Disaggregation of Federal Transfers

To this point we outlined various aspects of the main result. Monetary shocks have contemporaneous effects on federal transfers. Next, we disaggregate the latter to better understand which types of transfers are those that trigger the main effect. This disaggregation will serve to motivate our focus on an equity-based transfer mechanism, and to test the robustness of the observed monetary-fiscal nexus.

We examine six main categories of federal transfers to states: public welfare, health, employment security, education, highways, and natural resources. The first covers federal aid for major welfare programs, including Medicaid and food stamp administration; consequently, it represents the largest group, accounting for approximately 40% of all federal transfers. The second largest group, with a 15% share of total transfers, is education which mainly includes federal payments for federal education and research programs. Then comes payments for highways (12%) that fund transportation projects and highway safety. Health (4%), employment security (2%), and natural resources (2%) comprise the smaller groups. The remaining balance is covered by additional, smaller categories not covered in this analysis. Notably, the first group (welfare) represents the main federal equalization tool, via Medicaid, as outlined earlier.

To that end, we estimate Equation (37) following the benchmark specification, as per Column 2 of Table 3, for each of the mentioned sub-categories. The GSP share of each represents the dependent variable (*outcome*) in each case. Estimates appear in Table 5, with each column representing a different sub-category.

The results indicate that monetary shocks mainly affect transfers related to public welfare. This is observed through the estimated θs, being statistically significant only in Column 1. The positive sign, together with the larger magnitude (twice that estimated under the benchmark, average case), are consistent with the main effect estimated initially. Finally, realizing that the triggering sub-group is welfare is consistent with the equity-based equalization perspective taken throughout the analysis.

5 Conclusion

This paper has put forward a novel mechanism by which monetary policy interplays with fiscal federalism. We first presented a medium-scale two-region monetary union model that established a valuable conceptual base upon which to build the discussion of our empirical results. Our main theoretical result was that monetary policy shocks affect more strongly output in regions with a higher capital share, while having largely identical effects on investment and consumption. Therefore, theory implied that monetary policy shocks affect regional inequality and can thus have important implications for fiscal inequality issues in case an equity-based fiscal equalization mechanism is at work.

Then, exploiting the natural-resource induced variation in the capital share across U.S. states, we conducted a detailed empirical study of the empirical role played by monetary policy shocks in fiscal federalism and redistribution. The empirical results were consistent with their theoretical counterparts: monetary policy shocks produce a bigger change in output of states with higher capital share, while not inducing a significant differential effect on investment and consumption. Taken together, our theoretical and empirical analyses implied that monetary policy shocks have implications that encompass more than just the aggregate economy, directly affecting fiscal inequality and regional inequality across U.S. states.

Our results indicate that monetary policy shocks may have welfare implications that go beyond those conventionally considered in typical macroeconomic models which mostly abstract from heterogenous regional effects of monetary policy. These welfare implications may be especially relevant in times in which the economy is at the zero-bound on interest rates. As Coibion et al. (2016) point out, in a time at which the zero-bound on nominal interest rates binds, systematic monetary policy usually calls for negative nominal interest rates; however, since these can not be applied, being at the zero lower bound effectively implies a contractionary monetary policy stance. Hence, given that such shocks appear to have an important connection to fiscal inequality, standard currency union models that do not account for this connection are prone to be biased in their analysis of the welfare costs of hitting the zero lower bound.[22]

[22]Note that the direction of the bias is expected to be downward for a model that is consistent with U.S. data, where capital intensive regions are richer, since in this case the zero lower bound episode would actually be contributing to greater fiscal equality.

Appendix

A Data

We use an annual-based, state-level, panel that covers the 50 U.S. states over the period 1969-2007. Unless otherwise specified, variables are based on data from the U.S. Bureau of Economic Analysis and the U.S. Census Bureau. Descriptive statistics for all variables appear in Table A1.

Variable definitions

Real per capita GSP: Real Gross State Product divided by state population.

Hours worked per capita: Number of hours worked per week. Sample excludes Alaska and Arizona, and covers the period 2000-2007 (Source: variable 'UHRSWORK', IPUMS-USA).

Resource income: Share of severance tax revenues in states' total tax revenues.

Real per capita capital stock: State-level measure of capital stock, divided by state population, in constant prices (Source: Garofalo and Yamarik (2002), including an extension of it available at the second author's homepage).

Mining share: GSP share of the mining sector.

Price measure: An interaction of the real international oil price and a dummy variable that includes the 6 states with an average of at least 10% share of mining output in GSP over our sample period, namely: Alaska, Louisiana, New Mexico, Oklahoma, Texas, and Wyoming.

Monetary policy shocks: Monetary policy shocks a-la Romer and Romer (2004). (Source: Tenyero and Thwaites (2016)).

Capital share: One minus the GSP share of labor compensation.

Real federal transfers per cpaita: Real transfers from the federal the state governments, divided by state population, examined in total, as well as in the following categories: public welfare, health and hospitals, employment security administration, education, highways, and natural resources.

Real investment per capita: Real investment, divided by state population (Source: Garofalo and Yamarik (2002), including an extension of it available at the second author's homepage).

Real consumption per capita: Real consumption, divided by state population. Sample covers the period 1997-2007.

Population: State population.

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Table 1: Model Parameterization

Parameter	Description	[Domestic,Foreign]
β	Discount factor	[0.99,0.99]
σ	Risk-aversion coefficient	[1.62,1.62]
h	Habit formation parameter	[0.69,0.69]
σ_l	Elasticity of labor supply	[2.45,2.45]
ξ_p	Degree of nominal rigidities in the goods market	[0.87,0.87]
ξ_w	Degree of nominal rigidities in the labor market	[0.8,0.8]
ι_p	Degree of price indexation to past inflation	[0.66,0.66]
ι_w	Degree of wage indexation to past inflation	[0.64,0.64]
ω	Capital utilization elasticity	[0.31,0.31]
ϖ	Steady-state elasticity of the capital adjustment cost function	[5.86,5.86]
r_π	Coefficient on inflation in the interest rate rule	[1.48,1.48]
r_y	Coefficient on output in the interest rate rule	[0.08,0.08]
$r_{\Delta\pi}$	Coefficient on inflation change in the interest rate rule	[0.24,0.24]
$r_{\Delta y}$	Coefficient on output growth in the interest rate rule	[0.24,0.24]
ρ	Degree of interest rate smoothing	[0.88,0.88]
α	Capital share	[0.1,0.25]
φ_w	Labor market elasticity of substitution	[3,3]
φ_p	Goods market elasticity of substitution	[3,3]
δ	Depreciation Rate	[0.025,0.025]
η	Home goods consumption share	[0.8,0.8]
κ	Steady state government spending share	[0.18,0.18]
θ	Trade elasticity	[1.5,1.5]

Notes: The table consists of the parameters values used for the model presented in Section 2. The third column shows the values for both the domestic and foreign economies; the only parameter that differs across the two economies is the capital share parameter.

Table 2: Capital intensity and natural resource abundance, (panel, 1-year, 2000-2007, OLS)

Dependent variable: ln(yN)	(1) No interaction	(2) Resource income	(3) Mining share	(4) Price measure
ln(kN)	0.68***	0.61***	0.56***	0.56***
	(0.11)	(0.09)	(0.09)	(0.11)
ln(hoursN)	0.43***	0.33***	0.38***	0.39***
	(0.13)	(0.12)	(0.11)	(0.09)
ln(kN) * Resource abundance		0.14***	0.24**	0.0005**
		(0.02)	(0.09)	(0.0002)
State fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
R-squared, within	0.82	0.84	0.84	0.85
Observations	384	384	384	384

Notes: Standard errors are robust, clustered by state, and appear in parentheses for independent variables. Superscripts *, **, *** correspond to a 10, 5 and 1% level of significance. Sample covers all U.S. states with the exclusion of Alaska and Arizona, for the period 2000-2007. All regressions include an intercept and the corresponding resource abundance measure in regressions that include the interaction term. 'ln(yN)' is the natural logarithm of the real GSP per capita. 'ln(kN)' is the natural logarithm of the real capital stock per capita. 'ln(hoursN)' is the natural logarithm of the hours worked per capita. 'Resource abundance' is a measure of natural resource wealth that changes by regression: 'Resource income' is the share of severance tax revenues in total state tax revenues; 'Mining share' is the GSP share of the mining sector; 'Price measure' is an interaction of the real international oil price and a dummy variable that includes the 6 states with an average of at least 10% share of mining output in GSP over our sample period (namely: Alaska, Louisiana, Montana, New Mexico, North Dakota, Oklahoma, Texas, and Wyoming). For further information on variables see data Appendix.

Table 3: Cross-state regressions; monetary shocks and state-level indicators, (panel, 1-year, 1969-2007, OLS)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Dependent variable:	Annual rate of change in ln(yN), Δ(t-1,t)	Annual rate of change in ln(transferY), Δ(t-1,t)	Annual rate of change in ln(hoursY), Δ(t-1,t)	Annual rate of change in ln(invY), Δ(t-1,t)	Annual rate of change in ln(consY), Δ(t-1,t)	Annual rate of change in ln(kY), Δ(t-1,t)	Annual rate of change in ln(pop), Δ(t-1,t)
Monetary shocks * Capital share	-0.09***	0.14**	-0.09	-0.11	-0.02	0.04	-0.01
	(0.03)	(0.06)	(0.06)	(0.32)	(0.04)	(0.04)	(0.01)
State fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R-squared, within	0.32	0.32	0.43	0.46	0.27	0.39	0.29
Observations	1950	1950	336	1950	500	1950	1950

Notes: Standard errors are robust, clustered by state, and appear in parentheses for independent variables. Superscripts *, **, *** correspond to a 10, 5 and 1% level of significance. Sample covers the period 1969-2007 (Regressions 1,2,4,6,7), 2000-2007 (Regression 3), and 1997-2007 (Regression 5), and includes the 50 U.S. states with the exception of Regression 3 in which Alaska and Arizona are excluded. All regressions include an intercept, and the following controls: 'Capital share' – one minus the GSP share of labor compensation; 'Monetary shocks' – monetary policy shocks derived from Tenyero and Thwaites (2016); the dependent variable in levels in the preceding period. 'ln(yN)' is the natural logarithm of the real GSP per capita. 'ln(transferY) is the natural logarithm of the GSP share of federal transfers. 'ln(invY)' is the natural logarithm of the GSP share of investment. 'ln(hoursY)' is the natural logarithm of the GSP share of hours worked. 'ln(consY) is the natural logarithm of the GSP share of consumption. 'ln(kY)' is the natural logarithm of the GSP share of capital stock. 'ln(pop)' is the natural logarithm of state population. For further information on variables see data Appendix.

Table 4: Cross-state regressions; monetary shocks, output, and transfers -- IV estimation, (panel, 1-year, 1969-2007)

	(1)	(2)	(3)	(4)	(5)	(6)
	Growth (OLS)		Transfers (OLS)		2SLS (2nd stage results)	
Dependent variable:	Annual rate of change in ln(yN), Δ(t-1,t)	Annual rate of change in ln(yN), Δ(t-1,t)	Annual rate of change in ln(transferY), Δ(t-1,t)	Annual rate of change in ln(transferY), Δ(t-1,t)	Annual rate of change in ln(transferY), Δ(t-1,t)	Annual rate of change in ln(yN), Δ(t-1,t)
Monetary shocks * Price measure	-0.0002***	-0.0001	0.0001**	-0.00005		
	(0.00001)	(0.0001)	(0.00005)	(0.0001)		
Monetary shocks * Capital share		-0.07**		0.13**	-0.13***	0.29**
		(0.03)		(0.06)	(0.04)	(0.14)
State fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	No	Yes	No	Yes	No	Yes
R-squared, within	0.31	0.34	0.33	0.33	0.31	0.32
Observations	1950	1950	1950	1950	1950	1950

Notes: Standard errors are robust, clustered by state, and appear in parentheses for independent variables. Superscripts *, **, *** correspond to a 10, 5 and 1% level of significance. Sample covers the 50 U.S. states for the period 1969-2007. All regressions include an intercept, and the following controls: 'Capital share' – one minus the GSP share of labor compensation; 'Monetary shocks' – monetary policy shocks derived from Tenyero and Thwaites (2016); the dependent variable in levels in the preceding period. 'ln(yN)' is the natural logarithm of the real GSP per capita. 'ln(transferY) is the natural logarithm of the GSP share of federal transfers. 'Price measure' is an interaction of the real international oil price and a dummy variable that includes the 6 states with an average of at least 10% share of mining output in GSP over our sample period (namely: Alaska, Louisiana, Montana, New Mexico, North Dakota, Oklahoma, Texas, and Wyoming). Regressions 5 and 6 present 2nd stage results, with 'Price measure' instrumenting for 'Capital share'; in the 1st stage the coefficient on 'Price measure' is positive and significant at the 0%, and the F-Statistic surpasses 1000 in all cases. For further information on variables see data Appendix.

Table 5: Monetary shocks and federal transfers, (panel, 1-year, 1969-2007, OLS)

	(1)	(2)	(3)	(4)	(5)	(6)
Dependent variable:	Annual rate of change in ln(pubwelY), Δ(t-1,t)	Annual rate of change in ln(healthY), Δ(t-1,t)	Annual rate of change in ln(empY), Δ(t-1,t)	Annual rate of change in ln(educY), Δ(t-1,t)	Annual rate of change in ln(transY), Δ(t-1,t)	Annual rate of change in ln(nrY), Δ(t-1,t)
Monetary shocks * Capital share	0.25***	0.18	0.27	0.16	0.21	0.19
	(0.09)	(0.13)	(0.25)	(0.1)	(0.19)	(0.17)
State fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
R-squared, within	0.31	0.19	0.12	0.25	0.25	0.19
Observations	1950	1950	1950	1950	1950	1950

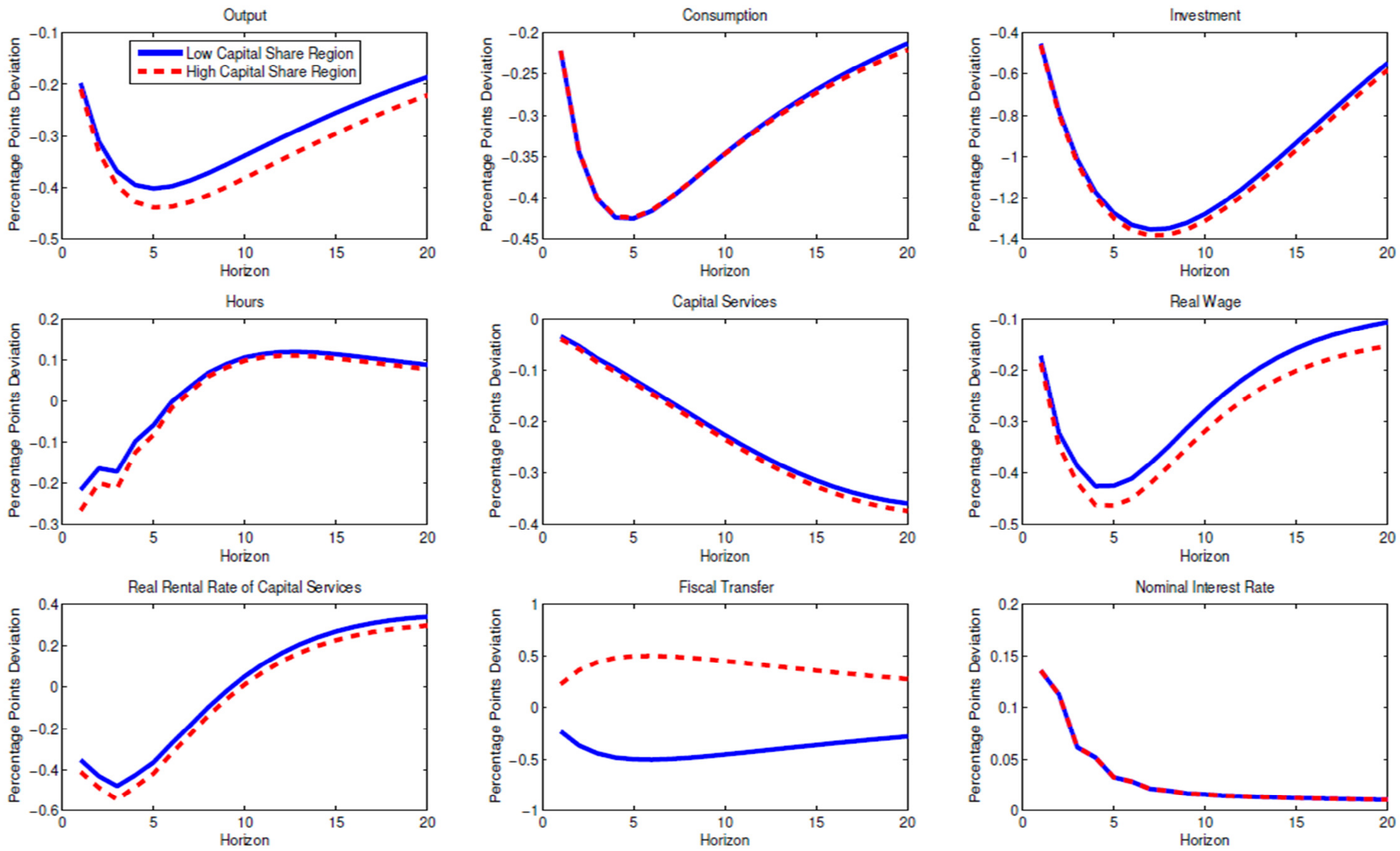
Notes: Standard errors are robust, clustered by state, and appear in parentheses for independent variables. Superscripts *, **, *** correspond to a 10, 5 and 1% level of significance. Sample covers the period 1969-2007, and includes the 50 U.S. states. All regressions include an intercept, and the following controls: 'Capital share' – one minus the GSP share of labor compensation; 'Monetary shocks' – monetary policy shocks derived from Tenyero and Thwaites (2016); the dependent variable in levels in the preceding period. The dependent variables cover the GSP share of the following categories of federal transfers: 'pubwel' is public welfare, 'health' is health and hospitals, 'emp' is employment security administration, 'educ' is education, 'trans' is highways, 'nr' is natural resources. For further information on variables see data Appendix.

Table A1: Descriptive Statistics

	Mean	Std. Dev.	Min.	Max.
Real GSP per capita	31619.69	11151.97	11351.5	110865.7
Real capital stock per capita	26846.76	8651.962	9250.53	68286.04
Hours worked per capita	18.30481	1.36269	14.8783	22.91994
Resource income	0.0348191	0.094621	0	0.823653
Mining share	0.0334141	0.067046	0	0.496563
Price measure	5.063374	15.83982	0	106.36
Monetary shocks	-2.05E-09	0.971825	-2.41639	2.015558
Capital share	0.6935806	0.145417	0.37526	0.92539
Real investment per capita	1745.464	1034.03	38.0431	17584.89
Real consumption per capita	26372.18	5344.057	15184	42644
Population	4826166	5278753	256000	3.66E+07
Change in GSP share of capital stock	-0.0026787	0.03656	-0.23018	0.461217
Change in population	0.011229	0.012326	-0.05694	0.104478
Real federal transfers per capita	584.7454	539.8263	27.2048	4061.261
Real federal public welfare transfers per capita	246.3111	258.4386	5.4925	1498.65
Real federal health transfers per capita	25.1398	29.3257	0.3981	247.03
Real federal employment security transfers per capita	11.3909	7.9191	0	93.4875
Real federal education transfers per capita	90.3892	76.2813	2.264	640.3828
Real federal highways transfers per capita	72.0708	66.3577	0	642.1352
Real federal natural resources transfers per capita	10.0903	19.458	0	382.6919

See Appendix for detailed description of variables.

Figure 1: Impulse Responses to a one standard deviation positive monetary policy shock

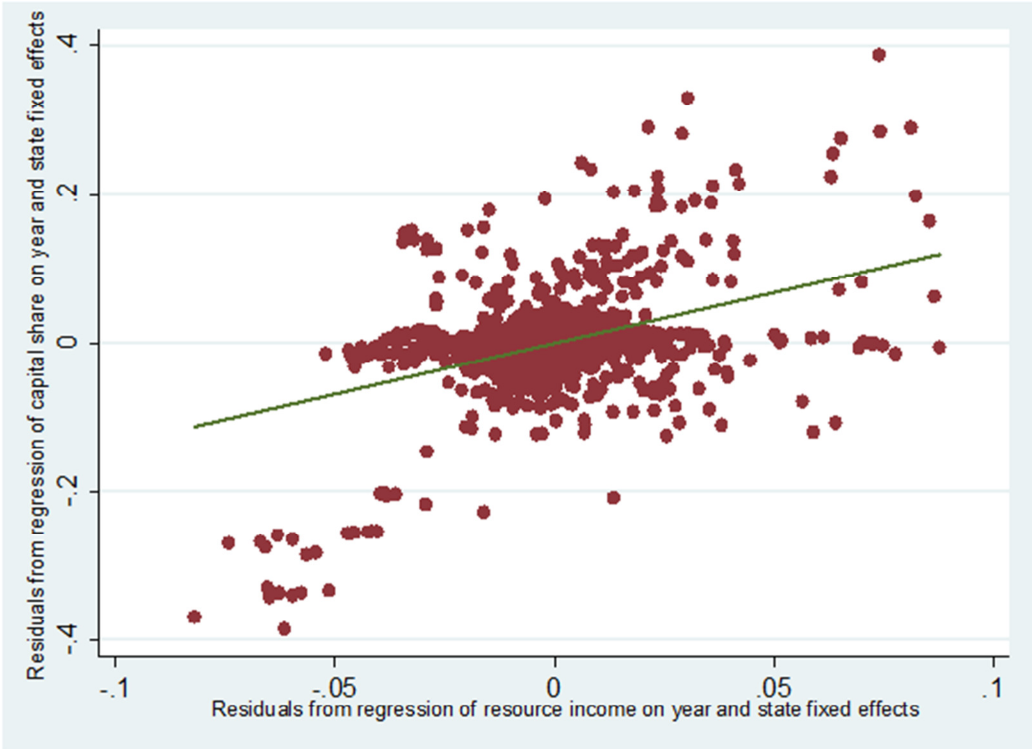


Notes: The figure presents the impulse responses to a monetary policy shock from the model presented in Section 3. The responses are shown in terms of percentage deviations from steady state values. Horizon is in quarters. See Appendix for detailed description of variables.

Figure 2: Average capital share across U.S. States, 1969-2007

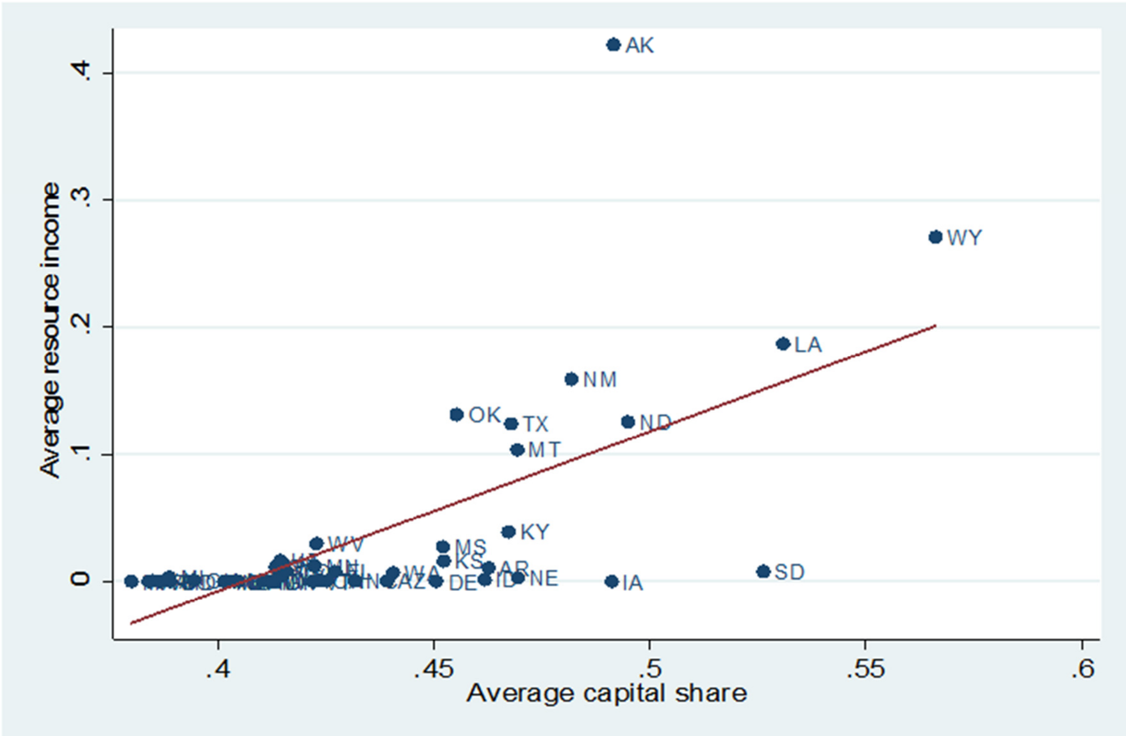
Notes: The figure presents the average capital share across U.S. states, 1969-2007. 'Capital share' is one minus the GSP share of labor compensation. See Appendix for detailed description of variables.

Figure 3: Capital share and resource income, net of year and state fixed effects, U.S. states, 1969-2007



Notes: The figure presents the residuals from regressing capital share on year and state fixed effects against residuals from regressing resource income on year and state fixed effects. Correlation is 0.42, and p-value 0.00. Sample is 50 U.S. states, 1969-2007. 'Capital share' is 1 minus the GSP share of labor compensation. 'Resource income' is the share of severance tax revenues in total state tax revenues. See Appendix for detailed description of variables.

Figure 4: Capital share and resource income, cross-section of averages, U.S. States, 1969-2007



Notes: The figure presents the cross-sectional correlation between capital share and resource income, each averaged over the period 1969-2007, across U.S. states. Correlation is 0.65, and p-value 0.00. 'Capital share' is 1 minus the GSP share of labor compensation. 'Resource income' is the share of severance tax revenues in total state tax revenues. See Appendix for detailed description of variables.