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State-level Taylor rule and monetary policy stress

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Abstract

Research background: Taylor rule is a widely adopted approach to follow monetary policy and investigate various mechanisms related to or triggered by monetary policy. To date, no in-depth examination of scale, determinants and spillovers of state-level monetary policy stress, stemming from the Federal Reserve Board's (Fed's) policy has been performed.
Purpose of the article: This paper aims to investigate the nature of monetary policy stress on US States delivered by the single monetary policy by using a quarterly dataset spanning the years between 1989 and 2017.
Methods: We apply a wide array of time series and panel regressions, such as unit root tests, co-integration tests, co-integrating FMOLS and DOLS regressions, and Spatial Panel SAR and SEM models.
Findings & value added: When average stress imposed on states is calculated, it is observed that the level of stress is moderate, but the distribution across states is asymmetric. The cross-state determinants behind the average stress show that states with a higher percentage of

working-age and highly educated population, as well as those with higher population density and more export-oriented are negatively stressed (i.e. they experience excessively low interest rates), whereas higher unemployment rate contributes to a positive stress (too high interest rates). To the best of our knowledge, the contribution of this paper lies in estimating monetary policy stress at the state level and unveiling some of the determinants of this stress. Moreover, the paper makes the first attempt to empirically test spatial spillovers of the stress, which are indeed found significant and negative.

Introduction

Over the last few decades, the Taylor Rule (TR) framework has been the most influential toolbox to design policy prescriptions for central banks around an inflation-targeting world (Gerlach & Schnabel, 2000; Taylor, 1999; Woodford, 2000; Yağcıbaşı & Yıldırım, 2019; Avdijev & Hale, 2019; Bernanke *et al*., 2019). Its main advantage is often argued to lie with providing macroeconomic stabilization by reducing uncertainty about future monetary policy actions (Gerlach & Schnabel, 2000), while also improving communication between central banks and the general public (Orphanides, 2007).

The outcomes produced by integrating Taylor (or Taylor-type) rules into monetary policymaking, in terms of inflation stabilization and output growth, have been reasonably good (Orphanides, 2003; Caputo & Diaz, 2018; Chertman *et al*., 2020). When policy rates deviated from the rule-implied level, for example, due to deliberate decisions to exert some desirable effects in financial markets or in other segments of an economy, the statutory targets related to inflation and output often had to be sacrificed to some extent. Given the suboptimal rates leading to the accumulation of economic and financial imbalances, the link is evidently not straightforward. For example, policy rates systematically below TR-implied rates in the U.S., are often identified as a reason for imbalances in financial circumstances, driving the global financial crisis (Hofmann & Bogdanova, 2012; Bakhit & Bakhit, 2014).

For deeper research insights into sub-optimal monetary policy, it is convenient to turn to the rich strand of theoretical and empirical studies examining the functioning of EMU in Europe. Theoretical studies, equipped mostly with the Mundell's (1961) Optimum Currency Areas (OCA) theory optics, explored various possible problems arising from imposing a single monetary policy in a relatively heterogeneous area (Montoya & De Haan, 2008; Weyerstrass *et al*., 2011; Duran, 2013, 2015; Duran & Karahasan, 2022;

Deskar-Škrbić *et al.*, 2020). A universally accepted conclusion in these studies was that a centrally decided interest rate would be far from optimality for at least some of the countries/regions unless they possessed perfectly synchronous business cycles and commoving inflation patterns (Duran, 2013, 2015). Under heterogeneous environment and asymmetric shocks, however, each country/region naturally has a different optimal path of interest rate, and uniform interest rates generate deviations of actual interest rate from its optimal level, termed as "monetary policy stress" (Clarida *et al.*, 1998), which in turn produce asynchronous business cycles, creating "rotating slumps" (Blanchard, 2007; Höpner & Lutter, 2018; Montoya & De Haan, 2008; Weyerstrass *et al.*, 2011; Duran, 2013, 2015; Deskar-Škrbić *et al.*, 2020).

Empirical studies performed after the launch of the EMU document substantial amount of this stress, experienced especially in peripheral European countries such as Greece, Spain and Ireland, coinciding with structural and cyclical dissimilarity of these countries against the EMU "core" (Drometer *et al.*, 2013; Gajewski, 2016). Gajewski (2016) explicitly connects this stress with the accumulation of internal and external imbalances (during the global crisis), which subsequently exacerbated its real effects in these countries.

More recently, the overall heterogeneity in reactions to single monetary policy in Eurozone is confirmed by Mandler *et al*. (2022) and Almgren *et al.* (2022), while Grandi (2019) provides evidence of asymmetries in the transmission and monetary framework across members. Indirect evidence of possible problems with adequacy of single monetary policy is provided by Syed (2021), who shows striking differences in the expectations adjustments following monetary policy changes in two core Eurozone member states: Germany and France. All those heterogeneities are bound to produce Blanchard's rotating slumps across the countries, illustrating possible non-optimality of the Eurozone as a currency area and raising the necessity of having the regional perspective of a monetary policy on a research agenda (Blanchard, 2007; Höpner & Lutter, 2018; Duran & Karahasan, 2022)

In the context of testing Eurozone against OCA's criteria, empirical studies were in need of a benchmark, i.e. a relatively well-functioning common currency area of a similar size, where high capital and labor mobility, similar sub-national economic structures, and high business cycle synchronization at the regional level would constitute an effective shelter against major asymmetric shocks (e.g. Magrini *et al.*, 2013; Mundel, 1961).

The U.S. was discussed as it is the best possible reference to OCA while also being a convenient subject due to availability of statistical data (Beckworth, 2010; Kouparitsas, 2001).

The role of the US as a benchmark OCA, however, has been questioned by (admittedly scarce) papers examining this issue, such as Carlino and de Fina (1999), who find substantial cross-state differences in responses to the national monetary policy, Crowley (2001), who explicitly concluded that the US is not an OCA or Chrysanthidou *et al.* (2013), who broadly confirmed this finding. More recently, Furceri *et al.* (2019) show that monetary policy has diverse influence on different states and also spatial connectivity matters. According to our knowledge, this is the only study on monetary policy effects, where spatial effects are accounted for and found very important.

If the US is indeed not an OCA, some critical questions arise, related to the extent of monetary policy stress faced in different subnational areas and the determinants of this stress. This study aims to address those important questions by investigating the geography of TR validity and implied monetary policy stress across the US states, estimated using a quarterly dataset from 1989 to 2017.

In this context, our contribution to the literature is at two points:

First, although the monetary policy impact on regional economies is well examined, there are no studies (to our knowledge) that estimate implied stress through TR at the state level and explicitly display the extent of the stress driven by the Federal Reserve Board's (Fed's) policies. Rather, the literature has focused on the differential impact of interest rate decisions on state level output and employment. It has been shown that the impact of monetary shocks has quite diverse effects on states depending on their industrial structure, productive capacity and institutional arrangements (Carlino & De Fina, 1999; Owyang & Wall, 2009; Dominguez-Torres & Hierro, 2019). We extend this stream by explicitly showing the extent of the "stress" and discovering its geography.[1]

Second, the determinants behind the cross-state variation of monetary stress are yet to be analyzed in the literature, which so far seemed to be preoccupied with investigating reasons behind cross-state differences in

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[1] An exceptional study is implemented by Malkin and Nechio (2012) who estimated TR rule for the regions of US and found a quite homogenous structure. However, regions in US are big economic entities, possibly masking many heterogeneities. We focus on states that include substantial diversity across each other.

vulnerability to monetary shocks. It is often claimed that regions which have industries more exposed to monetary policy decisions, such as manufacturing (interest rate hypothesis), those with small firms and banks (credit channel), and the ones which are more open to trade (i.e. exports) (exchange rate hypothesis), are possibly more vulnerable to policy shocks (Duran & Erdem, 2014; Duran & Fratesi, 2020; Carlino & DeFina, 1998; Taylor, 1995; Mishkin, 1996; Bernanke & Gertler, 1995; Gertler & Gilchirst, 1993; Carlino & DeFina, 1999; Oliner & Rudebusch, 1996; Kashyap & Stein, 2000).

We depart from this stream by focusing on the determinants of stress and analyze the socio-economic, demographic, and spatial determinants behind it.

In the remaining parts, Section 2 explains the theoretical foundation of TR, Section 3 focuses on estimating the TR, Section 4 describes the geography of monetary stress, Section 5 analyzes the cross-state determinants of monetary stress by applying spatial panel regression analysis. Finally, the study is concluded in Section 6.

Theoretical framework and research methods

In the Taylor's (1993) seminal paper, the Fed's policy is clearly followed by a basic feedback rule, such that the interest rate reacts to both contemporaneous output gap and inflation. This rule, known as the standard TR, reads (Gerlach & Schnabel, 2000):

$$"i_t = r^{equi} + \pi_t + 0.5\ [(y_t - y_t^*) + (\pi_t - \pi_t^*)"] \tag{1}$$

where i represents the interest rate (effective Federal funds rate), variable π denotes consumer inflation rate, $(y_t - y_t^*)$ is the output gap, expressed in terms of deviation from the long-run trend (y_t^*) and $(\pi_t - \pi_t^*)$ is the inflation gap, subtracted from targeted inflation (π^*) Gerlach & Schnabel, 2000). Re-arranging the terms in equation (1) yields an alternative representation:

$$i_t = \alpha + 1.5\,\pi_t + 0.5\,\hat{y_t} \text{ where } \alpha = r^{equi} - 0.5\,\pi^*, \text{ output gap: } \hat{y_t} = y_t - y_t^* \tag{2}$$

The concept gained much research interest in that it attempted to fine-tune the TR to better represent or guide monetary policies around the world. An important strand of studies departed from the well-known argument of Friedman (1972) that monetary actions influence the economic variables with a remarkable time lag. This statement subsequently gained firm empirical support, part of which was competently summarized in a meta-study by Rusnák *et al.* (2013). As a consequence, monetary policy making is generally advised to embrace the forward-looking perspective and target projected rather than contemporaneous or past variables. Forward-looking rules are seen as good copies of the behavior of central banks (e.g. Gajewski, 2016; Caputo & Diaz, 2018), which additionally often use official statements to shape future expectations.

r^{equi} in equation 1 is constant over time. It may be possible to allow for time varying r^{eq} instead of a constant one (Bauer & Rudebusch, 2020; Del Negro *et al.*, 2017), which is calculated by Laubach and Williams (2003) for the US economy. However, the calculation of time varying r^{equi} is pursued by incorporating variables such as real GDP, Fed funds rate and inflation related data. Since these variables are (implicitly) already included in the TR equation, we find it safe to continue with the constant r^{equi}.

The coefficients of the TR, as an instrument linking interest rates to output gap and inflation dynamics, hinges upon the nature of the transmission process of monetary policy, existing in a given area (Taylor, 2002). The latter, however, can spatially differ due to regional heterogeneity in terms of the industry mix and sensitivity of economic activity to policy shocks (Beck *et al.*, 2009; Furceri *et al.*, 2019). Additionally, as noted by Burriel and Galesi (2018) and Capasso *et al*. (2021), the monetary policy transmission mechanism is affected by cross-regional/country interactions. If the natural interest rate differs across regions and if cross-regional spillovers exist, a single monetary policy might not be well-suited for at least some of the regions in an area subjected to it (Duran, 2013, 2015).

Despite these arguments, attempts to model cross-regional heterogeneity in the context of monetary policy are scarce and limited to tracking heterogeneous responses to policy impulses, employing methods from the vector autoregressive toolbox (Burriel & Galesi, 2018; Carlino & De Fina, 1999; Capasso *et al*., 2021; Owyang & Wall, 2009). Since we are explicitly interested in the determinants of region-specific monetary stress, and the cross-regional differences and spillovers of this stress, it is possible to use precise metrics of spatial relatedness and exploit spatial econometric modelling techniques.

Taylor Rule estimations

The three TR specifications that frame our empirical strategy are as follows (Gajewski, 2016; Rusnák *et al*., 2013; Caputo & Diaz, 2018; Gerlach & Schnabel, 2000; Taylor, 1999; Woodford, 2000; Yağcıbaşı & Yıldırım, 2019, Avdijev & Hale, 2019; Bernanke *et al*., 2019):

$$i_t = \alpha + \beta\, \pi_t + \delta\, \widehat{y_t} + \epsilon_t \qquad \text{(Contemporaneous Model)} \qquad (3)$$

$$i_t = \alpha + \beta\, \pi_{t-1} + \delta\, \widehat{y_{t-1}} + \epsilon_t \qquad \text{(Backward-Looking Model)} \qquad (4)$$

$$i_t = \alpha + \beta\, \pi_{t+1} + \delta\, \widehat{y_{t+1}} + \epsilon_t \qquad \text{(Forward-Looking Model)} \qquad (5)$$

In equations (3) – (5), i_t denotes short-run nominal interest rate (Fed's Effective Federal Funds rate), π_t is the annualized rate of CPI inflation, and $\widehat{y_t}$ denotes the output gap.

The models (3)-(5) incorporate different assumptions on expectations. The model (3) assumes that the monetary policy decisions are reactive only with respect to contemporaneous values of output gap and inflation. In model (4), it is assumed that the interest rate decisions are backward-reactive (i.e. they are taken on the basis of output gap and inflation's former values) whereas, in model (5), a future-based policy framework is employed (Gajewski, 2016; Rusnák *et al*., 2013; Caputo & Diaz, 2018; Gerlach & Schnabel, 2000; Taylor, 1999; Woodford, 2000; Yağcıbaşı & Yıldırım, 2019, Avdijev & Hale, 2019; Bernanke *et al*., 2019). Since the three models differ fundamentally with regard to assumed expectations, the adopted policy framework might well be different. Hence, it is valuable to estimate all models and try to understand the robustness and differences between each other.

Our dataset contains quarterly data spanning the years 1987–2017, in 33 large US states, for which CPI inflation data is available.

The nominal interest rate is obtained from the electronic sources of Federal Reserve Bank of St Louis. Annualized quarterly consumer inflation rate has been obtained from Hazell *et al*.'s (2020) study and dataset.[2] Since

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[2] The dataset can be reached at: https://sites.google.com/view/jadhazell/state-consumer-

state-level GDP data is unavailable at the quarterly frequency, we resort to coincident index of macroeconomic conditions, published by the Federal Reserve Bank of Philadelphia at the monthly frequency (Crone & Clayton-Mathews, 2005). This index includes some important variables that mimic the GDP, such as "nonfarm payroll employment, average hours worked in manufacturing, wages, salaries and the unemployment rate" (Crone & Clayton-Mathews, 2005; Jory *et al.,* 2019; Federal Reserve Bank of Philadelphia, https://fred.stlouisFed.org/series/USPHCI).[3] We convert this index into quarterly frequency and adjust the seasonality by using multiplicative ratio technique [4] (Eviews 4 User Guide).

Hodrick and Prescott (1997) (HP) filtering has been applied to estimate the output gap and it is a useful technique to de-trend the coincident indexes by removing the actual series from the long-run trend component. HP filtering is known to have various merits, such as accuracy and simplicity in applications. Hence, it is a commonly adopted tool in business cycle studies. The smoothing parameter is set as 400, as is standard in the empirical literature (Hodrick & Prescott, 1997). Our sample runs until 2017, so it escapes the well-known end-of sample problems, associated with this filter (Figure 1). Anyhow, to provide a robustness check, we estimated the output gap also by using the Baxter-King filter (Baxter & King, 1999). The comparison of both evolutions were illustrated in Figure 2. It visually seems that the two cycles move almost in perfectly synchronous fashion, confirming the validity of both filtering techniques in case of our data. Hence, for the sake of parsimony we continue with the HP filter.

As Figure 1 shows, output gap fluctuates around a constant and depends on a business cycle phase. However, inflationary developments and interest rates seem to follow a declining trend, as well as different characteristics in different periods.

In order to examine the unit root features of the variables, a Phillips and Perron (1988) test (PP) is applied to all series under 4 different assumptions; including in the test equation i. only intercept and the test is applied to the level of variables, ii. only intercept and the test is applied to first differenced data, iii. intercept and trend, the test is applied to the level of

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price-index

[3] This explanation is obtained from FRED, Federal Reserve Bank of Philadephia and Federal Reserve Bank of St. Louis; https://fred.stlouisfed.org/series/USPHCI, April 8, 2021.)

[4] In this paper, Eviews 4, Eviews 10, "R" programming SPLM,PLM ; SPDEP packages (Millo & Piras, 2012; Millo *et al.*, 2022; Croissant & Millo, 2008; Bivand *et al.*, 2022) and Stata 13 programs are used in empirical analysis.

variables, iv. intercept and trend, the test is applied to the first differenced data. The results, presented in Table 1, indicate that the interest rate is mostly non-stationary, whereas inflation is firmly stationary and output gap is only partially stationary.

Having observed signs of non-stationary evolutions, Johansen's co-integration test has been applied (Johansen, 1991; 1995) by assuming 4 quarters lag length. Different specifications were allowed, such as inclusion of intercept and/or linear/quadratic trend in test. Trace and Maximum Eigen Statistics were used in the decision. Also, log-likelihood, Schwarz (1978) and Akaike (1973) criteria information were provided. In terms of significance level, p-value<0.05 was accepted as a threshold. The results, shown in Table 2, suggest that there is at least one co-integrating equation. Hence, it becomes necessary to adopt a co-integrating regression method in TR estimation.

FMOLS (Fully modified OLS) and DOLS (Dynamic OLS) regressions are accepted as reliable techniques to model co-integrating relationships, these methods are known to be successful in exploring co-integrating relationships (e,g, Saikkonen, 1992; Saidi, 2018; Phillips & Hansen, 1990; Stock & Watson, 1993). Hence, we employ both FLMOLS and DOLS in TR estimation (in equations 3–5) for the US aggregate economy (Table 3).

It may be theoretically possible to observe co-integrating relationships between inflation, interest rate and output gap since economic shocks and dynamic circumstances may influence inflation and output which requires changes in monetary policy that induces policy-triggered shocks to output and inflation. However, since the variables are not fully non-stationary or stationary a cross validation is needed which OLS estimates are considered to be adequate in that manner (Carvalho *et al.*, 2021). In Table 4, we provide OLS estimates with Newey-West HAC errors (Newey & West, 1987a; 1987b).

Monetary stress

The focus of our paper is the extent of monetary policy stress in different states. It can be broadly decomposed into the country-wide component, resulting from the deviation of actual interest rate from the rule-consistent rate, and state-specific component, defined as the deviation of interest rate from the state-specific rule-consistent rates. The latter occurs if there are fundamental asymmetries across states, such as imperfect business cycles and idiosyncratic evolution of inflation path (Clarida *et al*., 1998; Gajewski, 2016).

Here we focus on the total stress, defined as:

$$Stress_i = i_{actual} - i_{TR,i} \tag{6}$$

where:

i states,
TR TR-consistent

A positive monetary stress occurs when actual interest rate is higher than the Taylor-rule implied one ($i_{TR} < i_{actual}$). In contrast, negative stress occurs when actual interest rate is below the Taylor-rule implied rate ($i_{TR} > i_{actual}$). When there is positive stress, the interest rate faced by a region (state) is excessively high. In this case, price dynamics might be well under control, but economic growth and labor market can suffer. Conversely, when there is negative stress, the interest rate is lower than the optimal one which may induce investments and economic growth but does not provide an adequate solution to inflation and in fact may fuel asset price bubbles (Clarida *et al*., 1998; Gajewski, 2016).

The question of why some states are more stressed than others is our another area of interest. To address this issue, we collect a battery of demographic and economic variables, which might impact our dependent variable $stress_{i,t}$. All the variables are defined and summarized in Table 6. Our panel model is subsequently augmented with independent variables spatially filtered and also with spatially lagged error terms. Hence, we set up the following spatial panel regression:

$$\begin{gathered} stress_{i,t} = \partial + \delta\ Demographic_{i,t} + \gamma\ Economic_{i,t} + \\ +\rho W stress_{i,t} + \theta_i d_i + \omega_t T_t + \varepsilon_{i,t} \quad \varepsilon_{i,t} = \lambda W \varepsilon_{j,t} \end{gathered} \tag{7}$$

Where W denotes the raw standardized inverse distance spatial weighting matrix. d_i is the dummy variable for each state that captures the state-specific fixed effects. T_t is a dumy variable that captures the time specific effects. Hence, the model incorporates two-way fixed effects, both state-specific and time-specific.

The dependent variable is the average stress imposed by Fed's interest rate decisions, expressed as:

$$average\ stress = \sum_{q=1}^{4}(i_{actual,q} - i_{TR,q})/4 \tag{8}$$

Where q represents quarters, TR denotes the Taylor rule consistency. Only DOLS estimator and the forward-looking TR rule is used in the calculation of these dependent variables, since it fits to the data.

Spatial Autoregressive Model (SAR) occurs when $\lambda = 0$, whereas Spatial Error Model (SEM) is applied when $\rho = 0$ (Anselin, 1988; Manski, 1993; Anselin & Bera, 1998; Anselin & Moreno, 2003; Haining, 2003; Anselin & Rey, 1991; Anselin *et al.*, 1996; Elhorst, 2003; 2010; 2014; Baltagi, 2013; Baltagi *et al.*, 2003; 2007; 2012).

Results

Firstly, the results regarding the aggregate US economy are presented in Table 3. It is clearly evident that Fed's interest rate decisions react significantly to both inflation and output gap. However, greater weight is given to inflation as it has higher and more significant coefficients in all regression specifications. The reaction coefficient of inflation ranges between 1.26–1.51 whereas coefficient of output gap ranges between 0.74–0.93. Among these models, the forward-looking model fits best data as it produces the highest R^2 values.

OLS results, presented in Table 4, confirm the FMOLS and DOLS results. Both the inflation coefficient (0.98-1.09) ant the output gap coefficient (0.71-0.84) are only marginally lower compared to those obtained with FMOLS and DOLS methods, while both also remain statistically significant. Hence, the results appear robust and point to a greater weight attributed to inflation in the Fed's monetary policy conduct.

We compute, in Table 5, the statistics on the monetary stress of states. In the calculation, actual interest rate is subtracted from the TR consistent rate implied for the states where aggregate TR coefficients are used in calculation. Total stress is expressed under the colon of MAE (Mean Absolute Error), which is calculated in the following manner: MAE= $\sum_{n=1}^{n}\frac{|i_{actual,n}-i_{TR,s,n}|}{n}$, where n is the total number of quarters. Also, average values are provided. In the next column, the average stress is presented

(Wilmott & Matsuura, 2005). Only DOLS model is used, since it provides better fit to the data in Table 3. It is observed that rather homogenous total stress levels across states range between 0.016 (Georgia) and 0.029 (Hawaii). This seems a plausible and acceptable level of stress imposed by Fed.

The direction of the stress (average stress) however is rather heterogeneous across states: 19–24 states are, on average, positively stressed $(i_{TR} < i_{actual})$ whereas 9-14 states are negatively stressed $(i_{actual} < i_{TR})$.

Geographical pattern of stress is depicted in Figures 3. The total stress is illustrated in Figure 3.a. The darker blue color represents higher stress levels. Average stress is shown in Figure 3.b. Red colored states represent positively stressed areas, whereas blue colored states represent the negatively stressed areas. At a glance, no distinct spatial pattern is observed. Northwestern and mid-western states are positively stressed, whereas the remaining areas are more negatively stressed.

In order to select the proper model, we apply Lagrange Multiplier (LM) tests to the model. It tests the presence of spatial autocorrelation either by assuming spatial interaction among states in the dependent variable or in errors (Anselin, 1988; Manski, 1993; Anselin & Bera, 1998; Anselin & Moreno, 2003; Haining, 2003; Anselin & Rey, 1991; Anselin *et al.*, 1996; Elhorst, 2003; 2010; 2014; Baltagi, 2013; Baltagi *et al.*, 2003; 2007; 2012). Bera *et al.*, 2019). The results are presented in Table 7. Spatial association is present regardless of the type of interaction is assumed in dependent variable (Spatial Lag Model) or in errors.

Another type of specification test is provided by Hausman (1978) and Mutl and Pfaffermayr (2011). It tests whether both fixed and random effect models are consistent (Ho) or one of them is inconsistent (Ha). The result is presented in Table 8 in the context of SAR and SEM models. Both models indicate the validity of alternative hypothesis and, hence, the relevance of fixed effect estimator. Thus, we adopt fixed effects within the estimator.

The regression results are presented in Table 9 (Nonspatial-Panel Model) and Table 10 (Spatial Panel Model). In Table 10, besides the full model, the sub-models that include only demographic and economic variables are also estimated as a robustness check.

Looking at both tables, many variables have robustly significant coefficients. First, the share of working-age and well-educated population have negative coefficients. It means that states that have a higher shares of both are negatively more stressed. Another consistently significant variable is the population density. The highly urbanized states are negatively stressed.

Similar interpretation can also be made at this point. Highly urbanized areas have possibly higher internal demand and consumption. Hence, higher interest rate is likely to be optimal (TR consistent) in order to avoid further inflation.

Another robust finding is that states with higher unemployment rates are more positively stressed ($i_{TR} < i_{actual}$). Consistent with the Philips Curve, high unemployment cuts the pressures on inflation that requires lower actual TR consistent interest rates than the actual one (Roberts, 1995). The export-oriented states are more negatively stressed.

Finally, spatial interaction terms are negative and significant indicating geographical co-existence of both stress types. More precisely, regions facing excessively low interest rates are clustered by regions experiencing excessively high rates.

Discussion

Our results connect well to some of the recent findings in empirical literature. First of all, we confirm that despite changing macroeconomic environment, Taylor rule is not dead and remains a benchmark and a useful tool to mimic Fed's monetary policy (Chang *et al.*, 2022; Czudaj, 2021) and that the importance of inflation still seems to outweigh the role played by output gap within the function of interest rate reaction (Aguiar-Conraria *et al.*, 2018).

Just like Albuquerque (2019), we demonstrate that monetary policy in the US may display diverse impacts on the state-level economies and falls short from fitting all, which is most commonly linked to heterogeneity of regional banking sectors (e.g. Buch *et al.*, 2022) or housing markets (e.g. Beraja *et al.*, 2019; Aastveit & Anundsen, 2022). With some success, Pizzuto (2020) considers a somewhat broader set of structural variables, including regional industry-mix. By contrast, our study demonstrates that demography, labor market and openness are potential areas, where determinants of monetary policy stress can be tracked for.

Given the recent findings of Cloyne *et al.* (2020), who show that reaction of consumption patterns to the movements in interest rate is mainly affected by households with a mortgage in the US, demography and labor market can indeed play a crucial role for regional monetary policy effects. We provide strong support for these conjectures as both the share of working-age and well-educated population, as well as the overall unemployment rate appear significant in our study. These findings are also in line with arguments of Imam (2015). Indirectly, our paper takes a stance in the fierce academic discussion on the relationship between demography and inflation. It appears that higher share of working-age population drives inflation (an natural rate of interest) up, thereby exposing the state to a negative monetary policy stress. Such a mechanism is in line with findings of Bobeica *et al.* (2017), but against evidence presented by Albuquerque *et al.* (2020), among others.

Our most important contribution is the explicit modelling of spatial effects. In this regard, we obtain a result suggesting negative spatial spillovers. Positive monetary policy stress in one region thus appears to be related to a negative stress in neighboring regions. In the past, negative spatial dependence was considered to constitute some kind of a puzzle in regional science, but these have become more frequent in recent studies, which also proposed several plausible explanations (Kao & Bera, 2016; Santos *et al.*, 2022). In our case, the explanation of this situation might rely on the following argument: if growing productivity raises the natural interest rate in one region, this induces flows of labor from neighboring regions and consequently drains those regions of productive labor, lowering natural interest rate there. This is why some negative spatial dependence can be seen in the level of natural interest rates and also in the amount of stress from the monetary policy. Such processes can happen, especially if investments exhibit increasing returns (Krugman, 1991). Capital abundant, highly productive regions will attract more capital from nearby locations, so the disparity in natural rate of interest and the stress will increase (Neto *et al.*, 2019).

Conclusions

In this paper, the monetary stress imposed on states and the economic/demographic determinants of the stress pattern are investigated. By adopting quarterly data from 1987–2017 and a wide array of time series (co-integrating regressions) and spatial panel regressions, several important results are obtained.

First, when average stress imposed on states is calculated, it is observed that the level of stress is moderate, but the distribution across states is highly imbalanced. While some states are positively stressed ($i_{TR} < i_{actual}$), others are negatively stressed ($i_{TR} < i_{actual}$) by the monetary policy actions.

Second, once we investigate the cross-state determinants behind the average stress, it has been understood that states that have a higher share of working-age and educated population and those that are more urbanized, are more negatively stressed. This seems plausible as a high share of active and educated population and urban culture indicates high aggregate demand and consumption. In these states, TR normally implies a higher interest rate than the actual one, as inflationary pressures, driven by internal demand, are higher. High unemployment is found to bring higher positive stress: high unemployment rate is likely to cut the pressures on inflation that requires lower actual TR consistent interest rate than the actual one, and provides positive stress. The export-oriented states are more negatively stressed. The spatial dependence coefficients are found to be negative, indicating the geographical co-existence of positive and negative stressed areas.

As an outcome of our research, some important policy implications can be made. Fed should consider the state level disparities in inflation and output when deciding the future course of monetary policy because under large cross-state disparities, unique monetary policy might create policy distortions and sub-optimal monetary policy actions for some states (Mundell, 1961; Duran, 2013). On top of the cross-state disparities, our results point to possible issues in the urban/rural divide. They suggest that the amount of negative monetary policy stress builds up in densely populated, open areas with relatively well-educated population and low unemployment rate. These are predominantly metropolitan areas, whereas rural areas will tend to experience excessively high interest rate. Such pattern could exacerbate some of the currently observed imbalance accumulation processes, including fueling real estate bubbles in major cities, while simultaneously dwindling growth in stagnant, rural regions. Our approach is too aggregate, and therefore not capable of examining the urban/rural divide, but if these mechanisms are confirmed in further studies, reinforcing policy measures targeted at reducing urban/rural development inequalities could reduce overall asymmetry of monetary policy effects.

Finally, negatively stressed states should be supported to make the supply-side economy stronger, whereas positively stressed states are in need to have their internal demand stimulated. These policies might help smoothen deviations of interest rate from those implied by the states' TR rule.

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Annex

Table 1. Unit root, Philips Perron test, aggregate variables for US

Specification				
Levels or first differences	Levels	First Difference	Levels	First Difference
Intercept or Trend	Intercept, No Trend	Intercept, No Trend	Intercept and Trend	Intercept and Trend
Variables				
i	-2,33	-4.94***	-2.64	-5.05
Π	-3,37**	-6.43***	-4.39**	-6.41***
$y-y^*$	-3,03**	-10.05***	-3.02	-10.00***

Note: *** when $p<0.01$, ** when $p<0.05$, * when $p<0.1$.

Table 2. Johansen co-integration test, lag=4, significance level: $p<0.05$

Data Trend:	**None**	**None**	**Linear**	**Linear**	**Quadratic**
Rank or No. of CEs	No Intercept No Trend	Intercept No Trend	Intercept No Trend	Intercept Trend	Intercept Trend
Trace	1	1	1	1	3
Max-Eig	1	1	1	1	1
Log Likelihood by Rank (rows) and Model (columns)					
0	1403.691	1403.691	1404.284	1404.284	1404.604
1	1415.798	1417.913	1418.505	1419.578	1419.898
2	1417.867	1421.683	1422.055	1426.613	1426.788
3	1419.315	1423.752	1423.752	1430.137	1430.137
Akaike Information Criteria by Rank (rows) and Model (columns)					
0	-24.64308	-24.64308	-24.59970	-24.59970	-24.55143
1	-24.75312	-24.77321*	-24.74784	-24.74915	-24.71888
2	-24.68229	-24.71501	-24.70370	-24.74978	-24.73491
3	-24.60027	-24.62615	-24.62615	-24.68715	-24.68715
Schwarz Criteria by Rank (rows) and Model (columns)					
0	-23.76431*	-23.76431*	-23.64771	-23.64771	-23.52620
1	-23.72789	-23.72357	-23.64938	-23.62628	-23.54719
2	-23.51060	-23.49450	-23.45878	-23.45604	-23.41676
3	-23.28212	-23.23477	-23.23477	-23.22254	-23.22254

Source: own estimation based on Akaike (1973), Schwarz (1978).

Table 3. Co-integration regressions, TR estimation results for US aggregate economy

Variables	Contemporaneous		Backward		Forward	
	fmols	dols	fmols	dols	fmols	dols
π	1,450177***	1,387837***	1,305573***	1,259862**	1,49454***	1,507683***
y-y*	0,823147**	0,885602**	0,739474**	0,776191**	0,882934**	0,933907**
constant	-0,002478	-0,001199	0,000241	0,001168	-0,003042	-0,003252
N	115	113	114	112	114	113
R-Square	0,32	0,42	0,27	0,38	0,33	0,44

Note: *** when $p<0.01$, ** when $p<0.05$, * when $p<0.1$.

Table 4. OLS estimates

Variables	Contemporaneous	Backward	Forward
π	1.09**	0.98**	1.09**
y-y*	0.78**	0.71**	0.84**
constant	0.006	0.0008	0.0006
N	116	115	115
R-Square	0.36	0.3	0.38

Note: *** when $p<0.01$, ** when $p<0.05$, * when $p<0.1$.

Table 5. Monetary stress of states, DOLS

	MAE			Average		
DOLS	**Contemporaneous**	**Backward**	**Forward**	**Contemporaneous**	**Backward**	**Forward**
AL	0.0228	0.0218	0.0235	0.0014	0.0020	0.0007
AK	0.0247	0.0241	0.0253	-0.0001	0.0006	-0.0009
AR	0.0212	0.0209	0.0215	0.0059	0.0061	0.0057
CA	0.0186	0.0183	0.0190	-0.0012	-0.0005	-0.0022
CO	0.0238	0.0230	0.0246	-0.0043	-0.0033	-0.0055
CT	0.0230	0.0221	0.0239	0.0057	0.0059	0.0054
FL	0.0204	0.0202	0.0205	0.0013	0.0019	0.0006
GA	0.0166	0.0168	0.0165	0.0020	0.0025	0.0013
HI	0.0285	0.0268	0.0299	0.0013	0.0018	0.0006
IL	0.0194	0.0190	0.0197	0.0034	0.0038	0.0029
IN	0.0231	0.0224	0.0237	0.0012	0.0017	0.0005
KS	0.0229	0.0220	0.0238	0.0026	0.0030	0.0020
LA	0.0248	0.0242	0.0252	0.0012	0.0018	0.0005
MD	0.0244	0.0234	0.0253	0.0006	0.0013	-0.0001
MA	0.0238	0.0219	0.0251	-0.0019	-0.0010	-0.0029
MI	0.0224	0.0213	0.0231	-0.0015	-0.0006	-0.0024
MN	0.0221	0.0211	0.0228	0.0011	0.0017	0.0004
MS	0.0236	0.0228	0.0243	-0.0027	-0.0018	-0.0037
MO	0.0185	0.0186	0.0186	0.0009	0.0015	0.0002
NJ	0.0242	0.0236	0.0248	-0.0005	0.0002	-0.0014
NY	0.0175	0.0175	0.0177	0.0003	0.0009	-0.0005
NC	0.0180	0.0178	0.0184	0.0051	0.0054	0.0048
OH	0.0209	0.0205	0.0213	0.0013	0.0018	0.0006
OK	0.0234	0.0224	0.0245	-0.0030	-0.0020	-0.0040
OR	0.0191	0.0185	0.0198	-0.0082	-0.0068	-0.0097
PA	0.0187	0.0186	0.0188	0.0011	0.0017	0.0004
SC	0.0179	0.0172	0.0186	0.0032	0.0036	0.0027
TN	0.0248	0.0236	0.0257	-0.0024	-0.0015	-0.0034
TX	0.0204	0.0202	0.0206	0.0023	0.0027	0.0017
UT	0.0247	0.0237	0.0254	0.0060	0.0061	0.0057
VA	0.0209	0.0204	0.0213	0.0024	0.0029	0.0018
WA	0.0195	0.0186	0.0201	-0.0038	-0.0027	-0.0049
WI	0.0185	0.0186	0.0186	-0.0006	0.0002	-0.0014

Table 6. Definition of variables

Variables	Dependent/Independent	Definition	Data Source
stress	Dependent	Annual average calculated by sum of absolute deviations of actual interest rate from state-level rule consistent rate over 1 year (DOLS is the estimation method) (Represented in Equation 7,8)	Own calculation
share of young population (0-14)	Independent/demographic	Share of 0-14 age group in population	OECD’s database (https://stats.oecd.org/)
share of active population (15-64)	Independent/demographic	Share of 15-64 age group in population	
population density	Independent/demographic	Population per km2	
education level	Independent/demographic	Share of population 25 to 64 year-olds with Bachelor degree	
hefindahl index	Independent/Economic	$\sum_{J=1} s_j^{2}$ is the herdindahl index. s_j is the share of sector j in total state level employment. 20 NAICS industries are used.	BEA (Bureau of Economic Analysis), number of jobs (https://www.bea.gov/)
Share of manufacturing in aggregate employment	Independent/Economic	Share of manufacturing in aggregate employment	
Share of finance in aggregate employment	Independent/Economic	Share of finance in aggregate employment	
Share of trade in aggregate employment	Independent/Economic	Share of trade in aggregate employment	
unemployment rate	Independent/Economic	Unemployment rate for 15-64 age group	OECD’s database (https://stats.oecd.org/)
exports/population	Independent/Economic	Exports/population	Census (https://www.census.gov/) OECD (https://stats.oecd.org/)
bank size	Independent/Economic	Finance and insurance (Number of jobs)/ number of banks	BEA (https://www.bea.gov/) FDIC (https://www.fdic.gov/)
firm size	Independent/Economic	Average employment size of establishments	OECD’s Database (https://stats.oecd.org/)
patent applications per person	Independent/Economic	patent applications per person Source: OECD (stat.oecd.org)	OECD’s Database (https://stats.oecd.org/)
entrepreneurship	Independent/Economic	Establishment birth rate (in % of all establishments - same sector, same size class)	OECD’s Database (https://stats.oecd.org/)

Table 7. LM tests of spatial autocorrelation

Dependent variable	Robust LM Error Test Statistic (LM)	P-Value	Robust LM Lag Test Statistic (LM)	P-Value
stress	229.55***	< 2.2e-16	52.949***	3.423e-13

Note: *** when p<0.01, ** when p<0.05, * when p<0.1.

Table 8. Specification tests

Test Type	Test Statistics
5.Hausman Test (Ha: One model is inconsistent) (Chi-Sqr) for SEM model (Hausman, 1978; Mutl & Pfaffermayr, 2011)	71.49***
5.Hausman Test (Ha: One model is inconsistent) (Chi-Sqr) forSAR model (Hausman, 1978; Mutl & Pfaffermayr, 2011)	27.654**

Note: *** when p<0.01, ** when p<0.05, * when p<0.1.

Table 9. Panel non-spatial regression results

	Full Model	Demographic Model	Economic Model
share of young population (0-14)	0,013	-0,082	
share of active population (15-64)	-0,453*	-0,544**	
population density	-0,090**	-0,078**	
education level	-0,069**	-0,071**	
herfindahl index	0,053		0,085
Share of manufacturing in aggregate employment	0,010		0,017
Share of finance in aggregate total employment	0,001		-0,006
Share of trade in aggregate employment	-0,031		-0,011
unemployment rate	0,033***		0,033***
exports/population	-0,009**		-0,008**
bank size	-0,006		-0,009
firm size	-0,086		-0,071
patent applications per person	0,007		0,007
entrepreneurship	-0,022		-0,034
Two ways Fixed Effects (within)	yes	yes	yes
N	462	462	462

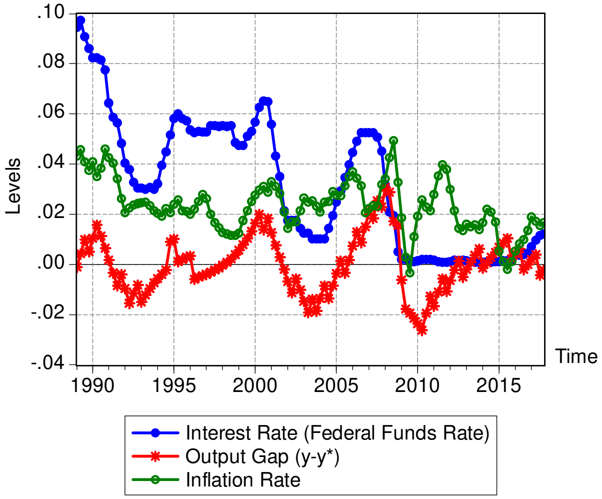
Note: *** when p<0.01, ** when p<0.05, * when p<0.1.

Table 10. Spatial panel regression results

Variables	Full model		Demographic Model		Economic Model	
	SEM	**SAR**	**SEM**	**SAR**	**SEM**	**SAR**
share of young population (0-14)	-0,001	0,007	-0,092	-0,084		
share of active population (15-64)	-0,504**	-0,477**	-0,593**	-0,563**		
population density	-0,095***	-0,093**	-0,083**	-0,080**		
education level	-0,073**	-0,069**	-0,073**	-0,071**		
herfindahl index	0,104	0,065			0,113	0,093
Share of manufacturing in aggregate employment	0,012	0,011			0,019	0,017
Share of finance in aggregate employment	0,007	0,003			-0,002	-0,005
Share of trade in aggregate employment	-0,036	-0,032			-0,013	-0,011
unemployment rate	0,033***	0,033***			0,034***	0,034***
exports/population	-0,009**	-0,009**			-0,008**	-0,008**
bank size	-0,006	-0,006			-0,009	-0,009
firm size	-0,077	-0,082			-0,063	-0,067
patent applications per person	0,008*	0,007			0,008*	0,007
entrepreneurship	-0,020	-0,021			-0,033*	-0,034*
Lambda	-0,395**		-0,409**		-0,318*	
Rho		-0,343**		-0,360**		-0,317*
Two ways Fixed Effect (Within)	Yes	Yes	Yes	Yes	Yes	Yes
Heteroskesdasticity Robust Errors	Yes	Yes	Yes	Yes	Yes	Yes

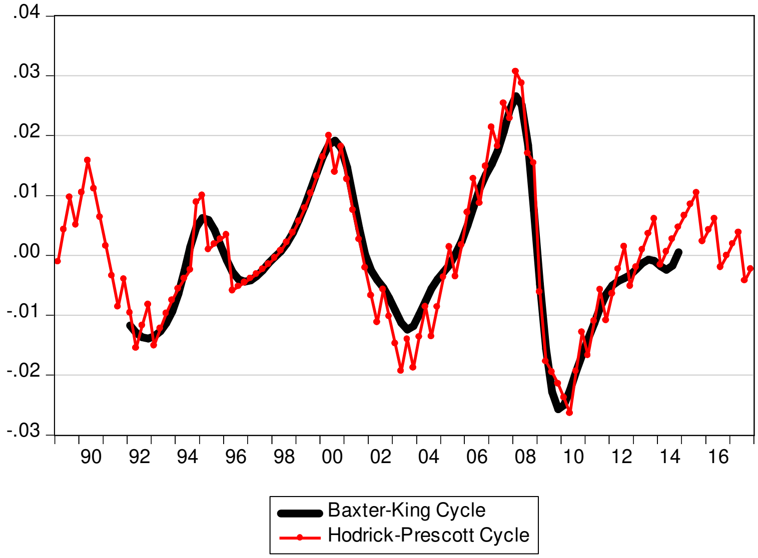
Note: *** when $p<0.01$, ** when $p<0.05$, * when $p<0.1$.

Figure 1. Evolution of main variables



Source: Hazell *et al.* (2020), Federal Reserve Bank of Philadelphia, Crone and Clayton-Mathews (2005), Federal Reserve Bank of St Louis.

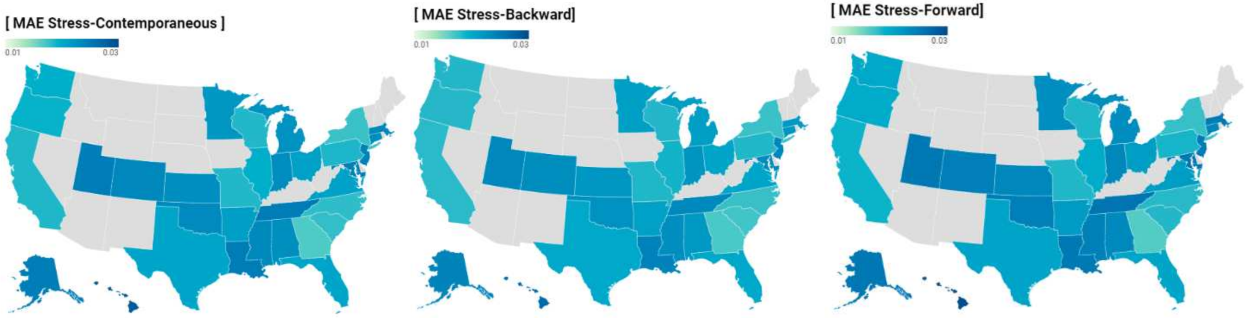
Figure 2. Output gap



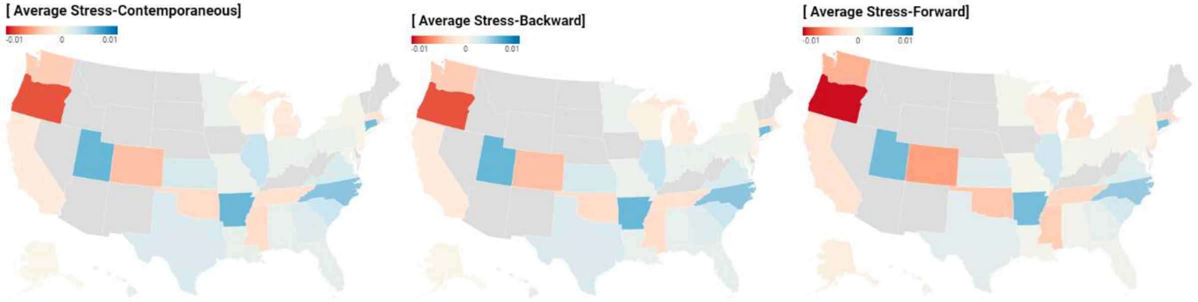
Source: Hazell *et al.* (2020), Federal Reserve Bank of Philadelphia, Crone and Clayton-Mathews (2005), Federal Reserve Bank of St Louis.

Figure 3. Geographcial distribution of stress

3.a. Total stress



3.b Average stress



Note: The maps are produced by the help of following online tool: https://www.datawrapper.de.