The Missing Link: Monetary Policy and The Labor Share*

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Abstract

The textbook New-Keynesian (NK) model implies that the labor share is pro-cyclical conditional on a monetary policy shock. We present evidence that a monetary policy tightening robustly increased the labor share and decreased real wages (and labor productivity) during the Great Moderation period in the US, the Euro Area, the UK, Australia, and Canada. We show that this is inconsistent not only with the basic NK model, but with medium scale NK models commonly used for monetary policy analysis and where it is possible to break the direct link between the labor share and the inverse markup.

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1 Introduction

Widely used structural models for monetary policy analysis that rely on price (and wage) rigidities establish clear transmission mechanisms from monetary policy shocks to real economic activity and inflation. One of the key mechanisms of transmission in these models operates through the redistribution between labor income and firm's profits (markups). In the basic model, when prices are rigid, a monetary policy (MP) tightening should lead to an increase in the markup and a decrease in the income share of labor as prices cannot react immediately to the fall in demand. This effect reduces unit labor costs leading to a downward pressure on inflation. For this transmission mechanism to be operative, MP shocks should affect the cyclical behavior of the labor share in ways that are consistent with these theoretical predictions. Despite its importance, studies on the effect of MP shocks on the labor share are very scarce.[1]

Our first objective is to fill this gap and provide a cross-country comprehensive study on the effects of monetary policy on the labor share. Using state of the art VAR identification techniques, we present a new and robust set of facts for the US, the Euro Area, UK, Australia, and Canada. Furthermore, we look at the reaction of real wages as one of the key drivers of the labor share. This is needed to identify the channels through which the labor share response operates. Once we establish the empirical facts, we address our second objective. We ask the question: are current models of economic fluctuations widely used for monetary policy analysis able to jointly match the response of the labor share and real wages? This is an important question given the above mentioned reliance of models on specific MP transmission channels.[2]

The first contribution of the paper is empirical. We uncover a new (and very robust) set of stylized facts: cyclically, a MP tightening (easing) increases (decreases) the labor share and decreases (increases) real wages.[3] These facts are robust across time periods, different countries, different measures of the labor share, different identification methods, different information sets, and immune to composition bias. To address concerns about identification of MP shocks, we use recursive Cholesky ordering and external instruments in the spirit of Stock and Watson (2012) and Mertens and Ravn (2013), and complement these results with sign restrictions.

To analyze whether theories are consistent with these robust stylized facts, we study the properties of medium scale models commonly used in macroeconomics for the analysis of monetary policy. We first study a simple NK model with both price and wage rigidity where we can obtain analytical results relating MP shocks and the response of the labor share and real wages. We then look at the quantitative properties of a larger model incorporating a combination of different rigidities that allow the model to separate the dynamics of the labor share from that of the markup.[4] We derive measures of the labor share from the model

[1] Ramey (2016), for instance, reviews the available evidence on MP shocks using all the available state of the art identification techniques in VAR models. However, there is no mention of the impact on real wages and labor productivity (the components of the labor share).

[2] Beyond the importance for understanding transmission, these questions are also important to understand the *cyclical* redistributive effects of MP at the factor level. Redistributive effects of MP between the owners of capital and labor can have important consequences. They can affect household income inequality depending on the structure of capital ownership, and can also lead to inter-generational redistribution as different cohorts live off changing proportions of labor and profit income. These aspects can have important political economy consequences, but we do not go as far in this paper.

[3] The labor share can be decomposed into real wages and labor productivity. Therefore by identifying the behavior of real wages we implicitly identify the response of labor productivity as well.

[4] We focus here on the model by Christiano, Eichenbaum, and Trabandt (2016), but we also provide a com-

and look at their response to a MP shock. This is carried out using a three step approach. We first look at the likelihood that the model can generate the observed responses obtained in the VAR by using a Prior Sensitivity Analysis (PSA) approach. Secondly, we identify the key model parameters driving the response of the labor share and real wages using Monte Carlo Filtering (MCF) techniques. Third, once these key parameters are identified, we estimate them by matching the model's impulse responses to those of the VAR.

To advance some intuition, it is well known that, in the simplest version of the New-Keynesian (NK) model (see Galí 2015), the labor share is equal to the inverse of the price markup (the marginal cost). This makes the labor share pro-cyclical (the price markup is counter-cyclical) conditional on a MP shock, which is at odds with the empirical evidence we find here. However, this direct correspondence between the price markup and the labor share does not necessarily hold in other versions of the model such as those that, for instance, consider a cost channel of monetary policy or fixed costs in production. We also consider the role played by wage rigidities. Analytically, we show that, in a canonical NK model with price and wage rigidity, it is not possible to obtain a positive response of the labor share to a MP contraction on impact. In other words, we look at a model that incorporates different channels that can break the relationship between markups and the labor share, since they are potentially able to generate labor share dynamics that differ from the canonical NK model.

The key result from our quantitative analysis, and our second contribution, is that there is a puzzling mismatch between data and theory. This is not just a feature of the basic NK model, but carries over in richer setups widely used for MP analysis. We show that, in the medium scale model, one can potentially generate a positive response of the labor share when wages are more rigid than prices, but this comes at the cost of a counterfactual (counter-cyclical) response of real wages. Our impulse response matching estimates show that the model does a reasonable job at matching the responses of key macroeconomic variables to an identified MP shock, but it is unable to reproduce the response of the labor share.

Related literature

Our paper is related to different strands of the literature that focus on the cyclical behavior of markups and labor market variables conditional on demand shocks.[5] The relationship between the markup, the labor share, and their cyclicality is the focus of, amongst many others, Barattieri, Basu, and Gottschalk (2014), Bils (1987), Bils, Klenow, and Malin (2018), Galí, Gertler, and López-Salido (2007), Hall (2012), Karabarbounis (2014), and Rotemberg and Woodford (1999). These papers are closely related to the cyclical behavior of the so-called 'labor-wedge'. Whereas papers such as Galí, Gertler, and López-Salido (2007) conclude in favor of a larger role of wage rigidities to explain the cyclical behavior of the labor wedge, Bils, Klenow, and Malin (2018) revive the role of price stickiness as they find a counter-cyclical price markup. The conditional correlation of the labor share to demand shocks is still empirically and theoretically an open question[6]. However, most

prehensive analysis of other types of models in a detailed online appendix.

[5]There is a literature on the cyclical behavior of the labor share conditional on technology shocks such as Choi and Ríos-Rull (2009), Ríos-Rull and Santaeulália-Llopis (2010) and León-Ledesma and Satchi (2019). However, our focus here is on the effects of MP innovations.

[6]Empirically, Christiano, Eichenbaum, and Evans (2005) and Altig et al. (2011) showed, only for the US and in a broader context, how wages and labor productivity respond pro-cyclically to an MP shock. However, they do not provide direct evidence on the labor share, and their focus is on the persistence of output and inflation inertia

of these related studies focus on the dynamics of markups. Whilst markups are not directly observable and require the use models to derive data counterparts, the labor share is directly observable. Our approach differs from these as we provide an analysis of the conditional correlations of measured labor shares in the data and their implied behavior in NK models. I.e. we start off analyzing national accounts based measures and then contrast them with consistent model-implied measures. Furthermore, our contributions relative to the extant literature are twofold: on the empirical side, we provide systematic, robust, as well as cross-country evidence and, on the theory side, we focus on the role of a wide set of real and nominal frictions and not only on price/wage stickiness.

Perhaps most closely related to ours is Nekarda and Ramey (2019). They discuss generalizations of the production function used in NK models that decouple the price markup from the measured labor share in the data. Using these theory generalizations as empirical proxies for the markup, they show that the markup is pro-cyclical or a-cyclical in the US. Like us, they also show a counter-cyclical response of the labor share conditional on a MP shock. Their conclusions, like ours, cast doubts on the standard transmission mechanism of NK models. Our approach differs from theirs because, as mentioned above, we first obtain evidence from directly measurable labor shares and then use NK models from which we derive the behavior of the labor share and real wages and analyze the coherence between their responses to a MP shock and that obtained in the VARs. We also make use of a wider variety of potential frictions that can decouple the dynamics of the labor share from markups. Finally, our empirical evidence on the conditional response of the labor share spans several countries and is more systematic. Importantly, while Nekarda and Ramey (2019) conclude that refocusing models around wage rigidity may resolve their empirical inconsistency, we show that, even with strong wage and labor market rigidities, models are unable to reproduce the joint behavior of the labor share and real wages.

Recently, Broer et al. (forthcoming) address the issue of MP transmission in a simple version of the heterogeneous agent NK model. In their model, distributional effects of MP shocks in a model with only price rigidity would imply no output response. Instead, with wage rigidity, the response of labor supply disconnects from workers' income leading to output effects. They show that, with wage rigidity, profits become pro-cyclical. However, the share of output accruing to profits (i.e. the markup) is still counter-cyclical as wage rigidity can only affect its magnitude and persistence but not its sign.[7] Thus, the problems faced by these types of models in reproducing the dynamics of the labor share also persist when we introduce distributional effects with heterogeneous agents.

Our paper casts doubts on the standard transmission mechanism of MP shocks in NK-DSGE models that runs from aggregate demand to the labor share and to inflation through the Phillips Curve. In this sense, our paper shares the concerns about the transmission of shocks in macroeconomic models studied by Angeletos, Collard, and Dellas (2018).

In the rest of the paper, Section 2 presents the data, and key results from the VAR analysis. An extended set of results and robustness is provided in section B of the Online Appendix accompanying the paper. Section 3 presents the quantitative analysis on medium scale DSGE models using a three step approach. We conclude in Section 4.

[7]In order to obtain their key result, they calibrate a very high value of wage stickiness that implies an almost a-cyclical markup. It is straightforward to show, however, that no parameterization can turn the markup pro-cyclical.

2 The labor share and monetary policy: Empirics

The share of labor in total income can be measured directly from national accounts. Loosely speaking, it represents the fraction of total income that is attributable to labor earnings. Unlike markups, measuring it does not require any specification of the production side of the economy. Its precise measurement is, however, complicated by issues associated with how to impute certain categories of income to labor and/or to capital earnings. The existence of self-employment income, the treatment of the government sector, the role of indirect taxes and subsidies, household income accruing from owner occupied housing, and the treatment of capital depreciation, are common problems highlighted in the literature, see e.g. Gollin (2002), Gomme and Rupert (2004) and Muck, McAdam, and Growiec (2015). As in Gomme and Rupert (2004) we consider the labor share in the non-financial corporate sector. Neither proprietors' income nor rental income are included in this sector accounts. We thus avoid the issues of properly apportioning proprietors' income to labor and capital or of accounting for labor income in the housing sector. Similarly, we consider the labor share in the domestic corporate sector in Australia and we imputed mixed income in the same proportion as unambiguous labor and capital income when computing the labor share in Canada. For the Euro Area and the United Kingdom we define the labor share as compensation of employees over nominal Gross Value Added at factor costs.[8]

Figure 1 plots the baseline quarterly labor share measures for all the countries under analysis. Low frequency fluctuations are visible across all countries, which is a well-established fact. However, it is evident that labor shares have also moved systematically in the short run. On average, we find that the labor share is counter-cyclical and tends to increase in recessions. This is confirmed by looking at the contemporaneous correlation with output, which is mostly negative, and with the policy rate, mostly positive except for the UK and the Euro Area. Table 1 presents the 95% confidence intervals of the estimated correlation between the labor share and HP filtered output and between the labor share and the short term interest rate.

In these five major economies the labor share fluctuates over the business cycles possibly in response to different types of shocks. The question is then, can an unexpected MP accommodation or tightening modify the share of labor income? By looking at the unconditional correlation between the labor share and the policy rate little can be inferred. As interest rates can vary for a variety of reasons, their co-movement could be the result of the systematic response of MP to other shocks hitting the economy, e.g. financial shocks. If we want to answer these questions, we need to impose more structure in order to isolate the changes in the labor share ascribed to an exogenous MP impulse. For this, we use the Vector Autoregressive (VAR) model which is a framework that has been extensively used to study the dynamic transmission of exogenous policy variations to macroeconomic aggregates. One of the advantages of VAR models is their extreme flexibility compared to theoretical business cycle models. This flexibility makes VAR-based analysis less likely to be distorted by incorrect specifications of the equilibrium conditions implied by the theoretical model. Also, under mild conditions, VARs can be regarded as unrestricted representations

[8] In the Appendix, we describe in more detail the data construction. In particular, we consider seven different proxies for the labor share in the US for the post WWII period. The Bureau of Labor Statistics provides measures of the labor share in the non-farm business and in the non-financial corporation sectors. Cooley and Prescott (1995), Gomme and Rupert (2004) and Fernald (2014) offer alternative measurements, which we considered in the empirical exercises in order to make our statements more sound. Being highly correlated, the different proxies do not matter for the results of the paper. For the other countries, where available, we used similar approaches and measurements.

of micro-founded structural macroeconomic models. Thus, the dynamic transmission of monetary shocks in the structural model can be mapped into the VAR impulse responses with a minimal set of restrictions.

More formally, we assume that the joint co-movements of our key macroeconomic variables can be described by a VAR of order p which takes the following form:

$$y_t = \Phi_0 + \Phi_1 y_{t-1} + ...\Phi_p y_{t-p} + e_t \quad e_t \sim N(0, \Sigma),$$

where ϵ_t is a vector of normal zero mean i.i.d. shocks with $\Sigma = E(\epsilon_t \epsilon_t')$. $\Phi_0, \Phi_1, ..., \Phi_p$ are matrices of appropriate dimensions describing the dynamics of the system. The reduced form VAR is compatible with several structural representations where reduced form residuals can be expressed as linear combination of structural uncorrelated innovations, i.e.

$$e_t = \Omega \nu_t,$$

where $\Omega\Omega' = \Sigma$ and $E(\nu_t \nu_t') = I_n$. To identify Ω, we explored two popular approaches proposed in the literature.

The first approach relies on an explicit observable measure of the MP surprise, i.e. the external/instrumental variable approach as pioneered by Stock and Watson (2012) and by Mertens and Ravn (2013). The basic idea of the structural VAR with external instrument is that the MP shock in the structural VAR is identified as the predicted value in the population regression of the reduced form VAR residuals on the instrument. For this result to hold, the instrument needs to be valid; that is, it needs to be relevant (correlated with the unobserved MP shock of the VAR) and exogenous (uncorrelated with the other shocks). This two stage regression allows to recover the the first column of the rotation matrix Ω, and thus to recover impulse responses and transmission mechanism.

We examined a number of proxy variables for the MP shock.[9] For the US, we considered jointly three different proxies or instruments; the Romer and Romer (2004) narrative instrument based on FOMC minutes and other quantitative records; the Gertler and Karadi (2015) high frequency variations in federal funds rate in a narrow window around the FOMC monetary policy communications; the Miranda-Agrippino (2016) high frequency variation of the federal funds rate adjusted for the information set (or signaling effect) of FOMC. For the Euro Area (EA), we considered the MP surprise constructed by Andrade and Ferroni (2016) based on the the high frequency variations of EONIA swaps around the time when monetary policy decisions and communications are publicly released by the ECB Governing Council. For Canada, we considered as instrument the MP surprise constructed by Champagne and Sekkel (2018) using Bank of Canada's staff projections.[10]

The second strategy to retrieve the MP innovation from the rotation matrix, Ω, is to assume a recursive timing restriction on the real variables of the VAR. The identification assumption is that a shock to the policy rate only has an instantaneous effect on the short term interest rate. This implies that all the other variables do not react contemporaneously to changes in the interest rate. It also implies that the policy rate does respond contemporaneously to all the macroeconomic shocks affecting prices and real variables. The specific ordering the labor share (before or after the short term interest rate) is not crucial for the results. The virtue of this approach is that it does not require explicit measures of MP surprises, which allows us to conduct inference also for those countries where we lack proxy

[9]More details on each proxy variable of monetary surprise can be found in Appendix A.6.

[10]We could not find any external instrument for MP surprises in Australia. Cloyne and Hürtgen (2016) developed a narrative measure of MP surprise for the UK, the results of which are discussed in footnote 12.

variables for these shocks, e.g. Australia. Moreover, as it will become apparent soon, these two approaches deliver very similar results.

Each country-specific VAR model consists of log of real GDP, the log of the GDP deflator, the log of an index of commodity prices, log of the CPI, log of real wages, the log of the labor share and short term interest rates. The sample spans used for each country VAR cover the Great Moderation period. Since we are interested in the relationship between the labor share and MP, we restrict the samples to periods where monetary policy was not constrained by the effective lower bound.[11]

Figure 2 reports the responses of the variables of interest to a MP shock (tightening) normalized to generate a 25 basis points increase in the short term interest rate. The black solid line reports the median response using a recursive identification scheme and the light (dark) gray the 90% (68%) confidence sets; the blue line indicates the response using the identification scheme based on the instrumental variables (IV) for the shock of interest. From top to bottom row, we have the US, Canada, the Euro Area, Australia and the UK. All responses are expressed in percentage terms.

A bird eye view of figure 2 suggests that the identified transmission reflects our priors about the dynamic propagation of monetary policy: in response to an interest rate hike output falls and prices decline slowly for all the countries considered. The persistence and the signs of the responses of our key macroeconomic variables are in line with what found in other studies. What is new is the response of the labor share. In every country it is positive and statistically significant. The increase in the labor share also appears to be persistent and does not vanish within few quarters. The peak effect is located between five and ten quarters for the US, Canada and Australia and before five quarters for UK and EA. Furthermore, the response of the shares are also quantitatively relevant. Across all countries, we observe that the magnitude of the increase in the labor share in percentage points is at least half of the one observed for output and, in some cases, even bigger. For example, if we look at the US with he recursive identification, we observe that the median response of output after 10 quarters is almost 20 basis points down while the increase in the labor share peaks at 20 basis points at about the same horizon. For the rest of the countries, instead, the labor share responses are about a half of the response of output.

The median impulse response functions identified via recursive ordering are very similar to those identified via proxy variables. For the US and Canada, these responses virtually overlap (first and second rows). Typically, we notice some differences on impact which occur by construction as a result of the recursive identification. Otherwise, the responses with these two identification schemes are very similar. This is not entirely surprising when looking at the correlation between these instruments and the recursive identified innovations which are in the range of 0.2-0.5 (not shown here). Albeit less striking than for the US and Canada cases, the responses with the two identification strategies are also very similar in the EA (third row). While real GDP and the GDP deflator tend to respond more with the IV identification, the median responses lie within the 68% confidence sets of the recursive identification. And, most importantly for our purposes, the labor share increases in the same qualitative and quantitative fashion. For both the UK and Australia, the recursive identification generates similar patterns which are in the ballpark of the estimates of other countries.[12]

[11] In particular we consider 1984:Q1-2007:Q4 for the US, 1999:Q4-2011:Q3 for the EA, 1985:Q1-2009:Q4 for Australia, 1985:Q1-2011:Q1 for Canada, and 1986:Q1-2008:Q1 for the UK. We use 3 lags for US, Australia, and Canada, two lags for UK and one lag for the EA; and VAR parameters are estimated using Bayesian methods with uninformative priors.

[12] For the UK, we considered also the instrumental variables identification and results are somehow puzzling,

To summarize, a MP tightening induces an increase in the share of labor in five large developed economies. Dynamic transmissions are remarkably similar when considering a timing restriction or an explicit measure of MP surprise. The real wage, a key component of the labor share, either falls or does not respond significantly to the shock. I.e. real wages do not increase after a MP tightening. To set our stylized fact on a sound ground we carried out a number of experiments to check whether the empirical results are robust to alternative specifications which we describe next.

2.1 Robustness

The key message here is that we find that the rise in the labor share (and non-positive response of real wages) following a MP tightening is a remarkably robust fact. We briefly summarize the experiments here. Details on all of them can be consulted in section B of the Appendix.

- For the US, Australia, and Canada, we use multiple measures of the labor share (see appendix A). All proxies constructed generate similar impulse responses profiles.
- For the US, we studied different subsamples. Basu and House (2016) and Ramey (2016) show that using samples with more recent data the impulse response functions change substantially relative to the ones obtained in Christiano, Eichenbaum, and Evans (2005), who use a less recent time span. Ramey (2016) concludes that the most likely reason for the breakdown in the later sample is simply that we can no longer identify MP shocks well. Thus, we estimate the VAR with the baseline information set for the 1965:Q1-1995Q3 sample and the 1965:Q1 until 2007:Q4 sample. Subsample estimates and larger information sets do not alter out main empirical finding.
- For the US, we considered a VAR specification including the baseline variables plus the Fernald (2012) measure of Utilization Adjusted TFP, labor productivity and the Gilchrist and Zakrajsek (2012) corporate bond spread.
- We considered the baseline VAR specification augmented with M2 and used an identification scheme based on sign restrictions to identify MP shocks (see Uhlig (2005)). We postulate that a MP shock
  - increased the short term nominal interest rate at $t = 0, 1, 2$
  - decreased prices, i.e. the GDP deflator and CPI at $t = 0, 1, 2$
  - induced a contraction in M2 at $t = 0, 1, 2$

  This identification scheme imposes a weaker restrictions relative to the recursive identification. Implicit is the idea that a MP tightening should at least raise interest rate, and depress the price level and monetary aggregates for at least three quarters. While one could impose more restrictions, these ones are uncontroversial and common to a wide variety of structural models with different types of frictions. We generate candidate draws for the rotation matrix satisfying these restrictions using the algorithm developed in Rubio-Ramírez, Waggoner, and Zha (2010). Figure B2 in the Appendix plots the results for all the countries. While there are quantitative differences between

see figure B9 in the appendix. While the sign implications are identical, i.e. after a monetary tightening prices decline, output contracts and labor share increases, magnitudes are extremely large, both in absolute values and also relative to other countries. E.g., a 10 bps increase in the short run interest rate generates a 100 bps decline in inflation after three years. These numbers are off the chart relative to standard magnitudes. Understanding the reason of this difference is beyond the scope of this paper.

this and the Cholesky identification restrictions, the qualitative results are unchanged. That is, after a MP contraction, the labor share increases for all countries (and for all labor share proxies). It is important to note that, for all the countries except the EA, we find that the impact response of output is non-negative, which is the same result obtained by Uhlig (2005) for the US.

- The results on the aggregate labor share response raise the question whether the observed response is due to changes in the composition of output from sectors with low to sectors with high labor shares rather than a change in the labor share within sectors. For this reason, we provide sectoral evidence on the response of the labor share. We carry out this analysis for the US economy using both the NBER-CES productivity database for 436 US manufacturing sectors as well as the Klems database for 30 sectors including agriculture, manufacturing, and services. For reasons of space, we present this analysis in supplementary Appendix C. The results confirm a similar pattern to that obtained with aggregate data. I.e., at the sectoral level, the labor share increases after a contractionary MP shock.

2.2 Discussion

Our results show that the labor share (robustly) responds positively to a MP contraction. Given that real wages fall or remain constant, this necessarily implies that labor productivity must fall more than real wages. This is because, loosely speaking, the labor share can be defined as the ratio between real wages and labor productivity: $LS = \frac{WL}{Y} = \frac{W}{Y/L}$.[13] Therefore, to compare the empirical results with theory models, we focus on the labor share and real wages since, in the models,[14] these two objects will automatically define the behavior of labor productivity.

It is also important to note that the results for real wages (and, thus, labor productivity) are not driven by composition biases in the labor force. This composition bias could arise as less productive (low wage) workers tend to exit the labor force during recessions and enter during expansions.[15] This bias would not affect the labor share as it is a ratio of two potentially biased responses (see Basu and House (2016)). In the case of real wages (or labor productivity) this bias may potentially affect our results. However, since we find that real wages fall or remain constant after a MP contraction, the bias can only reinforce our result: if low wage workers tend to exit during recessions, average real wages are likely to by fall more than aggregate real wages. In Appendix D we provide a detailed discussion of this problem together with estimates of the responses of wages of new hires which are less likely to be affected by composition changes. The response of wages of new hires to a contractionary MP shock is negative and stronger than for aggregate wages.

It is well know that, in standard NK models, the labor share is equivalent to the inverse

[13] In practice, output and wages are often deflated using different price indexes. CPI is used to deflate wages instead of the GDP deflator. In previous versions of this paper we discussed this issue in detail and showed that the effect of MP shocks on relative prices plays a minor role. Here we simply abstract from this and use the GDP deflator to construct real wages.

[14] In the data, the naïve definition of the labor share as $LS = \frac{WL}{Y} = \frac{W}{Y/L}$ is not necessarily true. This happens because of the presence of adjustments needed to deal with ambiguous income from proprietors, housing and interest payments (see Appendix A). Only in the case in which this decomposition is exact, like in the case of the US's non-financial corporate sector, including the labor share as well as real wages and labor productivity in the empirical analysis would lead to perfect collinearity.

[15] However, see Gertler, Huckfeldt, and Trigari (2019) who argue that wages of existing workers are a better guide to the cyclicality of the marginal cost of labor due to the cyclicality of match quality.

of the price markup (Galí, Gertler, and López-Salido (2007), Nekarda and Ramey (2019)). Rearranging the linear version of the New Keynesian Phillips curve (NKPC) as in Galí (2015), we have:

$$mc_t = \frac{\pi_t - \beta \mathbb{E}_t \pi_{t+1}}{\kappa_p}, \tag{1}$$

where mc_t represents real marginal costs (inverse of the price markup), β is the discount factor, π_t is inflation, and κ_p is the slope. From this expression, it is clear that a temporary decline in inflation (because of tighter monetary policy, for example) implies a decline in marginal costs (*labor share*) and an increase in the markup. This one to one relationship is independent of the presence factor adjustment costs, or financial frictions[16] and it is true in an economy with and without capital accumulation provided that the production function is either Cobb-Douglas or linear in labor.

In models where the dynamics of inflation can be represented by a NKPC such as (1), the finding that the labor share increases after a MP contraction is at odds with the observed dynamics of prices and inflation. To illustrate this, we can look at a simple example. Using the basic NKPC, we can calculate the implied response of prices to a MP shock if the labor share responds as in the baseline VAR presented in the previous section, and compare it to the actual response of prices in the same VAR. In the NK model, $\kappa_p = \frac{(1-\theta_p)(1-\theta_p\beta)}{\theta_p}$, where $(1-\theta_p)$ is the proportion of firms that are allowed to reset prices. We calibrate these parameters to standard values for illustrative purposes ($\theta_p = 0.6$, $\beta = 0.99$).[17] Figure 3 shows, given the response of the labor share, the evolution of prices from the theoretical NKPC compared to the actual evolution of prices in the VAR. Prices would increase after the MP shock compared to a decrease in the data. Hence, either the labor share is not a good proxy for marginal costs, or the NKPC is not a good representation of inflation dynamics.[18] In the next section we discuss theoretical mechanisms that could separate the dynamics of the marginal cost and the labor share and hence potentially generate a positive response.

3 The labor share and monetary policy: Theory

We now tackle our second question: are models of economic fluctuations widely used for monetary policy analysis able to jointly match the response of the labor share and real wages?

3.1 Analytical results

We start with a simple model where we can obtain analytical expressions to illustrate the basic mechanisms. In log-deviation from the steady state, the labor share is defined as $ls_t = w_t + h_t - y_t$, where w_t is the real wage, h_t is hours, and y_t output. In a competitive labor market, labor is paid at its marginal product and hence $w_t = mc_t + y_t - h_t$, where mc_t is the real marginal cost (the inverse of the price markup). This then implies that $mc_t = ls_t$, a standard result in NK models. When production uses only labor and the production function displays constant returns to scale (CRS), $y_t = h_t$, which implies that

[16] In the form of a wedge between the real interest rate and return to capital.

[17] Appendix E shows the details of this derivation.

[18] An important related question is whether this problem also applies to other shocks such as TFP and cost-push shocks. Although this is beyond the scope of this paper, in appendix F, we also look at the response of the labor share to TFP and cost shocks for the US and show that the results are mixed.

$mc_t = ls_t = w_t$. In principle, thus, the labor share could increase if nominal wages are more rigid than prices. After a MP contraction, prices fall more than nominal wages, potentially leading to an increase in real wages and the labor share. Thus, the response of the labor share should be a function of the relative degree of wage and price rigidity at least in a basic NK model. To show analytically this result, we use a simple NK model with price and wage rigidities as in Galí (2015). The set of equations describing the model are:

$$y_t = E_t[y_{t+1}] + (i_t - E_t[\pi_{t+1}]) \tag{2}$$

$$y_t = (1-\alpha)h_t \tag{3}$$

$$\pi_t = \beta E_t[\pi_{t+1}] + \lambda_p y_t + \kappa_p w_t \tag{4}$$

$$\pi_t^w = \beta E_t[\pi_{t+1}^w] + \lambda_w y_t - \kappa_w w_t \tag{5}$$

$$ls_t \equiv w_t + h_t - y_t \tag{6}$$

The model is written in "gap" form. Equation (2) is the IS curve, (3) is the production function, (4) and (5) are the price and wage Phillips curves respectively, and (6) is the definition of the labor share. Here, y_t is the output gap (deviations from the flexible price/wage economy), w_t is the real wage gap, π_t and π_t^w are price and nominal wage inflation respectively, h_t is the employment gap, and i_t is the interest rate *in deviation from the natural real rate of interest* (r^n). β is the discount factor, α is the degree of decreasing returns in production, and λ_p, λ_w, κ_p, and κ_w are (positive) slope coefficients of the Phillips Curves that are a function of deep parameters of the model as follows:

$$\lambda_p = \frac{\alpha}{1-\alpha}\kappa_p > 0 \tag{7}$$

$$\lambda_w = \left(\sigma + \frac{\alpha}{1-\alpha}\right)\kappa_w > 0 \tag{8}$$

$$\kappa_p = \frac{(1-\theta_p)(1-\beta\theta_p)}{\theta_p} > 0 \tag{9}$$

$$\kappa_w = \frac{(1-\theta_w)(1-\beta\theta_w)}{(1+\eta\epsilon_w)\theta_w} > 0 \tag{10}$$

where σ is the degree of risk aversion, $(1-\theta_p)$ is the fraction of firms that readjust prices, $(1-\theta_w)$ the fraction of workers that readjust wages, ϵ_w is the elasticity of substitution of differentiated labor inputs, and η is the inverse Frisch elasticity.

In order to obtain an analytical solution for the responses of real wages and the labor share, we assume that the monetary authority is able to set the interest rate to track the natural real rate of interest (and hence make the gaps zero) in every period except for the initial period in which it deviates by an amount ε_t^{MP}, the MP shock.[19] Written in terms of deviations from r^n, this then implies:

$$\begin{aligned} i_t &= E_t[\pi_{t+1}] + \varepsilon_t^{MP} \\ i_{t+j} &= E_{t+j}[\pi_{t+1+j}] \text{ for } j > 0 \end{aligned} \tag{11}$$

Appendix G shows the full derivation of the results below. We can show that, in this case, the responses of real wages and the labor share are just a linear function of the model parameters:

[19] This is similar to the exposition of McKay, Nakamura, and Steinsson (2016).

$$w_t = \frac{\lambda_p - \lambda_w}{1 + \kappa_w + \kappa_p} \varepsilon_t^{MP} \tag{12}$$

$$ls_t = \left(\frac{\lambda_p - \lambda_w}{1 + \kappa_w + \kappa_p} - \frac{\alpha}{1 - \alpha} \right) \varepsilon_t^{MP} \tag{13}$$

Since coefficients λ_p and λ_w are decreasing functions of the degree of price and wage stickiness, it is clear that real wages could increase after a MP contraction given a sufficient degree of wage relative to price stickiness. In the CRS case ($\alpha = 0$) the response of both variables would be equal. However, as long as $0 < \alpha < 1$, the response of the labor share will always be below the impact response of real wages. Thus, although nominal wage stickiness shapes the response of the labor share, this response is inconsistent with our empirical evidence. In the VAR, the labor share increases and is always above the response of real wages which generally fall after the MP contraction. Importantly, we can show that the response of the labor share *will always be negative* in this simple model. To see this, we find the value of κ_w in (13) that would make the expression in parenthesis zero. We call this value κ_w^0. It is easy to show that:

$$\kappa_w^0 = -\frac{\frac{\alpha}{1-\alpha}}{\sigma + 2\frac{\alpha}{1-\alpha}}, \tag{14}$$

which, given that $0 \leq \alpha < 1$ and $\sigma > 0$, would imply a negative κ_w. Thus, whatever the degree of wage stickiness, the labor share and, by implication, marginal costs must decrease after a MP contraction. The intuition behind this result is that it must be the case that a shock that reduces demand must be met by a decrease in supply in equilibrium. This can only happen if the demand for labor falls and, hence, so does its real unit cost. The labor share, which equals real marginal costs in a model with only labor in production, will then fall *regardless of the relative degree of wage and price rigidity.*

3.2 Medium scale models

The analytical results show that the relative degree of wage to price rigidity affect the responses of real wages and the labor share to a MP shock. However, relatively higher degrees of wage rigidity on their own are unable to generate the positive response of the labor share observed in the data. However, in a fully fledged model with capital, other types of frictions, and a standard MP rule, the response of the labor share will be modulated by many other factors besides wage and price rigidity. Also, the analytical results presented here are only valid on impact. The labor share may not equal marginal costs in medium scale models that incorporate a richer set of frictions. Thus, we must turn to numerical analysis as we move to larger models.

Several mechanisms commonly introduced in DSGE models can alter the relationship between the labor share and the inverse markup (marginal costs). The cost channel of monetary policy (see Ravenna and Walsh (2006) and Surico (2008)) introduces a direct effect of the interest rate on the marginal costs since firms need to borrow in order to pay in advance all or part of their labor input costs. In this setup, the markup can indeed become pro-cyclical and help generate a counter-cyclical response of the labor share. However, this cost channel also introduces a direct effect of the interest rate on the labor share which works in the opposite direction. Another way to introduce a wedge between the labor share and the markup is by relaxing the assumption of equality between the average and marginal wage (Bils (1987), Nekarda and Ramey (2019)). This is usually implemented through the introduction of fixed costs in production. Generalising the production function to the Constant Elasticity of Substitution (CES) family, as in Cantore et al. (2014), introduces a wedge between the labor share and marginal costs that depends on labor productivity and the elasticity of capital-labor substitution. Open economy models also offer a way to break the link between the labor share and marginal costs. In these models, the labor share equals the marginal cost times the terms of trade. If the elasticity of substitution between home and foreign varieties is low and/or the degree of home bias is high this could potentially increase the labor share even if marginal costs fall. Finally, relaxing the assumption of competitive labor markets and assuming search and matching (Galí (2010), Christiano, Eichenbaum, and Trabandt (2016)) implies that the real wage is related to the bargaining power of workers. In this setting, wages do not move anymore only proportionally to the markup and labor productivity.[20]

Since there is a wide array of possible models, here we focus on one of the benchmark medium scale NK-DSGE models in the literature, namely, the *Calvo-sticky-wage* DSGE model presented in Christiano, Eichenbaum, and Trabandt (2016). It is a NK model containing several of these channels including fixed costs, a cost channel of monetary policy through working capital, price, and wage rigidities. Wage rigidity is introduced via the standard sticky-wages-Calvo set up which makes it very similar to the model in Christiano, Eichenbaum, and Evans (2005) and Smets and Wouters (2007). Nevertheless, Christiano, Eichenbaum, and Trabandt (2016) show that this model, conditional on a MP shock, is observationally equivalent to a model where labor market and wage rigidities are microfounded using a model of alternating offer bargaining. Therefore, while we focus on the Calvo sticky wage model here, we consider it as also encompassing a wider array of labor market frictions (and we verify this in Appendix K). Moreover, in Appendix H and previous versions of this paper[21] we have considered the role of several other factors or combinations of them. These are: CES production, the combination of working capital and firm networking (see Phaneuf, Sims, and Victor (2018)), an open economy NK model (as in Galí and Monacelli (2005)), and a standard Diamond-Mortensen-Pissarides search and matching model. Our results using all these variations quantitatively point in the exact same direction as those obtained using the benchmark Christiano, Eichenbaum, and Trabandt (2016) model used here.

Following Christiano, Eichenbaum, and Trabandt (2016), we assume that the MP shock is not in the current (period t) information set of agents. This ensures that the timing assumptions implicit in the SVAR impulse responses identified using a recursive structure are comparable with the information set in the model. The only change we make to the model is to allow for extra persistence in the MP shock in the Taylor rule.[22] This will help the model match the persistence of the variables obtained in the SVAR.

The response of the labor share in this medium scale model will depend, by construction, on the specific parameterization chosen. Given the size of the model, it is not possible to derive analytical expressions that would allow us to discern whether it is able to match the responses of the labor share and real wages. For this reason, we now turn to a systematic quantitative analysis. We do this using a three step approach which we describe below.

[20]Supplementary Appendix H provides a detailed discussion of each of these theoretical channels, how they can separate the labor share from the inverse of the markup, and whether they can potentially generate the observed responses.

[21]See, for instance, Cantore, Ferroni, and León-Ledesma (2019).

[22]In their set up ε_t^{MP} is iid while we make it AR(1).

3.3 Quantitative analysis: missing the link

The three steps taken to analyse the quantitative ability of the model to replicate the VAR responses is as follows. We first ask whether there are combinations of parameters that can, at least a priori, replicate the response of the labor share and real wages.[23] Second, we single out the parameters/frictions that are important to generate those responses. Finally, we ask the model to replicate as close as possible the SVAR impulse response functions of our key macroeconomic variables by estimating the parameters that determine those key frictions.[24] To advance our main result, we find that, while the structural model does a decent job at matching the dynamic propagation of inflation and real quantities, it cannot replicate the propagation of the labor share and real wages.

3.3.1 Is the workhorse medium scale New Keynesian model able to replicate the empirical findings?

Only in very particular situations we can use analytical mappings between model structural parameters and the impulse response patterns of models. For most models, these linkages are blurred by the non linear relationships between the structural and the reduced form solution. However, Montecarlo techniques allow us to assess the likelihood of a model replicating certain moments of interest. As explained by Canova (1995), Lancaster (2004) and Geweke (2005), prior sensitivity analysis (PSA) is a powerful tool to shed light on complicated objects that depend on both the joint prior distribution of parameters and the model specification. By generating a random sample from the prior distributions, one can compute the reduced form solution and the model-implied statistics of interest, e.g. impulse responses. Many replicas of the latter generates an empirical distribution of the model- and prior-implied statistics of interest.[25] In other words, we can assess the likelihood that the model generates a set of sign patterns that are consistent with those observed in the data conditional on the model and the specification of priors.

To this end, we attach uniform prior distributions to almost all the parameters of the model. The only two parameters held fixed are the discount factor and capital depreciation (calibrated to 0.99 and 0.025 as standard) while fixed costs in production are set in order to maintain steady state profits equal to 0.[26] Table 2 shows the bounds of the uniform distributions we attach to all the other parameters. We allow for any economically meaningful value of the parameters, even for extreme values such as full price flexibility. We then generate a random sample from the prior distributions, compute the reduced form solution, and the model-implied impulse responses of interest. We repeat this many times and generate an empirical distribution of the model- and prior-implied impulse responses.

Table 3 summarizes the numerical analysis. Numbers in the table represents the percentage of the prior support that matches all the restrictions imposed on the impulse response

[23]As mentioned above, if the model is able to replicate the IRFs of the labor share and real wage, it would also be consistent with the response of labor productivity.

[24]A common concern when comparing IRFs of SVARs and of structural models is that SVARs may not be able to identify correctly DSGE model shocks (see Erceg, Guerrieri, and Gust (2005)). For this reason, in the spirit of the Sims-Cogley-Nason approach, we tested whether the SVARs were capable of retrieving the 'true' transmission of the labor share using simulated data from the structural models. Overall, the SVAR captures very precisely the 'true' IRFs. The results are presented in supplementary Appendix I.

[25]These techniques have been used to compute the prior sensitivity of fiscal multipliers implied by different DSGE models, see Leeper, Traum, and Walker (2015) and Féve and Sahuc (2014).

[26]The model also has non zero inflation, growth rate of output and growth rate of investment in steady state. We keep the same calibration of Christiano, Eichenbaum, and Trabandt (2016) for these parameters.

functions. We proceed in steps and first impose only the restriction that the impulse response of the labor share needs to be positive from quarters two to five inclusive and then impose separately the same restriction, with opposite sign, to the real wage. Finally we combine both together. We repeat the exercise by imposing the same restrictions from quarters five to eight.[27]

Looking at the first column we see that the model has a non-negligible portion (11.2%) of the parameter space able to reproduce the sign of the labor share from quarter two to five. This percentage increases substantially (42.2%) when looking at restrictions over quarters five to eight. However, notice that the probability of replicating the full profile, i.e. from quarter two to eight, is the product of these two percentages. In columns two and five we look at the proportion of the parameter space that generates negative real wages. In this case the percentage declines over the IRFs horizons but remains around 40% from quarters 5 to 8. However, when we combine both restrictions the probability of replicating the full array of sign patterns drops significantly, below 5% at both horizons (columns 3 and 6). As it will become clearer in the next section, the friction in the model that allows us to match the labor share behavior is the degree of wage stickiness relative to price stickiness. However, this comes at the cost of mismatching the response of real wages. This is consistent with the analytical results in section 3.1 although, in this medium scale model, as the labor share differs from marginal costs it is possible to obtain a positive response.

In any case, the results show that there exists a small but non-zero mass of the parameter space that is able to match the sign of the IRF of the labor share and real wages.

3.3.2 What are the frictions that matter?

In order to understand the relative importance of each specific friction in driving the above results we now turn to our second step: finding the parameters that are more important to generate the response patterns in each model. This question is more subtle compared to the one above because it requires an inverse mapping. Montecarlo filtering (MCF) techniques offer a statistical framework to tackle this issue. As described in Ratto (2008), MCF techniques are computational tools that allow us to recover, in a nonlinear model, the critical inputs that generate a particular model output. In our context, for example, we would be interested in the parameters of a model that are more important to drive a positive (negative) movement of the labor share (wages) in response to a contractionary MP shock. MCF has clear advantages over calibration sensitivity exercises. First, unlike sensitivity exercises, all parameters move simultaneously. Second, the Smirnoff test offers, implicitly, a statistical ranking of parameters from the most to the least influential. Finally, it unveils important relationships among parameters.

Details about this stage of the analysis and results are summarized in Appendix J.[28] Few regularities emerge from it. First of all, as expected, both price and wage stickiness are identified as crucial. In particular, when looking only at the restriction on the labor share, a positive responses to a MP shock arise typically when there is substantial wage rigidity and when wages are less flexible than prices. The left panels of Figure 4 report the wage stickiness Cumulative Density Functions (CDF) when the labor share IRFs are positive for

[27]Note that these restrictions are quite favorable to the model because we only use signs and not specific magnitudes. Had we used reasonable magnitudes derived from the SVAR results, the outcomes would imply lower likelihoods.

[28]Table J1 highlights parameters that have a p–value of the Smirnov statistic lower than the critical value of 0.001 for each model over the same horizons of table 3.

2-5 quarters or when they are not. Random draws of the wage stickiness parameter are split into those that generate a positive response of labor share (in blue) and those that do not (in red). For each of these two subsets, the empirical CDF is computed. As it stands out, the two distributions are different. In particular, most of the probability mass of the red CDF is located to the right of 0.75. This indicates that with relatively flexible wages we are unable to generate a positive response of the labor share to a MP shock.

Yet, this might not be enough. We also need prices to be more flexible than wages. This can be seen in the right panel of figure 4, where we plot the combination of random draws from price and wage stickiness that do (not) verify the labor share IRF in blue (red). In the southeast corner of the plot, where prices are more rigid than wages, the response of the labor share to MP shocks tends to be negative (more red dots). As we move towards the northwest corner (more flexible prices than wages), the likelihood of generating a positive response of the labor share to a MP shock increases.

In sum, price and wage stickiness parameters appear to be crucial in this model for the dynamic response of the labor share. This is consistent with the analytical results, but now a high degree of wage stickiness is able to generate a positive labor share response for the time span of interest. In the presence of very sticky nominal wages and relatively more flexible prices, following a monetary tightening, the real wage increases because prices will decline more than nominal wages. This, in turn, will lead to an expansion of labor income relative to total income. Hence, the labor share goes up but for the 'wrong' reasons, i.e. real wages increase.

There are a number of other parameters that turn out to matter statistically when looking at restrictions on both the labor share and wages at both horizons. The price markup parameter seems to be relevant over both horizons. This highlights the importance of fixed costs in production: fixed costs are calibrated to ensure zero entry in steady state and hence their value is directly related to the price markup parameter. Inertia in the nominal interest rate seems crucial as well, as captured by both the smoothing in the Taylor rule and persistence of the MP shock. The working capital fraction, wage and price indexation, the curvature of the investment adjustment costs function are also key. Other relevant identified parameters are habits in consumption and the response to output in the Taylor rule.

In summary, we have identified a few parameters that seem to matter to generate the right sign of the IRFs of interest. Each of them relates to a specific friction or mechanism that has an effect on the transmission of MP shocks in the model. The relative importance of each of these frictions or mechanisms is crucial also for the transmission of MP shocks to variables other than the labor share and its components. This will be important for next section when we estimate the model to replicate the empirical IRFs.

3.3.3 Can we replicate the VAR evidence?

In the previous two steps, we have identified the portion of the parameter space and the parameters responsible for generating IRFs patterns *qualitatively* similar to the ones in the SVAR for the labor share and real wages. Is the model able to *quantitatively* match the empirical response of the labor share *and* other relevant macro variables to a MP shock? The answer to this question is not trivial. Since we want to minimize the distance between model and SVAR IRFs for several variables, it may be the case that models turn out to be well equipped to match some variables but not others. The answer is also crucial to understand whether the transmission channels of MP shocks present in these models are adequate.

Figure 5 shows the impulse responses to a MP shock in the Calvo-sticky-wage model of Christiano, Eichenbaum, and Trabandt (2016) using their original estimation values. The labor share response in the model not only moves in the opposite direction to the one found in the VAR, but the magnitude is not quantitatively large either. The question is, how would this picture change if we estimated the parameters trying to match the labor share response as well?

To do so, we re-estimate the model parameters using the same Bayesian IRF matching approach of Christiano, Eichenbaum, and Trabandt (2016), and originally developed in Christiano, Trabandt, and Walentin (2010), which allows us to impose economically meaningful priors on the structural parameters. This estimation procedure consists in choosing the values of selected parameters in the DSGE model that minimize a measure of the distance between the SVAR impulse responses and the DSGE model-based ones.[29] The IRF matching is performed using the SVAR results for the US presented in section 2. As shown, the responses using proxy and Cholesky identification virtually overlap for all five variables. However, comparing confidence sets in Figures 2 and B1, we can see that the bands around the proxy responses are larger than for the Cholesky responses. Therefore the Cholesky SVAR seems to be more precise and we choose to use it for estimation.[30]

The model parameter space is partitioned into two subsets. One comprises calibrated parameters that are held fixed in estimation and the other parameters estimated to minimize the distance between the SVAR and DSGE models IRFs. Calibrated parameters in this exercise are again the households discount factor (0.99) and capital depreciation (0.025) plus another two that do not appear empirically relevant in the MCF exercise in the previous section. These are the wage markup (1.2) and technology diffusion into government spending (0.0136) for which we keep the same calibration as in Christiano, Eichenbaum, and Trabandt (2016). Table 4 summarizes the priors used in estimation. We use a Beta distributions for probabilities, habits, interest rate smoothness and working capital fraction. A Gamma distribution is used for investment adjustment costs, capital utilization, price markup, Taylor rule responses to inflation and output, and persistence of the MP shock.[31] All priors are centred around values chosen in line with the literature on Bayesian estimation of DSGE models.

In the third column of Table 4 we report the parameters estimates and 95% confidence intervals. Results are in line with what is usually found in similar models estimated using full-information Bayesian maximum likelihood methods. Notably we obtain very similar degree of price and wage stickiness and their respective indexation to past inflation.

Figure 6 plots the resulting IRFs. It reports the median response from the SVAR (black line), the 68% SVAR confidence sets (grey), and the IRFs from the estimated model (blue). Note that, for estimation, we match the implied IRF of inflation from the SVAR to the same object in the model. For consistency with the original SVAR, however, we report the implied price level. The model is able to reproduce fairly well the responses of the price level at all horizons and of GDP up to 6 quarters after the shock. The model underestimates the response of the real wage which is essentially flat. Importantly, it is unable to match

[29] As we follow closely Christiano, Trabandt, and Walentin (2010) and Christiano, Eichenbaum, and Trabandt (2016), we refer the readers to those sources for details on the minimum distance estimator used.

[30] The objective function of the IRF matching exercise is to minimize the (squared) distance between the responses of the empirical and structural model, weighted by the precision of the empirical model estimates. By using the Cholesky IRF, we are penalizing more the model-based responses that are far from the empirical ones (relative to the proxy IRFs). However, results using the proxy IRFs (not shown) show a similar pattern.

[31] Note that the MP shock standard deviation prior is centred around the estimated standard deviation value in the SVAR.

the response of the labor share despite it being an observable in the distance measure.

The results in figure 6 are in line with the intuitive discussion of the mechanisms present in the model. Although this model contains several elements that can separate the dynamics of the labor share from that of marginal costs, these mechanisms are not well equipped to generate a dynamic response that is consistent with the one obtained in the SVAR analysis. From the PSA analysis we know that there is a sub-set of the parameters space that can reproduce *qualitatively* the positive response of the labor share to a MP tightening. However, this subset is not selected when the whole model is estimated to match the IRFs of several variables of interest. In other words, models that can do a reasonable job at reproducing the dynamic responses of real and nominal variables cannot simultaneously match the dynamics of the labor share.[32] This fact sheds doubts on the transmission mechanism of MP in these models. Moreover, in estimated DSGE models for policy analysis, it is common practice to proxy marginal costs with the labor share as an observable (see, for instance, Del Negro et al. (2013)). However, if we take the evidence presented in Section 2 at face value, then the transmission mechanism assumed with this practice is at odds with the behavior of data and this can have important consequences for estimates of the model parameters.

4 Conclusions

A key transmission channel of monetary policy shocks in New Keynesian (NK) models works through the effect of monetary policy (MP) shocks on markups that have direct implications for the dynamics of the labor share. In its simplest version, the NK model implies that, after a MP shock, markups increase and the labor share falls. The direct link between the markup and the labor share, however, breaks down in a variety of models that introduce aspects such as different production functions, fixed costs, labor market frictions, and/or a cost channel of monetary policy. Despite its importance, there is no systematic evidence on the effect of MP shocks on the labor share. We fill this gap and provide the first cross-country empirical analysis on the effects of monetary policy on the labor share and real wages for a set of five economies: the US, the Euro Area, UK, Australia and Canada.

Using state of the art VAR identification techniques our evidence shows that, cyclically, a MP tightening (easing) increased (decreased) the labor share and decreased (increased) real wages (and labor productivity) during the Great Moderation period for all countries under study. These facts are robust across time periods, shock identification methods, information sets, and measures of the labor share.

We then analyze the ability of medium scale models for monetary policy analysis to reproduce these important facts. Unlike the previous related literature that focuses on the dynamics of the markup, our approach is to obtain measures of the labor share and real wages from models and analyze whether their response to MP shocks is consistent with the one observed in the data. We first show, analytically, that a simple NK model with price and wage rigidities is unable to reproduce the increase in the labor share after a contractionary MP shock. We then study a medium scale model with capital, adjustment costs, a working capital channel, fixed costs, and nominal wage rigidities. Because of the impossibility of obtaining analytical results, we take a numerical approach that consists of three steps. We first analyze whether there is a subset of the parameter space of the model that is qualitatively consistent with the responses obtained in the SVAR. We then

[32]To confirm this, we also estimated the DSGE model by matching *only* the labor share and Fed Funds rate. In this case, the model can obviously match the labor share, but the response of GDP, the price level, and real wages is grossly out of line with the data. See figure L1 in supplementary Appendix L.

select the subset of parameters that are important drivers of the response of the labor share and real wages. Finally, we estimate these parameters in the model using impulse response matching and compare the response of the labor share to an MP shock with that obtained in the SVAR.

We show that, in this and a wider set of models, there is a puzzling mismatch between data and theory which is not just a feature of simple setups such as the basic NK model but carries over in richer set ups. Although it is possible to obtain a positive response of the labor share, it comes at the cost of a counterfactual behavior of real wages. We also show that the model does a reasonable job at matching the response of a set of real and nominal variables but it cannot match the response of the labor share. That is, models that can do well at reproducing the dynamic responses of some key macroeconomic variables cannot simultaneously match the dynamics of the labor share in response to a MP shock. Our results then imply that either models are unable to separate the dynamics of the labor share from marginal costs, or that marginal costs do not respond in the way models predict.

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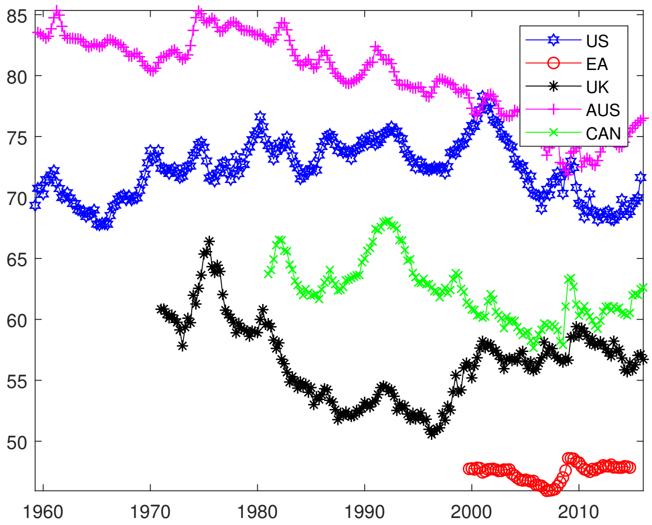


Figure 1: Cross Country Labor Share

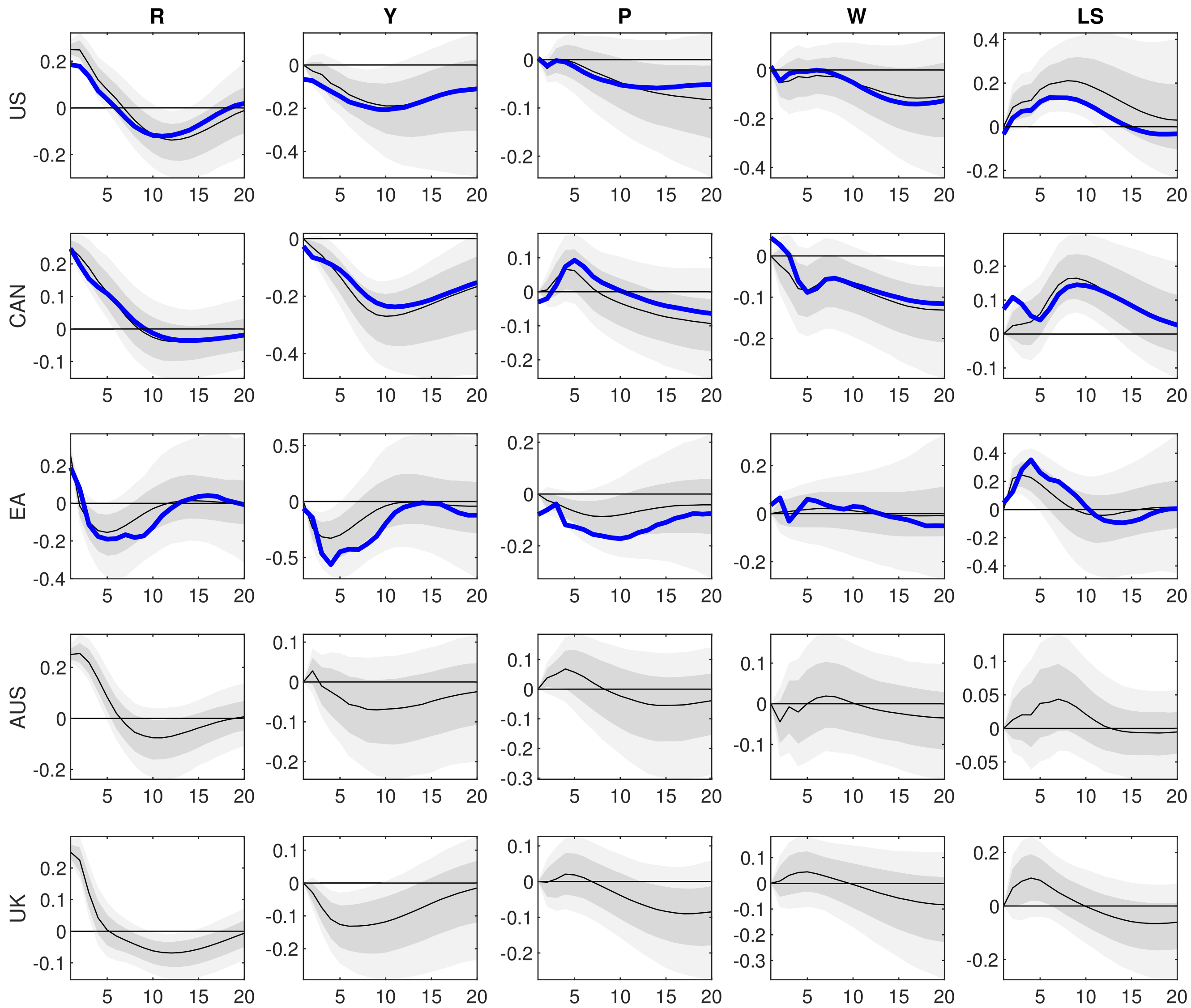


Figure 2: Impulse Response Function to a 25 bps increase in the short term interest rate using an identification scheme based on recursive ordering and proxy or instrumental variables (IV) for the shock of interest. The black solid line reports the median IRF using a recursive identification scheme and the light (dark) gray 90% (68%) bands. The blue line indicates the response of the using the IV identification. US MP instruments: Romer and Romer (2004), Gertler and Karadi (2015) and Miranda-Agrippino (2016). The EA MP instrument: Andrade and Ferroni (2016). The Canadian MP instrument: Champagne and Sekkel (2018).

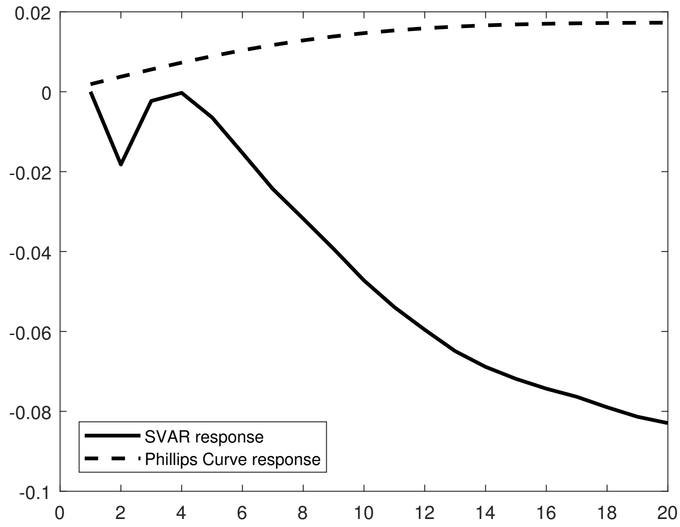


Figure 3: Median response of price level to a 1% MP shock in the SVAR and response implied by a NK Phillips Curve given the response of the labor share. Baseline SVAR using recursive identification.

Country	Sample	Output	Policy Rate
US	1955Q1-2015Q3	[-0.29 , 0.04]	[0.28 , 0.60]
EA	1999Q1-2014Q4	[-0.91 , -0.37]	[-0.76 , -0.28]
UK	1971Q1-2016Q1	[-0.41 , 0.11]	[-0.52 , 0.08]
AUS	1959Q3-2013Q4	[-0.23 , 0.12]	[0.49 , 0.70]
CAN	1981Q2-2013Q4	[-0.56 , -0.07]	[0.45 , 0.72]

Table 1: Correlation with HP filtered Output and Policy rate. GMM 95 % Confidence Intervals and sample coverage.

Description	
Inverse of Frish Elasticity of Labor Supply	$U[1, 10]$
Investment adjustment costs	$U[1, 20]$
Habits in Consumption	$U[0, 1]$
Capacity utilization costs	$U[0, 1]$
Price stickiness	$U[0, 1]$
Wage stickiness	$U[0, 1]$
Price markup	$U[1.1, 2]$
Wage markup	$U[1.1, 2]$
Interest rate smoothing	$U[0, 1]$
Taylor rule response to inflation	$U[1.01, 5]$
Taylor rule response to output	$U[0, 1]$
Price Indexation	$U[0, 1]$
Wage Indexation	$U[0, 1]$
Working capital fraction	$U[0, 1]$
Technology diffusion	$U[0, 1]$
AR(1) MP shock	$U[0, 1]$

Table 2: Uniform Distribution bounds for PSA and MCF.

Restrictions					
2:5 quarters			5:8 quarters		
ls (+)	w (-)	ls (+); w (-)	ls (+)	w (-)	ls (+); w (-)
11.2%	60.5%	2.5%	42.2%	39.4%	3.3%

Table 3: Results from prior sensitivity analysis. Percentage of the prior support that matches all the restrictions.

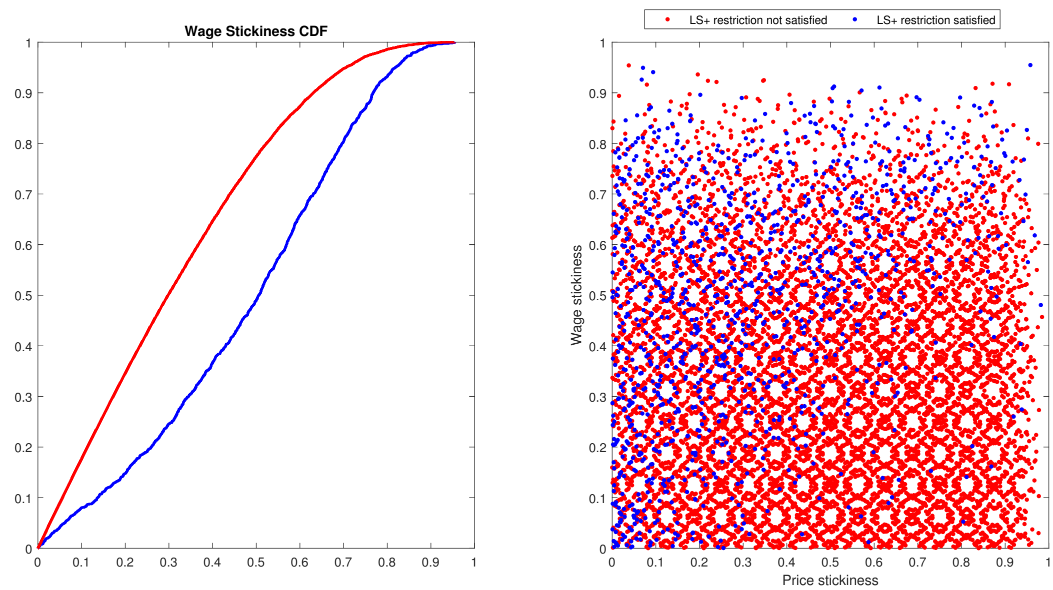


Figure 4: The wage stickiness Cumulative Density Function (CDF) on the left panels; in blue (red) the CDF that does (not) generate a positive response of the labor share. On the right panels, the combination of random draws from price and wage stickiness that do (not) verify the labor share IRF in blue (red).

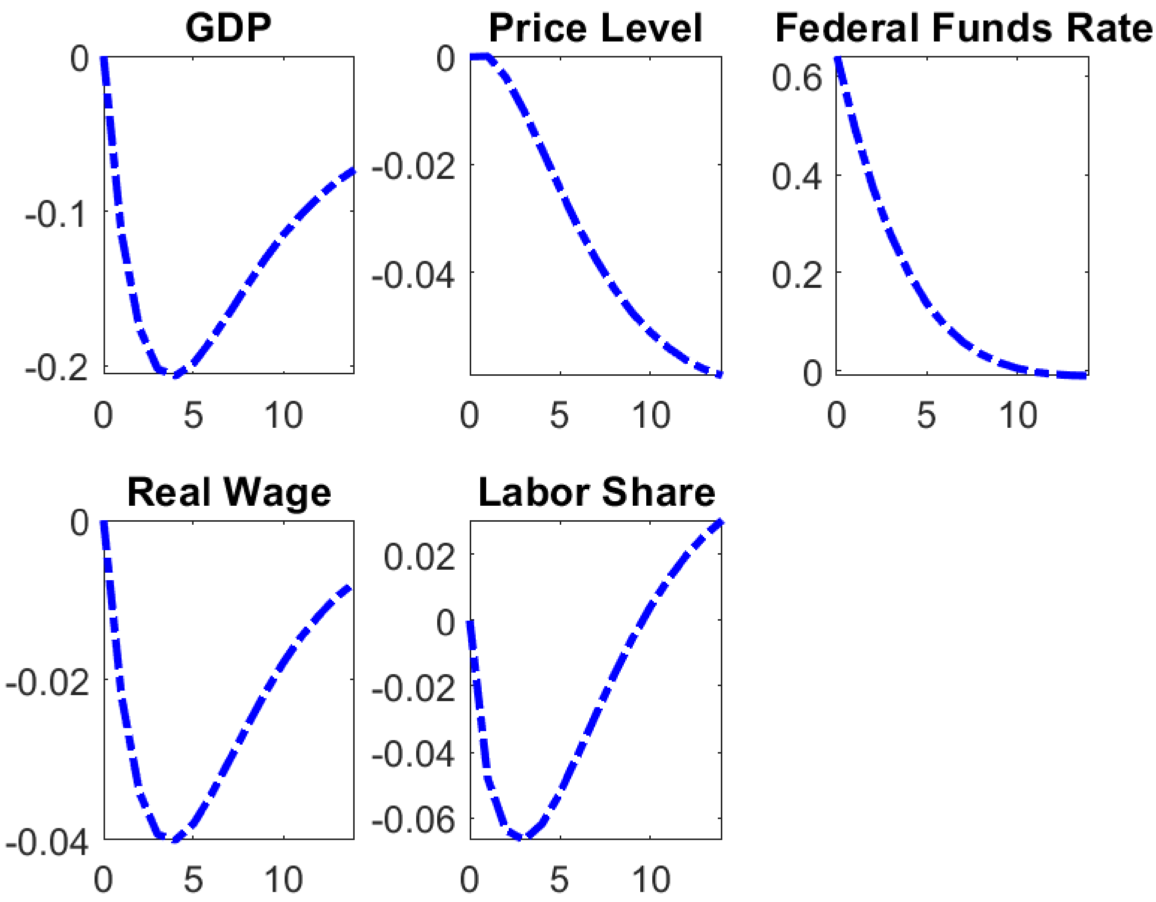


Figure 5: Implied Labor Share in Christiano, Eichenbaum, and Trabandt (2016) Calvo-sticky-wages model.

Description	**Priors**	**Posteriors**
Inverse of Frish Elasticity of Labor Supply	$\Gamma(1, 0.25)$	1.01 (0.55,1.49)
Investment adjustment costs	$\Gamma(8, 2)$	7.29 (3.73,11.10)
Habits in Consumption	$B(0.5, 0.15)$	0.58 (0.32,0.82)
Capacity utilization costs	$\Gamma(0.5, 0.3)$	0.49 (0.04,1.07)
Price stickiness	$B(0.66, 0.1)$	0.67 (0.52, 0.80)
Wage stickiness	$B(0.66, 0.1)$	0.68 (0.56,0.79)
Price markup	$\Gamma(1.2, 0.05)$	1.22 (1.13,1.32)
Interest rate smoothing	$B(0.7, 0.15)$	0.61 (0.37,0.82)
Taylor rule response to inflation	$\Gamma(1.7, 0.15)$	1.72 (1.44,2.00)
Taylor rule response to output	$\Gamma(0.1, 0.05)$	0.07 (0.01,0.14)
Price Indexation	$B(0.5, 0.15)$	0.53 (0.24,0.81)
Wage Indexation	$B(0.5, 0.15)$	0.58 (0.30,0.85)
Working capital fraction	$B(0.8, 0.1)$	0.78 (0.58,0.97)
MP shock stdev	$\Gamma(0.27, 0.05)$	0.30 (0.25,0.35)
AR(1) MP shock	$\Gamma(0.5, 0.15)$	0.50 (0.22,0.80)

Table 4: Priors and posterior means the parameters (95% HDP interval in parenthesis) - Bayesian Impulse Response Matching as in Christiano, Trabandt, and Walentin (2010). Distributions: Γ *Gamma*, B *Beta*.

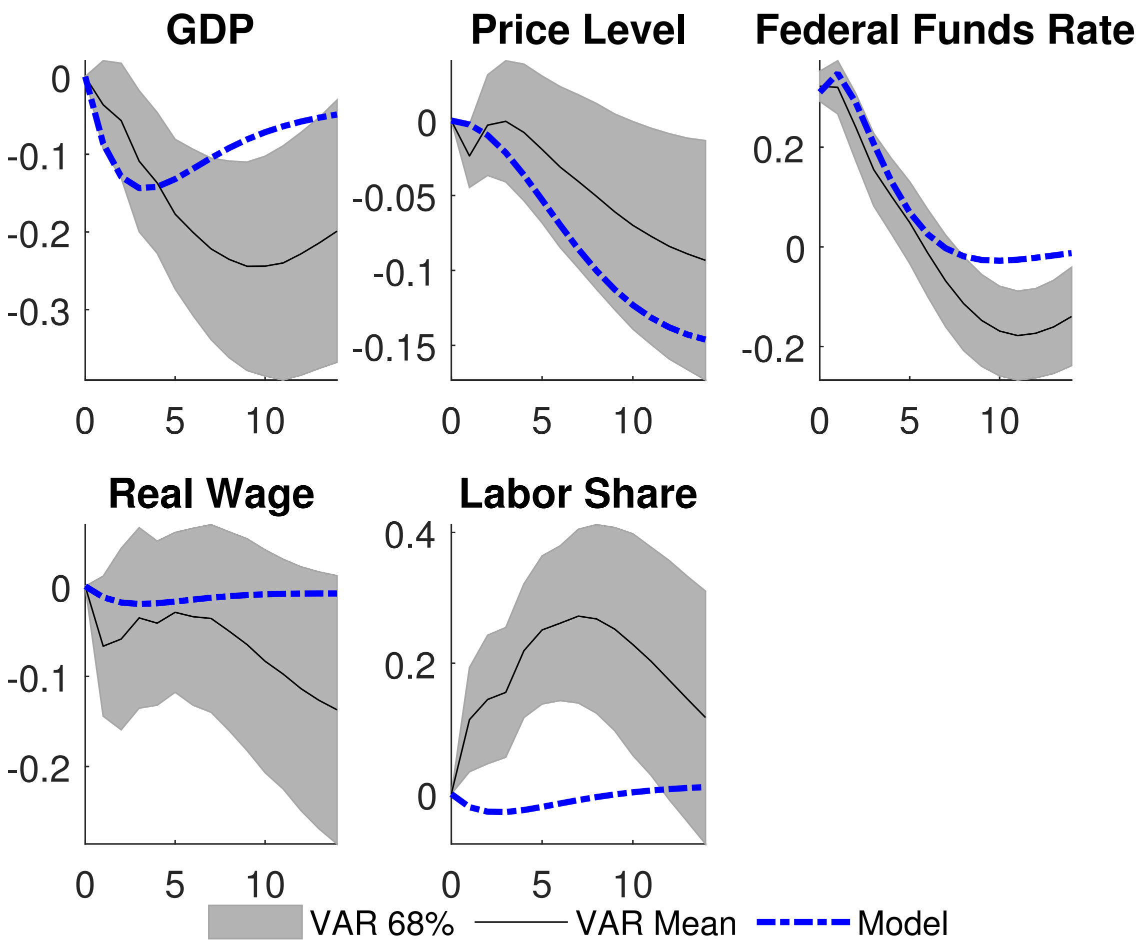


Figure 6: Bayesian Impulse Responses Matching - SVAR vs DSGE model

Not for publication: Appendix

The Missing Link: Monetary Policy and The Labor Share

Cristiano Cantore, Filippo Ferroni and Miguel A. León-Ledesma

December 23, 2019

A Main Data Sources and Constructions

In this section we describe the data construction and source separately for each country.

A.1 US

The seven measures used for the US are constructed using data from the BLS and the BEA NIPA Tables for the time period 1955:Q1-2015:Q3 and are as follows:

1. *Labor share 1*: Labor share in the non-farm business sector. This is taken directly from BLS.[1] The series considers only the non-farm business sector. It calculates the labor share as compensation of employees of the non-farm business sector plus imputed self-employment income over gross value added of the non-farm business sector. Self-employment imputed income is calculated as follows: an implicit wage is calculated as compensation over hours worked and then the imputed labor income is the implicit wage times the number of hours worked by the self-employed.

2. *Labor share 2*: Labor share in the domestic corporate non-financial business sector. This follows Gomme and Rupert (2004) first alternative measure of the labor share. The use of data for the non-financial corporate sector only has the advantage of not having to apportion proprietors income and rental income, two ambiguous components of factor income. It also considers the wedge introduced between the labor share and one minus the capital share by indirect taxes (net of subsidies), and only makes use of unambiguous components of capital income. This approach also takes into account the definition of aggregate output in constructing the labor share. Usually we use GDP in constructing measures of the Labor share (as we do for some of the other proxies), however sectoral studies often use gross value added (GVA) (see Bentolila and Saint-Paul (2003), Young (2010) and Young (2013)). Valentinyi and Herrendorf (2008) and Muck, McAdam, and Growiec (2015) show that factor shares in value added differ systematically from factor income shares in GDP, albeit with annual data. By considering gross value added net interest and miscellaneous payments (NI_t^{gva}, NIPA Table 1.14), gross value added corporate profits (CP_t^{gva}, NIPA Table 1.14), net value added (NVA_t, NIPA Table 1.14) and gross value added taxes on production and imports less subsidies (Tax_t^{gva}, NIPA Table 1.14) the labor share is thus calculated as:
$$\textbf{Labor Share 2}: LS_t = 1 - \frac{CP_t^{gva} + NI_t^{gva} - Tax_t^{gva}}{NVA_t}.$$

[1] FRED series PRS85006173 provided as an index number.

3. *Labor share 3*: This approach deals with imputing ambiguous income for the macroeconomy and corresponds to the second alternative measure of the labor share proposed in Gomme and Rupert (2004). The measure excludes the household and government sectors. They define unambiguous labor income (Y^{UL}) as compensation of employees, and unambiguous capital income (Y^{UK}) as corporate profits, rental income, net interest income, and depreciation (same series as above from NIPA Tables 1.12 and 1.7.5). The remaining (ambiguous) components are then proprietors' income plus indirect taxes net of subsidies (NIPA Table 1.12). These are apportioned to capital and labor in the same proportion as the unambiguous components. The resulting labor share measure is:

$$\textbf{Labor Share 3}: LS_t = \frac{CE_t}{CE_t + RI_t + CP_t + NI_t + \delta_t} = \frac{Y^{UL}}{Y^{UK} + Y^{UL}}.$$

4. *Labor share 4*: This is the same as the above *Labor Share 3* but not corrected for inventory valuation adjustment and an adjustment for capital consumption. Using rental income of persons (without CCAdj) (RI_t^a, NIPA Table 1.12) and corporate profits before tax (without IVA and CCAdj) (CP_t^a, NIPA Table 1.12):

$$\textbf{Labor Share 4}: LS_t = \frac{CE_t}{CE_t + RI_t^a + CP_t^a + NI_t + \delta_t} = \frac{Y^{UL}}{Y^{UK} + Y^{UL}}.$$

5. *Labor share 5*: Follows Cooley and Prescott (1995) in dealing with the issue of how to input mixed income. The labor share of income is defined as one minus capital income divided by output. To deal with mixed income, they assume that the proportion of ambiguous capital income to ambiguous income is the same as the proportion of unambiguous capital income to unambiguous income. It decomposes total income into two components: ambiguous income (AI_t) and unambiguous income (UI_t). AI_t is the sum of proprietors income (PI_t, NIPA table 1.12), taxes on production less subsidies ($Tax_t - Sub_t$, NIPA Table 1.12), business current transfer payments ($BCTP_t$, NIPA Table 1.12) and statistical discrepancy ($Sdis_t$, NIPA Table 1.12). UI_t instead can be easily separated into labor income (CE_t) and capital income (UCI_t) which consists of rental income (RI_t, NIPA Table 1.12), net interests (NI_t, NIPA Table 1.12), current surplus of government enterprises (GE_t, NIPA Table 1.12), and corporate profits (CP_t, NIPA Table 1.12). Using capital depreciation (δ_t, Consumption of fixed capital NIPA TABLE 1.7.5) we can construct the share of capital in unambiguous income (CS_t^U):

$$CS_t^U = \frac{UCI_t + \delta_t}{UI_t} = \frac{RI_t + NI_t + GE_t + CP_t + \delta_t}{RI_t + NI_t + GE_t + CP_t + \delta_t + CE_t}$$

Here the key assumption is that the share of capital/labor in ambiguous income is the same as in unambiguous income,

$$ACI_t = CS_t^U AI_t.$$

$$\textbf{Labor Share 5}: LS_t = 1 - CS_t = 1 - \frac{UCI_t + \delta_t + ACI_t}{GNP_t}$$

where we use Gross National Product instead of GDP (GNP_t, NIPA Table 1.7.5).

6. *Labor share 6*: Is taken from Fernald (2014) and it's utilization adjusted quarterly series. In computing the capital share he assumes that the non-corporate sector has the same factor shares as the corporate non-financial sector.

7. *Labor share 7*: Labor share in the non-finanical corporation sector. This is taken directly from BLS (FRED series id PRS88003173 provided as an index number). The series considers only the non-finanical corporations sector.

The remaining US variables are downloaded from the FRED database and their series ID is in parenthesis unless specified differently. For GDP we use Real Gross Domestic product (GDPC1). GDP deflator is the implicit price deflator of gross domestic product (GDPDEF). For CPI we used Consumer Price Index for All Urban Consumers and all Items for US (CPIAUCSL). For the price of commodity index we used the same CRB SPOT commodity index used by Olivei and Tenreyro (2007) and downloaded from datastream. Real wage is constructed as Wages and Salaries from NIPA 1.12 deflated by GDP Deflator and divided by hours worked in the total economy from Valery Ramey dataset. Labor productivity is the ratio between GDP and total hours from Ramey. TFP is the measure of Utilization Adjusted TFP constructed in Fernald (2014) while credit spread is the corporate bond spread described in Gilchrist and Zakrajsek (2012) . Money growth, used for sign restrictions, is the M2 for United states from the IMF database in log difference (MYAGM2USM052N). Federal Funds rates are downloaded from FRED database. Time span of the VAR analysis is the great moderation period in US, i.e. 1984Q1 to 2007Q4.

A.2 Australia

We use quarterly data for the 1959:Q3-2016:Q1 from the Australian Bureau of Statistics. We construct five alternative measures of labor share. The first two are total wages and salaries (including social security contributions) over GDP (AUS_LS1) or over total factor income (AUS_LS2). The third one is one minus gross operating surplus of private non-financial corporations as a percentage of total factor income (AUS_LS3). Fourth, one minus gross operating surplus of private non-financial corporations plus all financial corporations as a percentage of total factor income (AUS_LS4). The last measure is given by (total income minus surplus of all corporations minus gross operating surplus of government minus mixed income imputed to capital)/total income (AUS_LS5). For Real GDP and its deflator we use data from the OECD quarterly national accounts. For CPI we used OECD consumer prices of all goods and also the short term interest rates come from the OECD database. For the price of commodity index we used the same index used for the other countries. Money growth, used for sign restrictions, is constructed using money supply downloaded from datastream. Real wages are constructed by dividing nominal compensation of employees by the GDP deflator and the measure of total hours worked. Time span for the VAR analysis is 1985:Q1-2009:Q4 .

A.3 Canada

We consider quarterly data for the 1981:Q2-2016:Q1 period from Statistics Canada. We used two alternative measures. First, compensation of employees over total factor income (GDP corrected by taxes and subsidies) (CAN_LS1) . Second, we imputed mixed income in the same proportion as unambiguous labor and capital income, and added it to the previous measure of labor income (CAN_LS2) . For Real GDP and its deflator we use data from the OECD quarterly national accounts. For CPI we used OECD consumer prices of all goods and also the short term interest rates come from the OECD database. For the price of commodity index we used the same index used for the other countries. Money growth, used for sign restrictions, is constructed using money supply downloaded from datastream.

For real wages we divide nominal compensation of employees by the GDP Deflator and the measure of total hours worked constructed by Ohanian and Raffo (2012). Time span for the VAR analysis is 1985:Q1-2011:Q1.

A.4 UK

Quarterly data for the 1971:Q1-2016:Q1 period from the Office for National Statistics (ONS). We used one measure of the labor share: compensation of employees (DTWM) over gross value added at factor costs (CGCB) (UK_LS). From the ONS we take Gross Domestic Product: chained volume measures: Seasonally adjusted (ABMI) and Implied deflator for Gross domestic product at market prices (YBGB). From the OECD we take the CPI of all items and the short term interest rates. The price of commodity index is the same used for the US. Money growth, used for sign restrictions, is constructed using money supply downloaded from datastream (UKCMS2..B). Real wages are constructed by dividing nominal compensation of employees by the GDP Deflator and the measure of total hours worked constructed by Ohanian and Raffo (2012). Time span for the VAR analysis is 1986:Q1-2008:Q1.

A.5 EA

We take most of the data from the AWM database, where we use the following variables, real GDP and the GDP deflator, HICP excluding energy (seasonally adjusted) and the Short-term interest. The price of commodity index is the same used for the US. Money growth, used for sign restrictions, is taken from the IMF database on FRED (MYAGM2EZQ196N). We used one measure of the labor share: compensation of employees over GDP at factor costs. Real wages are given by nominal compensation of employees (from OECD Quarterly National Accounts) divided by the GDP Deflator and the measure of total employment from the New Area Wide Model Database. Time span of the VAR analysis is 1999Q1 to 2011Q3.

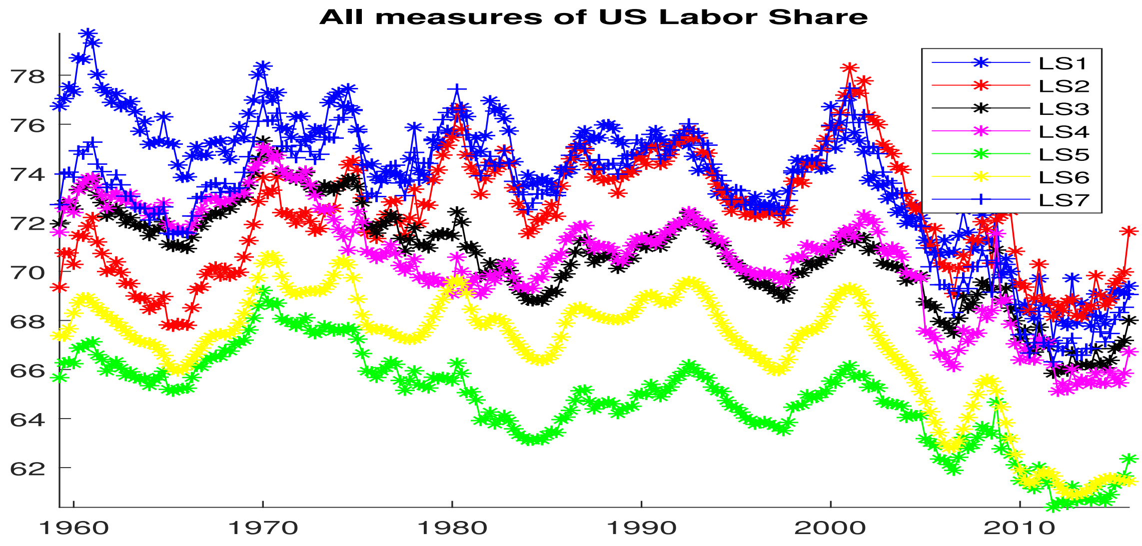
A.6 Monetary Policy instruments

In this section we describe in details the various proxy variables used for the monetary policy surprise. Some of these proxy variables are available at monthly frequency. In that case, we transformed into quarterly series by taking the cumulative sum, then computing the difference between the last months of adjacent quarters, e.g. December and September, March and December, June and March and September and June.

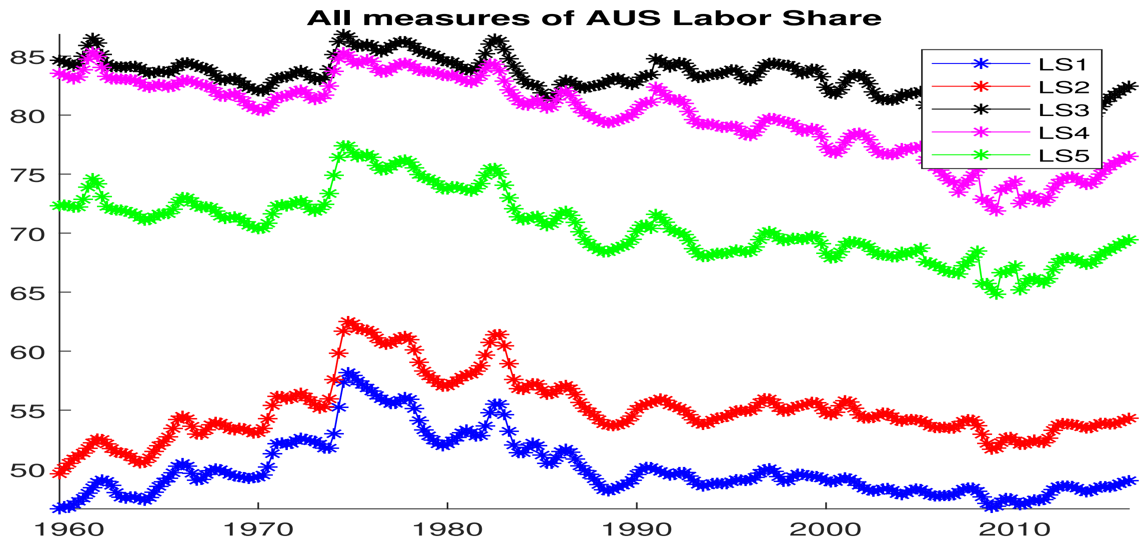
For the US, we considered three different proxies for the monetary policy surprise: the Romer and Romer (2004) narrative monetary policy shock (R&R), the Gertler and Karadi (2015) high frequency variations in current FFR around MP announcements (G&K) and the Miranda-Agrippino (2016) high frequency variation of the current FFR adjusted for the information set (or signaling effect) of FOMC (MIR).[2] The rationale behind the choice of these instruments is based on the consideration that they are constructed using slightly different information sets; e.g. the R&R narrative instrument based on FOMC minutes and other quantitative records; the G&K high frequency variations in federal funds rate in a narrow window around the FOMC monetary policy communications; the MIR is the component

[2]We also considered the Smets and Wouter (2007) DSGE estimated monetary policy shock and the target factor in the Gurkaynack, Sack and Swanswon (2005) HF identification; when adding them results do not change.

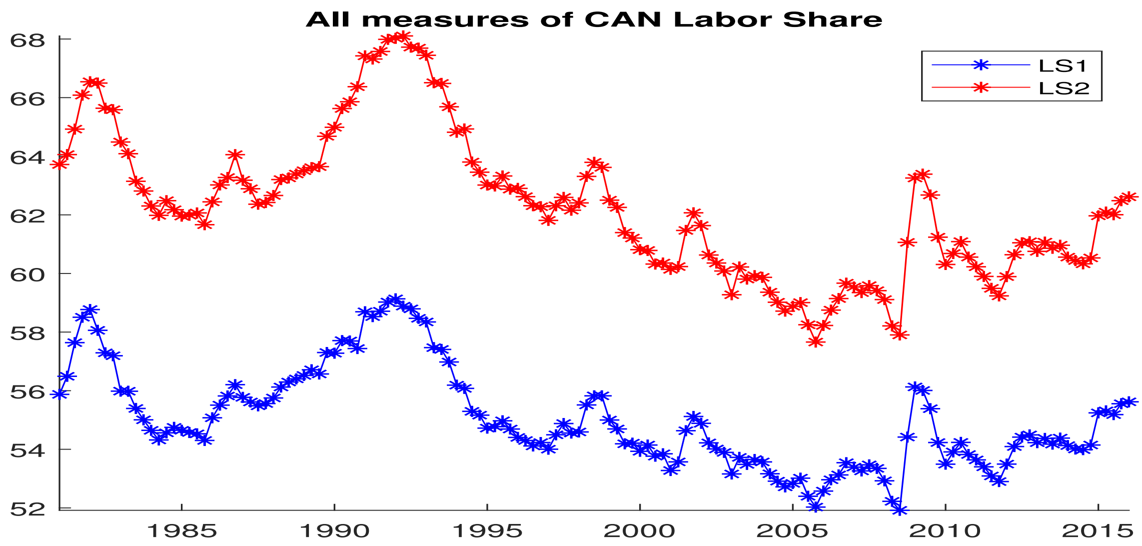
of the high frequency variation of the federal funds rate which is orthogonal to Greenbook and data records available before the FOMC decision. For Canada, we considered as external instrument the monetary policy surprise constructed by Champagne and Sekkel (2018) based on Bank of Canada's staff projections. For the EA, we considered the MP surprise in Andrade and Ferroni (2016) which is constructed as follows. Minute-by-minute midquote observations of EONIA Overnight Indexed Swap contracts (OIS) of maturities between 1 month and 2 years are considered around the time when monetary policy decisions are publicly released. The ECB communicates its decision in the following way: a monetary policy decision statement is first released at 1:45pm CET. It is then followed by a press conference with the ECB's President which begins around 2:30pm CET and lasts for about one hour. We compute the difference of OIS forward rates using five-minute averages ten minutes before the ECB interest rate communication and 20 minutes after the end of the press conference. The sample covers only the scheduled Governing Councils in between January 2002 to January 2015. The changes in the term structure of OIS futures is summarized following GSS's methodology by taking first principal components. After standardizing the variations, the first principal component is our measure of monetary policy surprise. For the UK, we considered as external instrument the monetary policy surprise constructed by Cloyne and Hürtgen (2016) where they employ a Romer-Romer identification approach to the UK experience.



(a) US



(b) Australia



(c) Canada

Figure A1: Labor share proxies for US, Australia and Canada.

B VAR Robustness

The response of the labor share after a monetary policy tightening under different information set, time span, labor share proxies and identification scheme are summarized in Table B1.

Country	Info set	Sample	Identification	Reference	Positive LS IRF
US	Baseline	84-07	Recursive	Figure B3	Yes
	Various LS proxy		Recursive	Figure B4	Yes
	Extended		Recursive	Figure B5	Yes
	Baseline*		Signs	Figure B2	Yes
	Baseline		Instruments	Figure B1	Yes
	Baseline	65-07; 65-95	Recursive	Figures B6-B7	Yes
EA	Baseline	99-11	Recursive	Figure B3	Yes
	Baseline		Signs	Figure B2	Yes
	Baseline		Instrument	Figure B8	Yes
UK	Baseline	86-08	Recursive	Figure B3	Yes
	Baseline		Signs	Figure B2	Yes
	Baseline	72-08	Instrument	Figure B9	Yes
CAN	Baseline	85-11	Recursive	Figure B3	Yes
	Various LS proxy		Recursive	Figure B11	Yes
	Baseline		Signs	Figure B2	Yes
	Baseline		Instrument	Figure B10	Yes
AUS	Baseline	85-09	Recursive	Figure B3	Yes
	Various LS proxy		Recursive	Figure B12	Yes but one
	Baseline		Signs	Figure B2	Yes

Table B1: Summary of the robustness exercises with the VAR model.
Baseline includes log of real GDP, the log of the GDP deflator, the log of an index of commodity prices, log of the CPI, log of real wages, the log of the labor share and short term interest rates.
*Baseline** includes the baseline variables and M2 which is used for identification using sign restrictions.
Extended includes the baseline variables plus the Fernald (2012) measure of Utilization Adjusted TFP, Labor Productivity and the Gilchrist and Zakrajsek (2012) corporate bond spread.
US Instruments: Romer and Romer (2004), Gertler and Karadi (2015) and the Miranda-Agrippino (2016)
UK Instruments: Cloyne and Hurtgen (2016)
CAN Instruments: Champagne and Sekkel (2018)
EA Instruments: Andrade and Ferroni (2016)

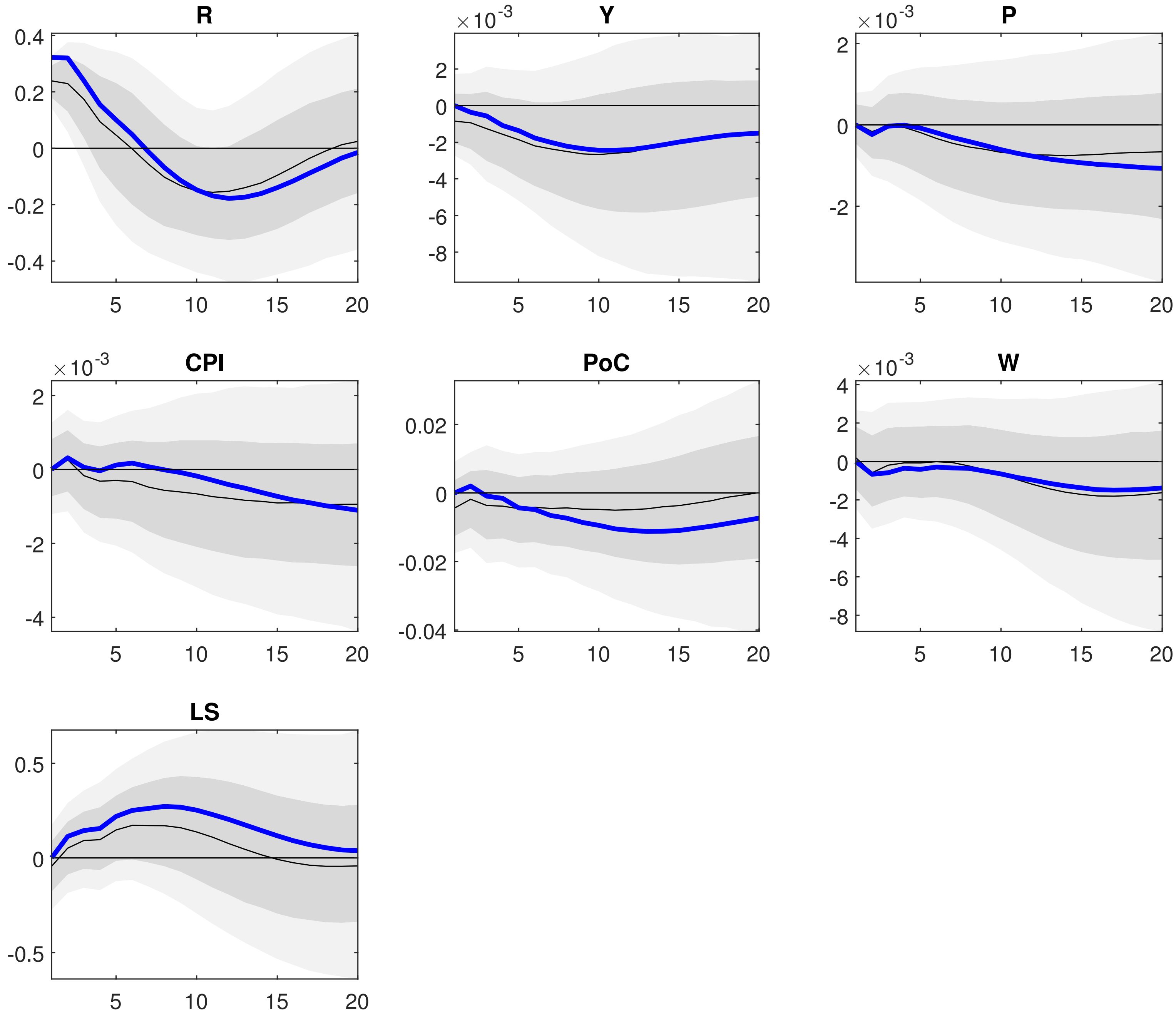


Figure B1: Impulse Response Function to a one standard deviation increase in the short term interest rate using an identification scheme based on **proxy variables or instruments** for the shock of interest. We considered three different proxies for the monetary policy surprise jointly: the Romer and Romer (2004) narrative, the Gertler and Karadi (2015) high frequency variations in interest rates around MP announcements and the Miranda-Agrippino (2016) high frequency variation adjusted for the information set (or signaling effect) of FOMC. Light (dark) gray 90% (68%) bands. The blue line reports the median IRF using a recursive identification scheme. US data

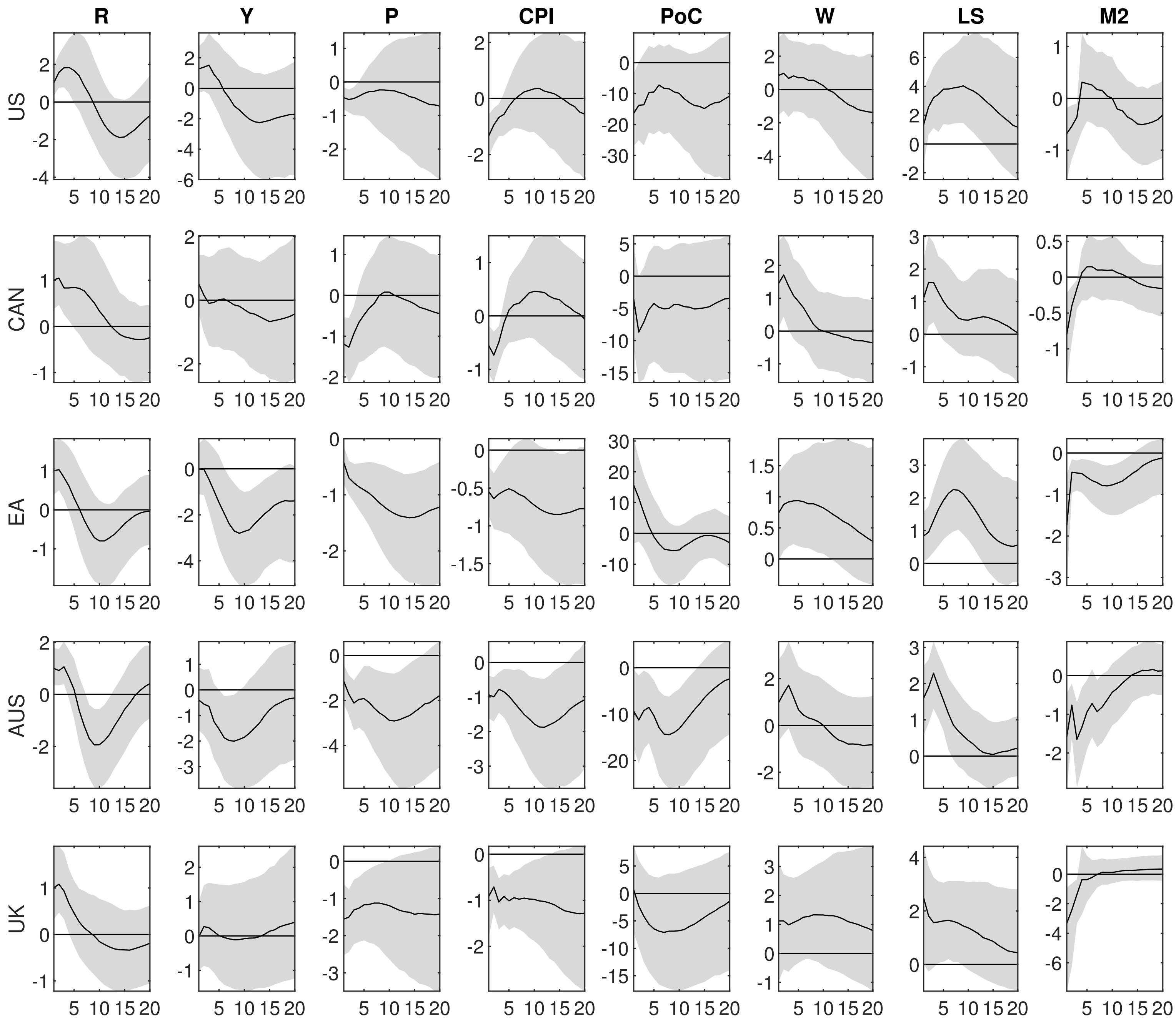


Figure B2: Impulse Response Function normalized to a 1% increase in the short term interest rate an identification scheme based on sign restrictions. From left to right, interest rate, (log of) real GDP, price deflator, CPI, Price of Commodities, real wages, labor share and M2. From top to bottom US, Euro Area, Australia, Canada and United Kingdom. Dark gray areas indicate 68% bands.

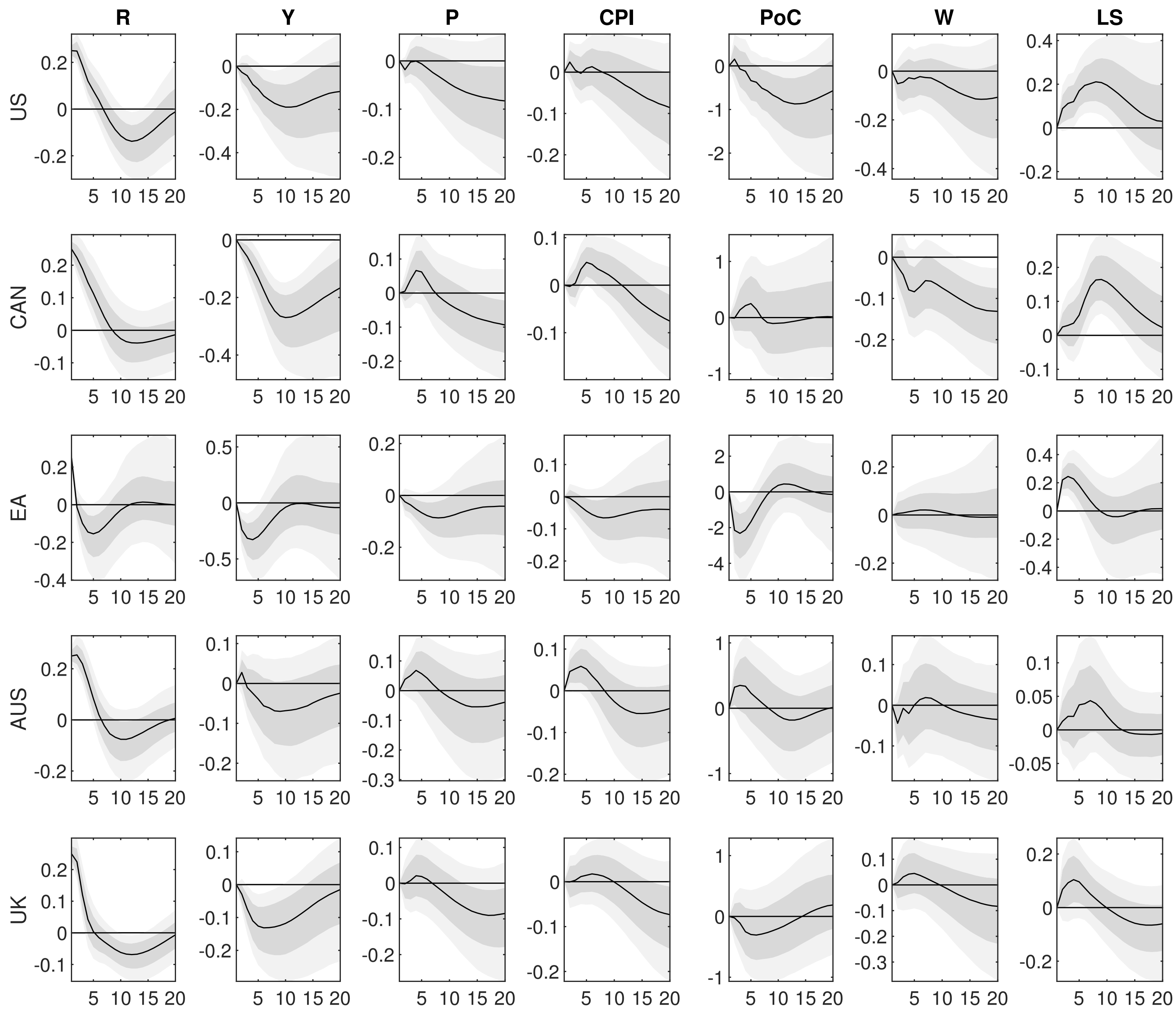


Figure B3: Impulse Response Functions normalized to a 1% percent increase in the short term nominal interest rate using an identification **recursive Cholesky** and the baseline variables specification. From left to right, interest rate, (log of) real GDP, price deflator, CPI, Price of Commodities, real wages and labor share. From top to bottom US, Euro Area, Australia, Canada and United Kingdom. Light (dark) gray areas indicate 90% (68%) bands.

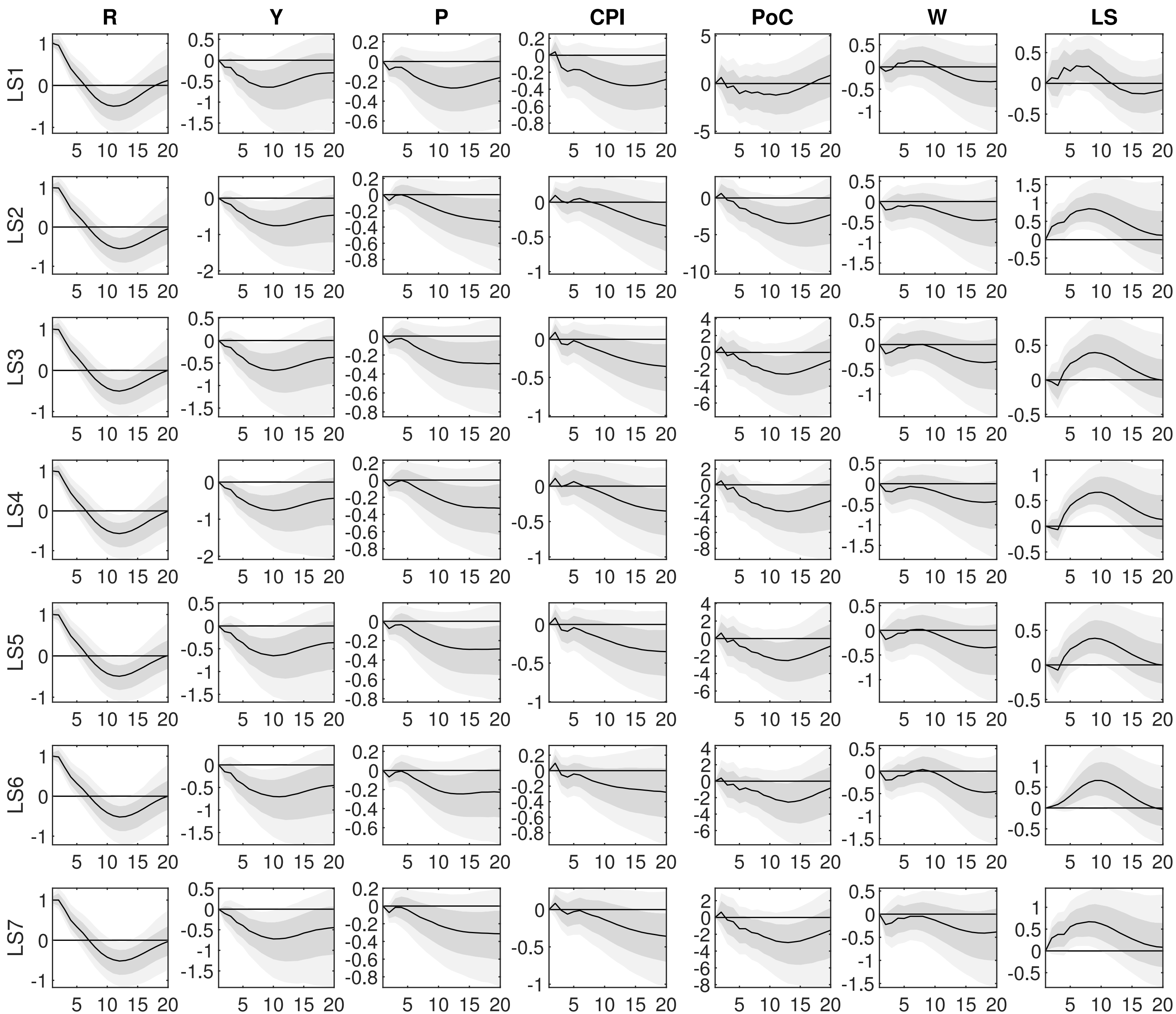


Figure B4: Impulse Response Function normalized to a 1% increase in the short term interest rate using recursive Cholesky. From top to bottom different proxy variables for the Labor Share in the US. Light (dark) gray 90% (68%) bands.

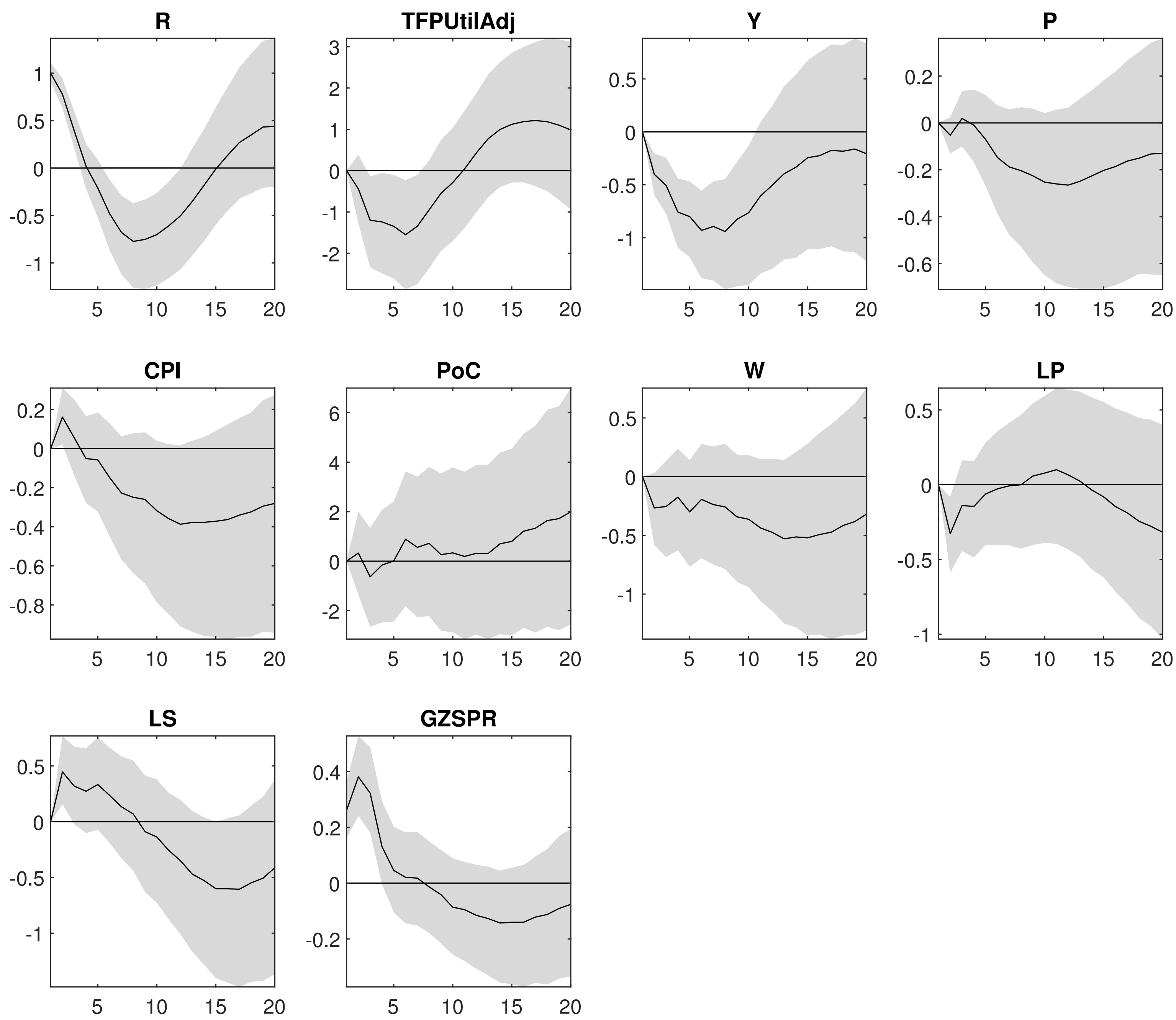


Figure B5: Impulse Response Function normalized to a 1% increase in the short term interest rate using recursive Cholesky and and extended variables specification for the US. From top left to bottom right, interest rate, Fernald (2012) measure of Utilization Adjusted TFP, real GDP, price deflator, CPI, Price of Commodities, real wages, Labor Productivity, labor share and the Gilchrist and Zakrajsek (2012) corporate bond spread. Dark gray areas indicate 68% bands.

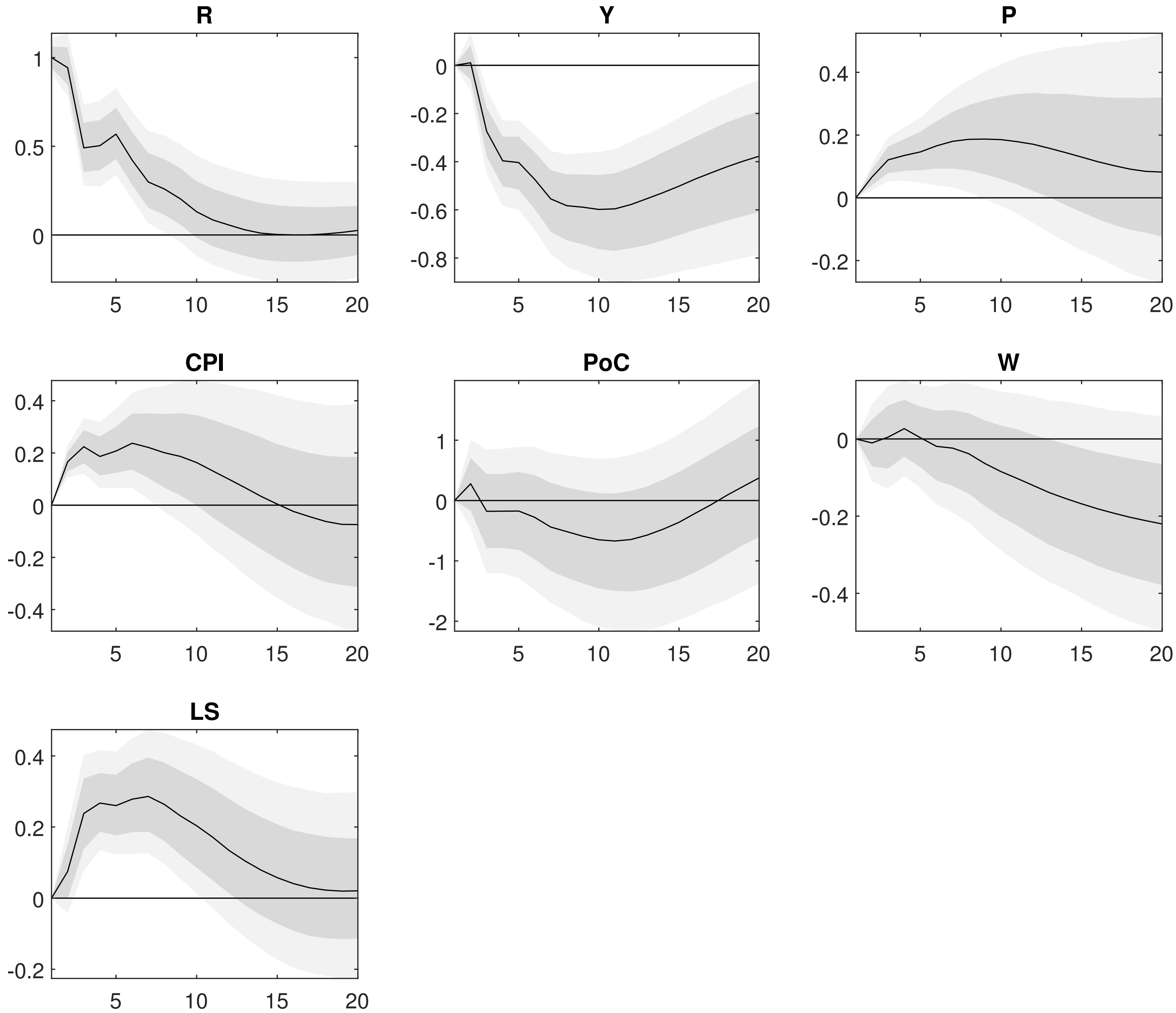


Figure B6: Impulse Response Functions normalized to a 1% percent increase in the short term nominal interest rate using an identification recursive Cholesky and the baseline variables specification. From left to right, interest rate, (log of) real GDP, price deflator, CPI, Price of Commodities, real wages and labor share. Sample span 1965q1-2007q4. Light (dark) gray areas indicate 90% (68%) bands.

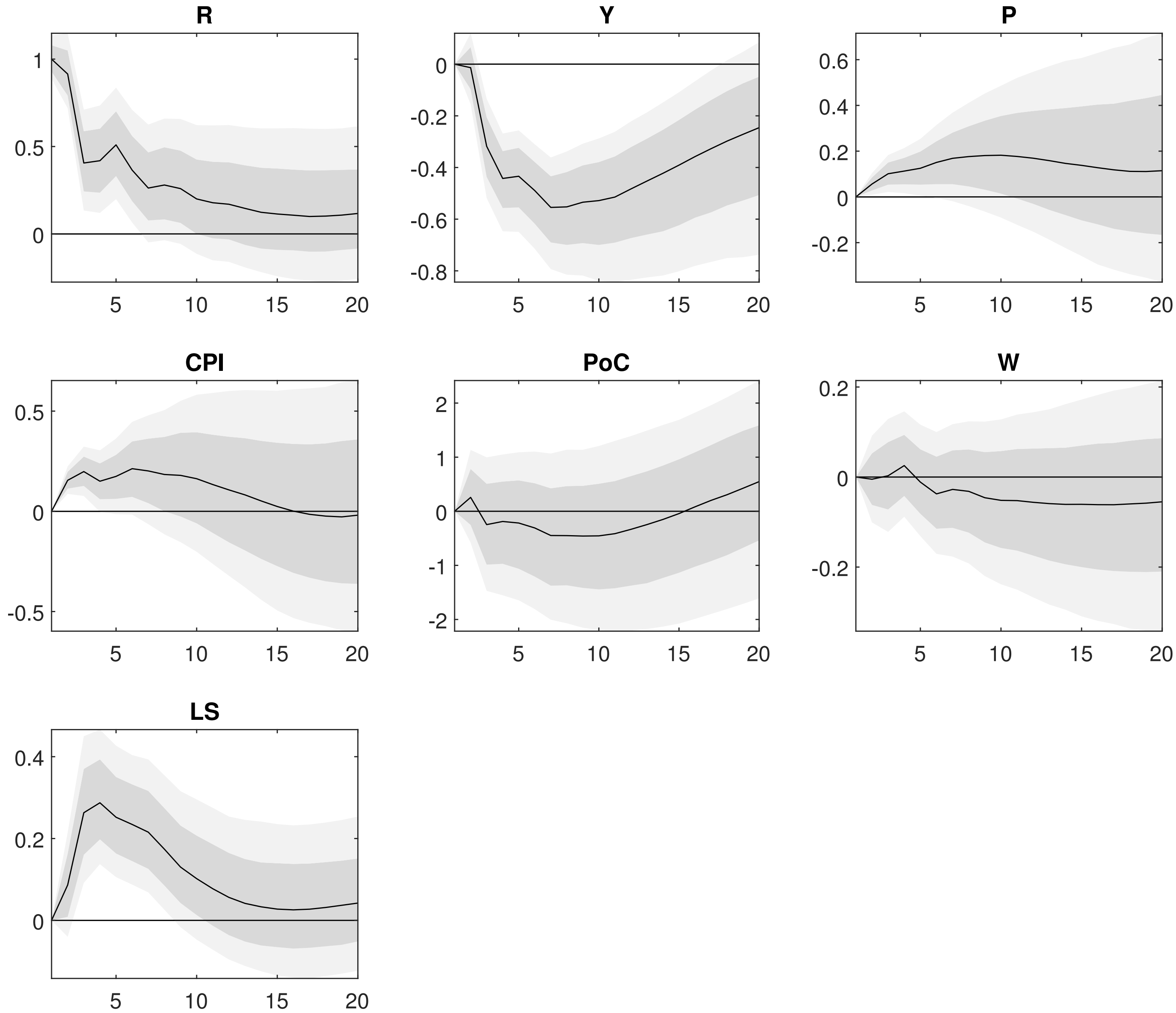


Figure B7: Impulse Response Functions normalized to a 1% percent increase in the short term nominal interest rate using an identification recursive Cholesky and the baseline variables specification. From left to right, interest rate, (log of) real GDP, price deflator, CPI, Price of Commodities, real wages and labor share. Sample span 1965q1-1995q4. Light (dark) gray areas indicate 90% (68%) bands.

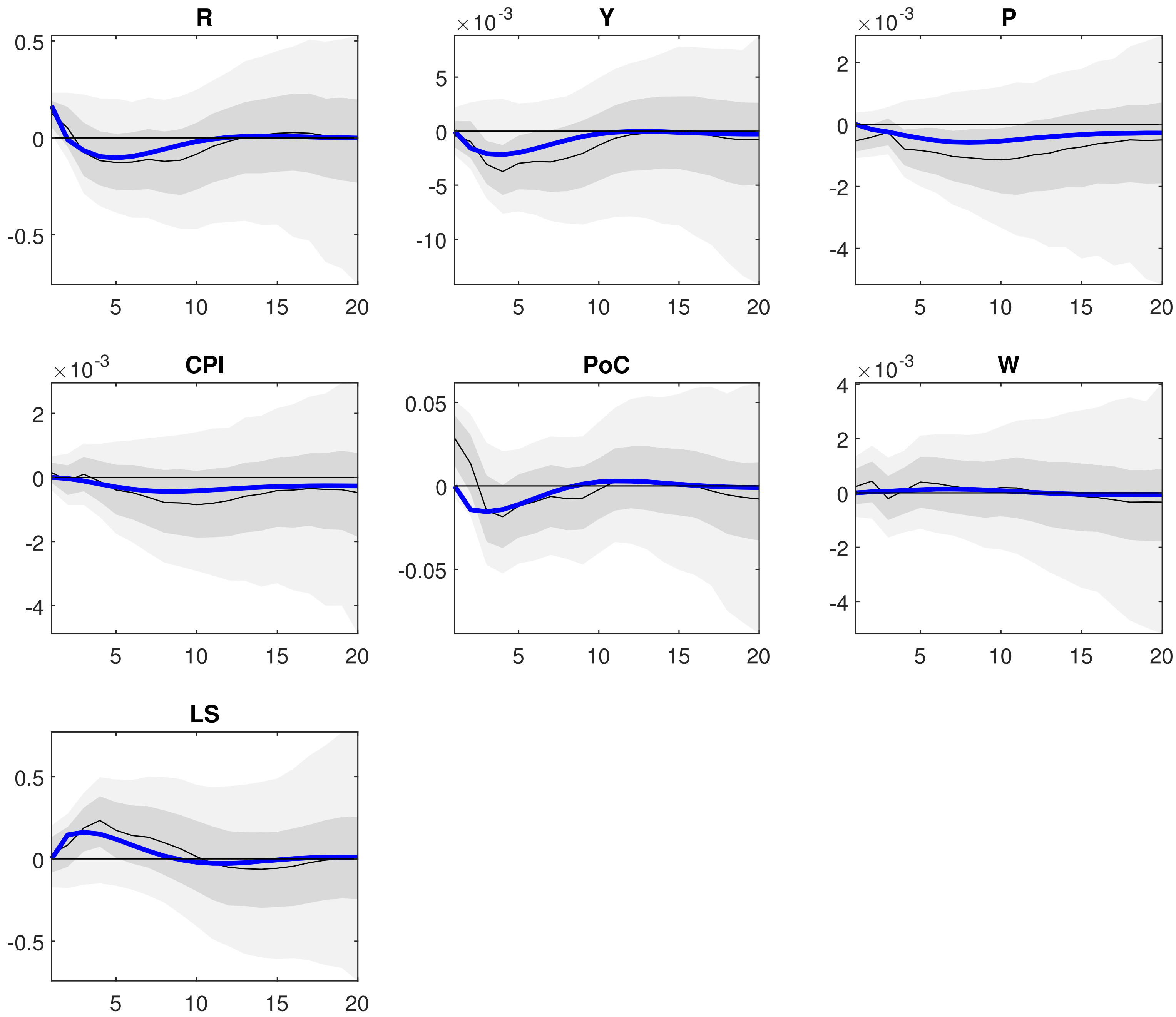


Figure B8: Impulse Response Function to a one standard deviation increase in the short term interest rate using an identification scheme based on **proxy variables or instruments** for the shock of interest. Monetary policy instrument constructed by Andrade and Ferroni (2016). Light (dark) gray areas indicate 90% (68%) bands. The blue line reports the median IRF using a recursive identification scheme. EA data

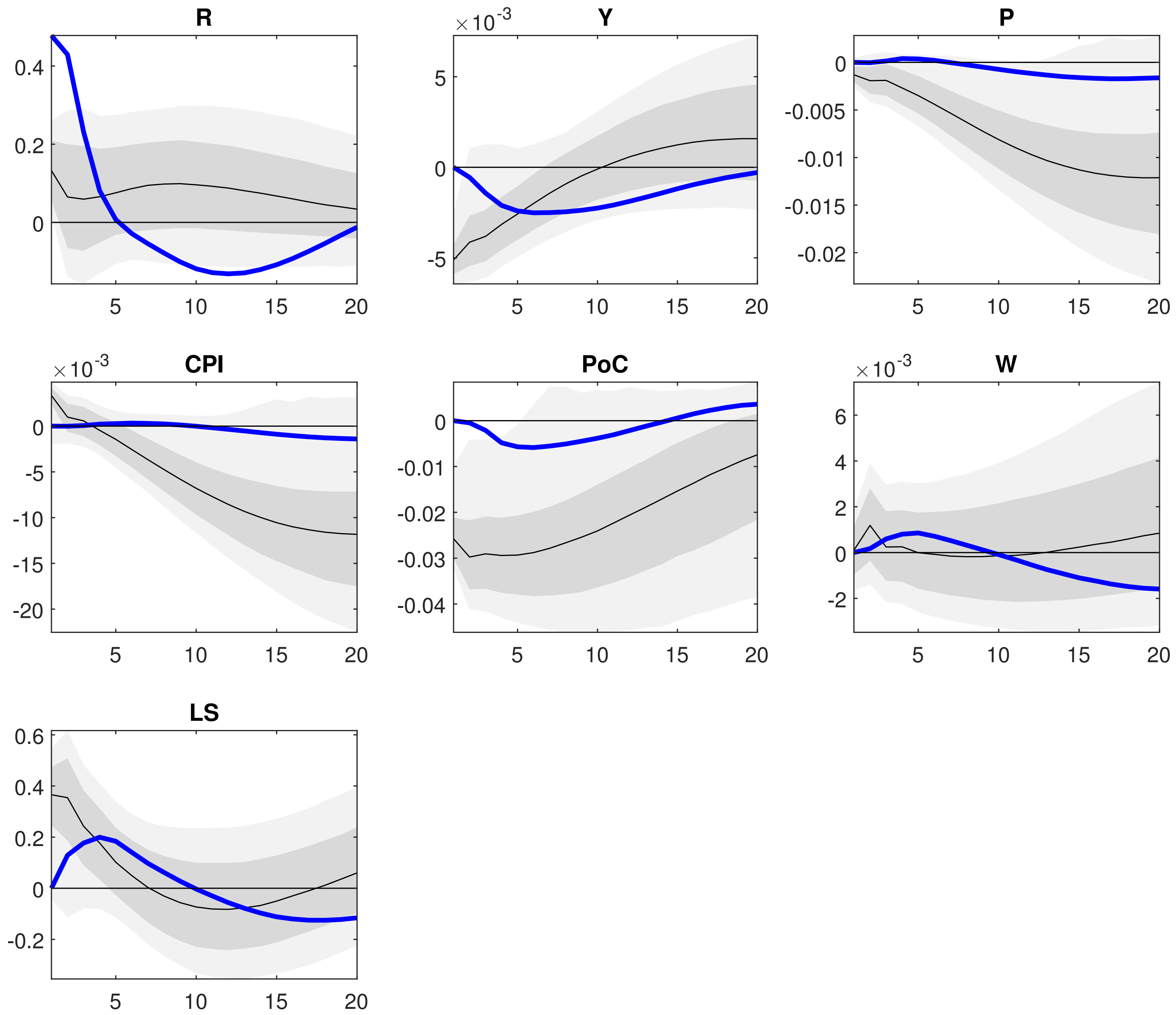


Figure B9: Impulse Response Function to a one standard deviation increase in the short term interest rate using an identification scheme based on **proxy variables or instruments** for the shock of interest. Monetary policy instrument constructed by Cloyne and Hurtgen (2016). Light (dark) gray areas indicate 90% (68%) bands. The blue line reports the median IRF using a recursive identification scheme. UK data

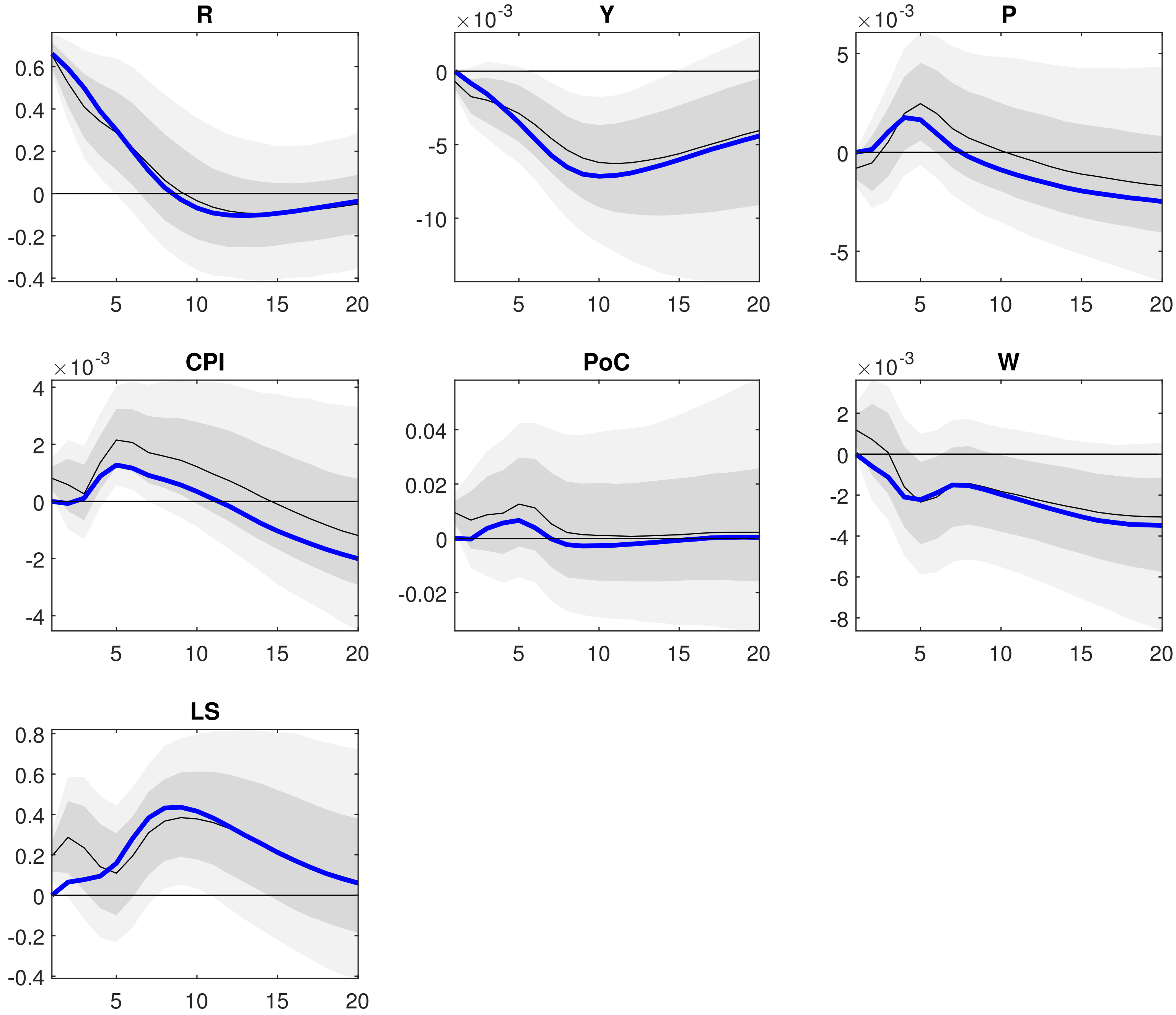


Figure B10: Impulse Response Function to a one standard deviation increase in the short term interest rate using an identification scheme based on **proxy variables or instruments** for the shock of interest. Monetary policy instrument constructed by Champagne and Sekkel (2018). Light (dark) gray areas indicate 90% (68%) bands. The blue line reports the median IRF using a recursive identification scheme. Canadian data

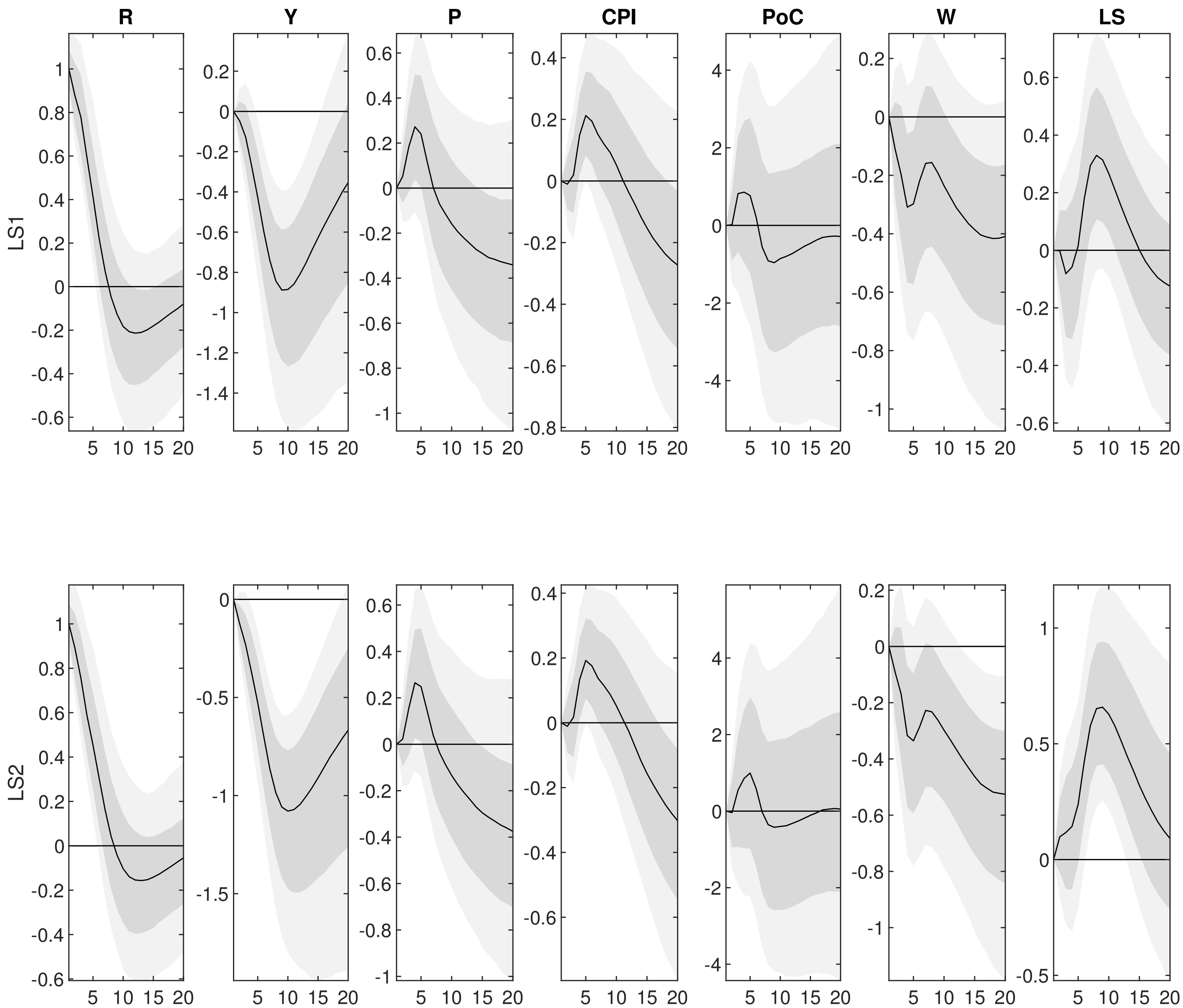


Figure B11: Impulse Response Function normalized to a 1% increase in the short term interest rate using recursive Cholesky. From top to bottom different proxy variables for the Labor Share in Canada. Light (dark) gray 90% (68%) bands.

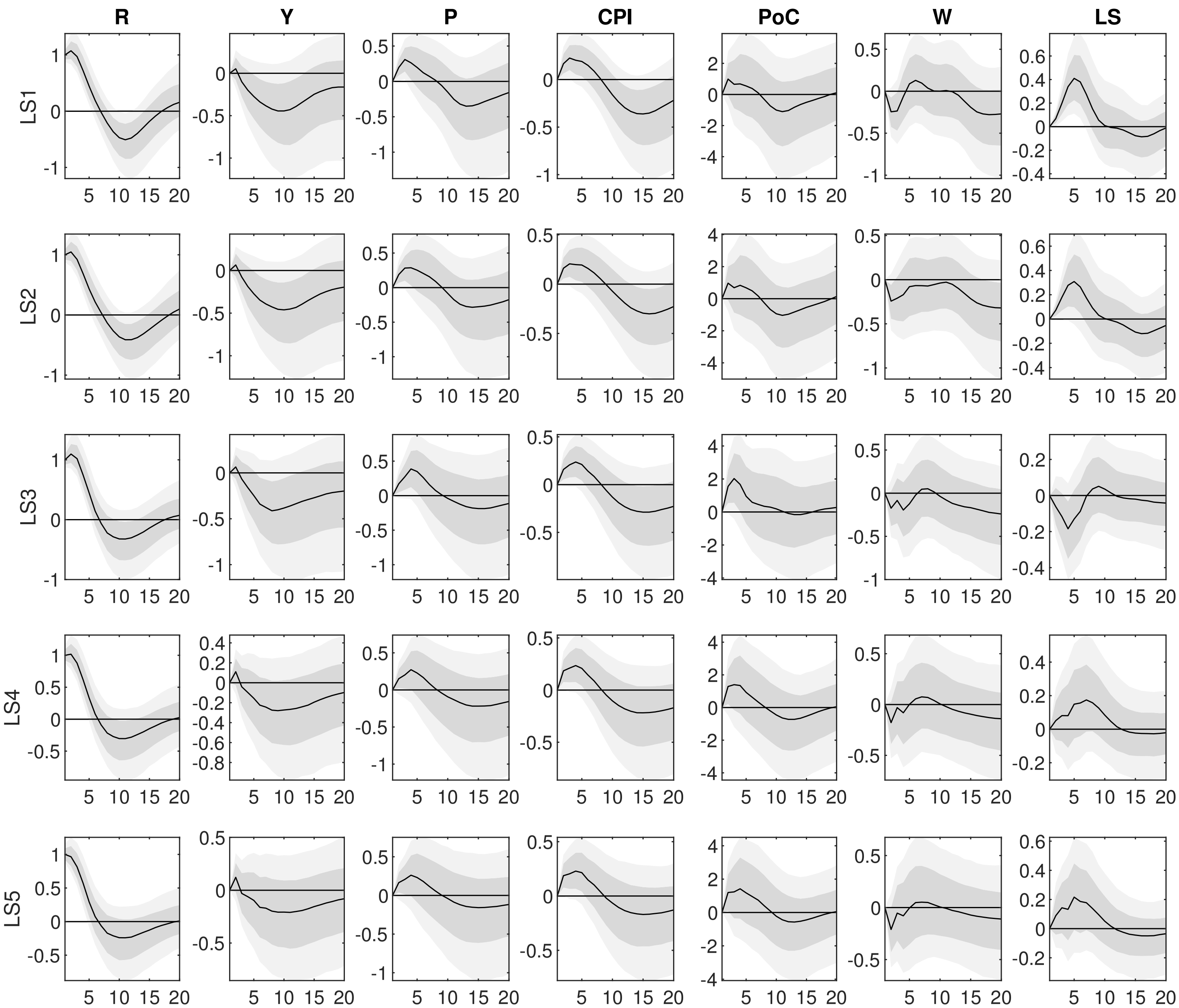


Figure B12: Impulse Response Function normalized to a 1% increase in the short term interest rate using recursive Cholesky. From top to bottom different proxy variables for the Labor Share in Australia. Light (dark) gray 90% (68%) bands.

C Sectoral evidence

The results using different measures of the labor share, different countries, and identification methods, show a robust increase in the labor share after an MP contraction. We now look at whether this effect is also robust across sectors. I.e., it may be the case that the increase in the labor share is due to changes in the composition of output from sectors with low to sectors with high labor shares rather than a change of the labor share within sectors.

To do this, we exploit the cross-section and time-series variation of labor shares at the disaggregated sector level. Define the (log) labor share for sector i at time t as $LSH_{i,t}$, and the (cross-section invariant) aggregate monetary policy shock as MP_t. We can estimate the impact of the shock on sectoral labor shares by running the following panel model:

$$LSH_{i,t} = \alpha_i + \alpha_t + \rho LSH_{i,t-1} + \theta MP_t + \epsilon_{i,t}, \tag{1}$$

where α_i and α_t are sector and time-specific fixed effects, and $\epsilon_{i,t}$ is an error term. The fixed effects capture unobserved sector characteristics that are time-invariant, whereas the time-effect captures aggregate time variation in the labor share that is independent of the sector. Coefficient θ then captures the contemporaneous effect of the MP shock on the labor share controlling for past values of the labor share as well as sector and time fixed effects.[1] To capture the effect of the MP shock on the labor share after the shock, we estimate:

$$LSH_{i,t+h} = \alpha_i + \alpha_{t+h} + \rho LSH_{i,t+h-1} + \theta_h MP_t + \epsilon_{i,t+h}. \tag{2}$$

with $h = 1, 2, 3, 4$. Coefficient θ_h then captures the effect of the MP shock at time t on the labor share $t + h$ periods ahead. The time profile of the θ_h coefficients thus gives us an impulse response for the labor share at the sectoral level.

C.1 Data

We use two databases for the US economy. The first one is the NBER-CES productivity database. This annual database covers a highly disaggregated split of the US manufacturing sector. The second is the Klems database that has a less disaggregated split by sectors but covers not only manufacturing but all sectors in the economy including services.

The labor share at the sector level is defined as compensation of employees over value added, which is the only available proxy. After eliminating sectors for which the labor share exceeded one in any period, we are left with 464 sectors for the CES-NBER database, and 30 sectors for Klems.

The measure of MP_t is obtained by aggregating quarterly shocks from the Cholesky SVAR using aggregate data. We also used the Romer and Romer monetary surprise instrument as a cross-check. The sample period is 1985-2007 for the NBER database and 1987-2007 for the Klems database as compensation of employees is only available from that point onwards.

Pre-tests showed that, using the NBER data, the model displayed heteroskedasticity and autocorrelation. Hence the standard errors reported are robust clustered standard errors. For the Klems data, as well as heteroscedasticity and autocorrelation, there were signs of contemporaneous cross-sectional correlation. Thus, the standard errors are estimated following Driscoll and Kraay (1998). The error structure is assumed to be heteroskedastic, autocorrelated up to one lag, and correlated between the sectors. Time effects appeared to

[1] With yearly data, a single lag appears to be sufficient to capture the persistence of the labor share. Adding more lags does not change the results in a significant way.

be significant in all specifications. This is consistent with the general fall in the labor share experienced by all sectors as is evidenced by figure C1. Between 1985 and 2007, the labor share falls in the manufacturing sector by 10 percentage points.

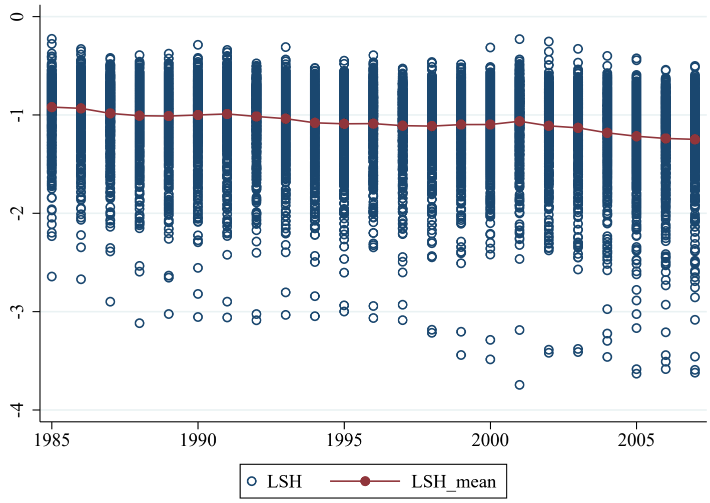


Figure C1: Average and dispersion of (log) labor shares in the NBER productivity database, 1985-2007.

C.2 Results

The results from the estimated θ_h for horizons $h = 1, ..., 5$ for the NBER database are reported in figure G1, where t_1 represents the contemporaneous effect. The MP shock leads to a significant increase in the labor share on impact and a further increase in the second year. The effect then falls as the horizon increases. Quantitatively, the impact is similar to that obtained from the aggregate VAR, although slightly less pronounced. The shape is also consistent with the aggregate results, where the labor share peaks between quarters 5 and 10 after the shock. Figure C3 shows the results using the Romer and Romer proxy. In this case, the effect is positive, peaks in quarter 3, and quantitatively similar to the aggregate results. However, the effect at $h = 5$ is strongly negative, which differs from the results using aggregate data. Finally, figure C4 presents the results using the Cholesky SVAR proxy for MP shocks and using the Klems database. The standard errors are larger given the much smaller sample size. On impact, the effect is not significant, but the labor share increases one year later and then falls, though not monotonically. The quantitative impact is smaller than using aggregate data, however, it is still positive and significant one and three years after the shock. These results, thus, confirm that the increase in the labor share after a MP contraction is also a feature that occurs within sectors and not the result of cross-sectional aggregation of sectors with different labor shares.

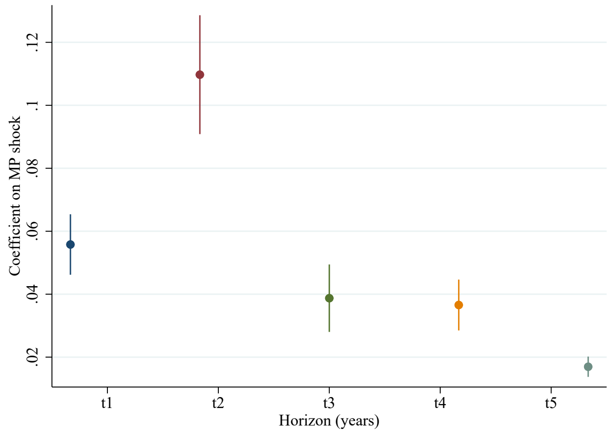


Figure C2: Coefficient on monetary policy shock variable (Cholesky VAR) using the NBER manufacturing database (464 manufacturing sectors). Period is 1985-2007. The plot shows the coefficient on the year of impact (t_1) and four years after.

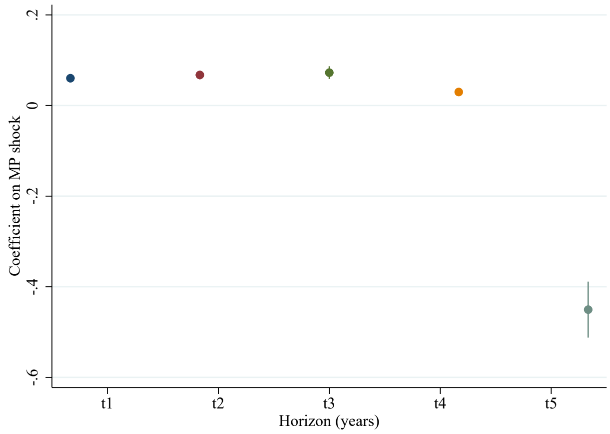


Figure C3: Coefficient on monetary policy shock variable (Romer and Romer) using the NBER manufacturing database (464 manufacturing sectors). Period is 1985-2007. The plot shows the coefficient on the year of impact (t_1) and four years after.

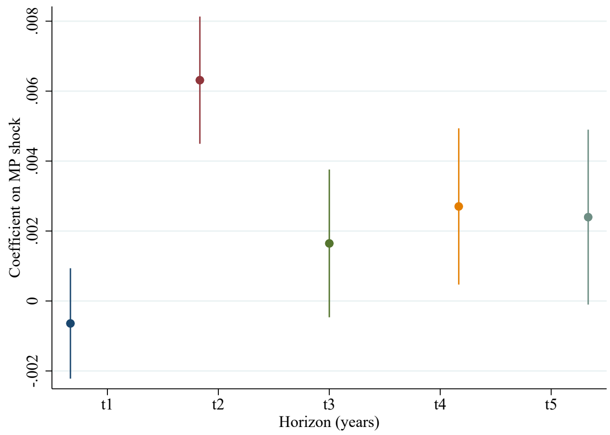


Figure C4: Coefficient on monetary policy shock variable (Cholesky VAR) using the Klems database (30 sectors). Period is 1987-2007. The plot shows the coefficient on the year of impact (t_1) and four years after.

D Composition Bias and the response of wages and productivity

One of the advantages of using the labor share is that the *composition bias* in the response of real wages and productivity is alleviated when one takes their ratio as argued convincingly by Basu and House (2016). However, this bias can still affect the results for real wages (and labor productivity if entered separately). It is then important to analyze whether, given our results, the composition bias may invalidate our results.[1]

In order to understand this, we simplify the argument in Basu and House (2016). We abstract from entry and exit of new workers and matching quality, since these effects would only reinforce our argument here. Define x_t as our measure of *aggregate* labor productivity or real hourly wages (LP_t,W_t^r). Now assume we can classify workers in a discreet grid of N levels of "human capital" or skills from lowest to highest, $j = 1, \ldots, N$. We implicitly assume that wages/productivity increase with the level of human capital. Then, aggregate productivity or wages are simply the weighted sum by level of human capital: $x_t = \sum_j x_{j,t}\alpha_{j,t}$ where $\alpha_{j,t}$ is the weight of hours worked by workers of human capital level j in total hours worked ($\alpha_{j,t} = \frac{H_{j,t}}{\sum_j H_{j,t}}$). It is easy to show that we can decompose that measure in two terms:

$$x_t = \sum_j x_{j,t}\alpha_{j,t} = \overline{x}_t + \sum_j \left(x_{j,t} - \overline{x}_t\right)\left(\alpha_{j,t} - \overline{\alpha}_t\right) = \mu_t + \varrho_t,$$

where $\overline{x}_t$ and $\overline{\alpha}_t$ are the averages of wages/productivity and the shares of workers of different levels of human capital respectively. This expression tells us that observed aggregate wages or productivity can be decomposed into two components: the un-weighted average wage/productivity of workers (μ_t), and the covariance between wages/productivity and the share of workers by level of human capital (ϱ_t). The first term is the wage/productivity of the "representative" worker. The second term tells us about the structure of the labor force: whether shares are increasing or decreasing in productivity (the skill-composition). Changes in this term would precisely be related to the composition bias: they tell us whether during booms or recessions the composition of the labor force changes. For instance, if during booms the share of high productivity workers decreases, then the covariance would fall.

Our interest is in the cyclical evolution of μ_t conditional on a MP tightening, since this is the direct correspondence between data and models in a large class of representative agent DSGEs. To settle notation, call $f(.,t)_{MP}$ the impulse response function (IRF) over $t = 1, \ldots, T$ of any variable to a MP tightening. Since the IRF of two additive variables is also additive, we have that: $f(x_t, t)_{MP} = f(\mu_t, t)_{MP} + f(\varrho_t, t)_{MP}\ \forall t$. Now suppose, for simplicity, that the effect of a MP shock on aggregate wages/productivity is zero at all horizons of the IRF. This implies that: $f(\mu_t, t)_{MP} = -f(\varrho_t, t)_{MP}$. Now, suppose we know that, in an expansion, the share of low skilled workers increases and it falls in a recession as discussed in Basu and House (2016). Thus, the change in this covariance is negative during an expansion. Basu and House (2016) also show that, conditional on a MP shock, the composition bias changes: the covariance increases (falls) with a MP tightening (loosening). It immediately follows then that, if the aggregate response is zero, then the "representative worker" response must be negative with a MP tightening.

Our findings show that aggregate real wages respond *at least* non-positively (and negatively in many cases) and the response of aggregate labor productivity is negative. From

[1] Another important dimension of heterogeneity has been emphasised by Gouin-Bonenfant (2018) where the way productivity gains pass through onto wages depends on the productivity dispersion across firms. When firm productivity dispersion is high, pass through of productivity changes onto wages is low.

the above argument, the response of the representative agent wage/productivity would then be negative. That is, it will be more negative than the one obtained using aggregate data. If there is a composition bias and that bias is counter-cyclical, at least we know that the *sign* of the response of real wages and productivity is negative.[2]

As a second cross-check of this argument, we use data on composition bias corrected measures of wages for the US. Here we present results using the baseline Cholesky specification used in the paper substituting the real wages with data on composition bias corrected measures of wages as constructed by Haefke, Sonntag, and Van-Rens (2013). The sample is 1984-2006 as their dataset stops in 2006.[3] For details about data construction we refer the reader to the original paper of Haefke, Sonntag, and Van-Rens (2013). As expected the negative response of adjusted wages is more pronounced than that of unadjusted wages.[4]

[2]Note that this is not to say that, from our VAR results, we know the *magnitude* of this effect, but at least we do know its *sign*. Had we found a positive response of wages and productivity, then the true sign would be indeterminate unless we know the exact magnitude of the composition bias. Also, if the composition bias in wages and productivity cancels out when constructing the labor share, both the sign and value of this response would be identified.

[3]In their original dataset there are 4 missing observations in the sample. We interpolate the data but our results are robust to this interpolation. For the last two specification with wages of newly hired workers the BIC criterion suggested 2 lags instead of 3 as in the baseline specification.

[4]Note, however, that Gertler, Huckfeldt, and Trigari (2019) claim that: *"[...] the interpretation of new hire wage cyclicality as direct evidence of wage flexibility ignores confounding cyclical variation in wages that is due to workers moving to better job matches during expansions. [...] We find that, after controlling for composition effects, the wages of new hires are no more flexible than those of existing workers. A key implication, which we make precise, is that the low variability of existing workers' wages provides a better guide to the cyclicality of the marginal cost of labor"*.

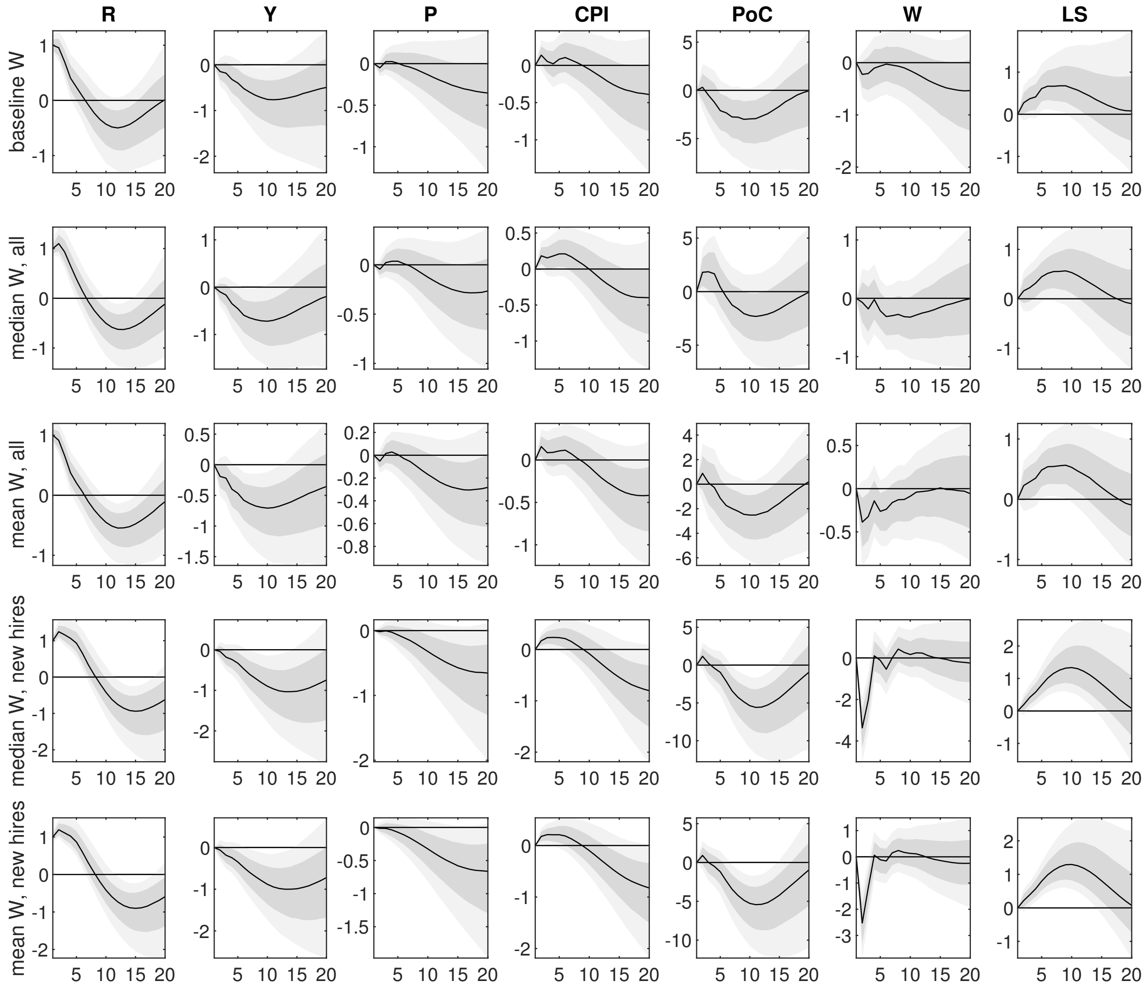


Figure D1: Impulse Response Functions comparing the response of Aggregate Wages in the US and composition bias corrected measures for all and newly hired workers.

E Theoretical response of prices conditional on the observed labor share

We show how the theoretical impulse response of prices to a MP shock can be derived from the Phillips Curve given an impulse response for the labor share in the data as in Figure 3 in the main text. We take a New Keynesian Phillips Curve (NKPC) using standard parameter values and feed it the response of the labor share assuming, as is the case in the basic NK model, that the labor share is the marginal cost. We then compare the implied response of inflation to the MP shock from the PC and that from the SVAR.

Take a basic NKPC of the form:

$$\pi_t = \beta E_t[\pi_{t+1}] + \kappa_p mc_t, \tag{1}$$

where π_t is inflation, mc_t are marginal costs, parameter $\kappa_p = \frac{(1-\theta_p)(1-\theta_p\beta)}{\theta_p}$, and $(1-\theta_p)$ is the proportion of firms that are allowed to reset prices. β the discount factor.

The NKPC can be solved forward like an asset price, such that inflation today is simply the present discounted value of all future expected marginal costs:

$$\pi_t = \kappa_p \sum_{k=0}^{\infty} \beta^k E_t[mc_{t+k}], \tag{2}$$

Now, using this expression, we can compute π_t, π_{t+1}, π_{t+2}, etc., conditional on an MP shock. We set $mc_t = ls_t$ for $\forall\ t$. The expectation today of ls_{t+k} conditional on an MP shock, $E_t[lsh_{t+k}|\epsilon_{MP,t} = 1]$ is the impulse response series of the labor share to a MP shock. Because this IRF converges to zero as $t+k$ grows large, the expected value at $t+k+1, 2, 3...$ is zero. We then obtain the IRF, and compute the discounted present value of π_t, given parameter values for θ_p and β, from $t = 1$ to $t = S$, where S is the period when the response becomes insignificant. We then compute the price level from inflation and compare it to the response of prices in the SVAR.

F Labor share response to other shocks

We briefly look at the transmission of other non-policy shocks to the labor share for the US. It is interesting to see how TFP or cost-push shocks propagate in our empirical environment and the extent to which they are consistent with the NK model predictions. In theoretical NK models, a positive technology shock increases the marginal product of labor; since producing the same quantity of goods becomes cheaper, the marginal cost falls, profit share rises and, by construction, the labor share falls. In the aggregate, output increases and prices drop. Cost-push shocks dynamics are slightly different. An exogenous fall in prices induce an immediate increase in the real wage; this generates a rise in marginal cost which in turn pushes the share of labor to total income up. At the same time, an increase in real wages pushes hours up and hence aggregate output expands. To summarize, after a positive technology shock we expect GDP to be positive, price negative, and labor share negative. After a negative cost-push shock we expect GDP to be positive, prices negative, and labor share positive. While these two supply-side shocks imply negative comovements between prices and quantities, they have different implications on the labor share. So care is needed when confronting these theoretical predictions with empirical outcome.

With this caveat in mind, we can nevertheless try to identify technology and cost-push shocks in our empirical VARs. Identifying the former is relatively straightforward. We considered the Fernald measure of utilization adjusted TFP, ordered this variable first and looked at the transmission of orthogonalized innovation to it. Identifying the latter is more difficult. Our strategy relied on sign restrictions and we assumed that a cost-push shock generates a negative comovement between output and prices. However, many other supply-side shocks can generate this pattern, e.g. the very same technology shocks or a combination of all of them.

Results for the are mixed. Figures F1 and F2 present the results. The TFP shock is identified only for the US as we do not have good proxies for quarterly TFP for the other countries. For the technology shock, the empirical IRFs clash with the theory see figures F1; in fact, we obtain that the labor share typically increases after a positive technology shocks. This is, nevertheless, a well known result in the literature following Ríos-Rull and Santaeulália-Llopis (2010) and León-Ledesma and Satchi (2019). However, a generic supply side shock identified with sign restrictions would generate labor share dynamics that are consistent (except for the EA) with the labor share propagation after a cost-push shock in the NK model.

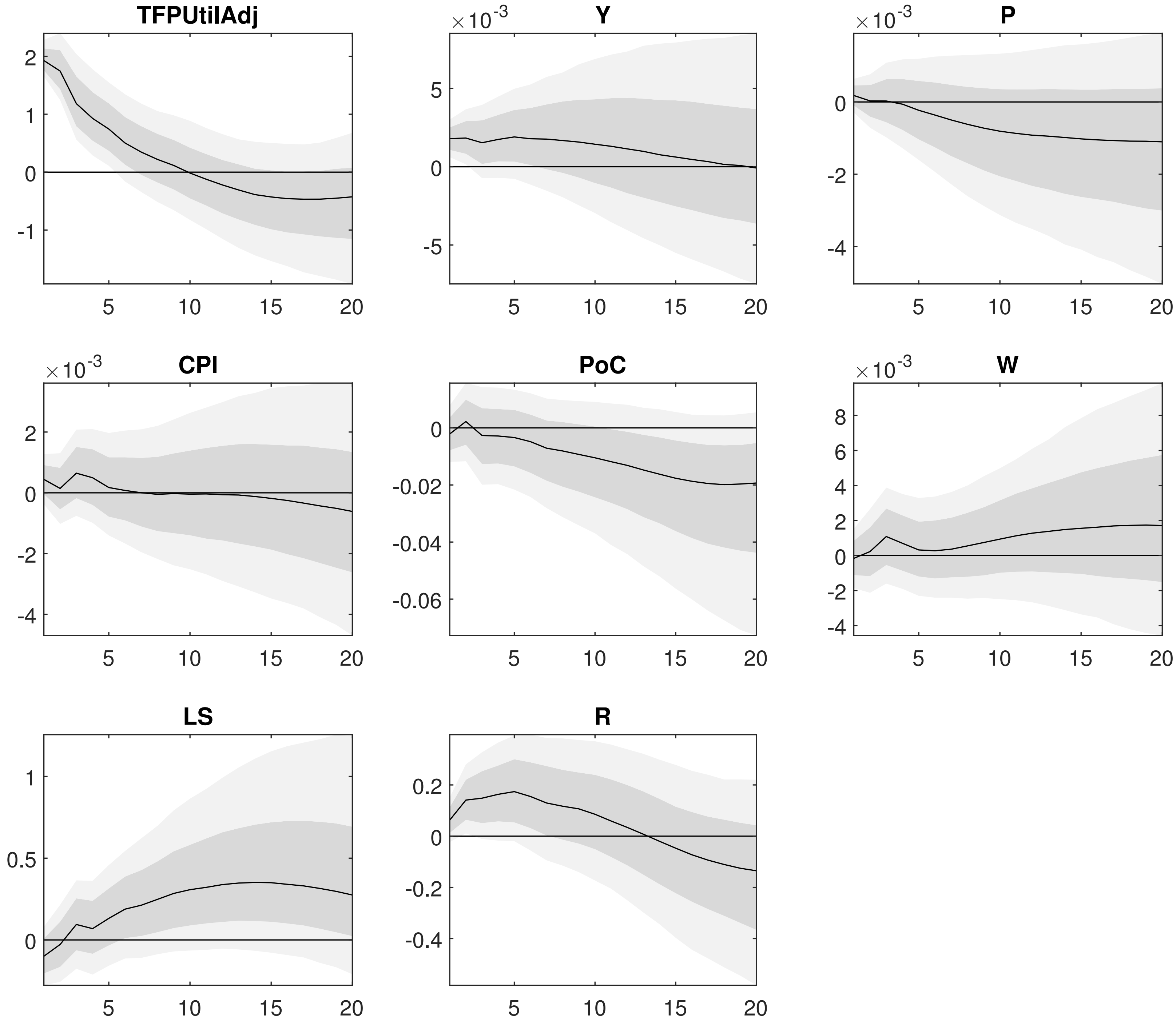


Figure F1: Impulse Response Function to TFP shock (recursive ordering).

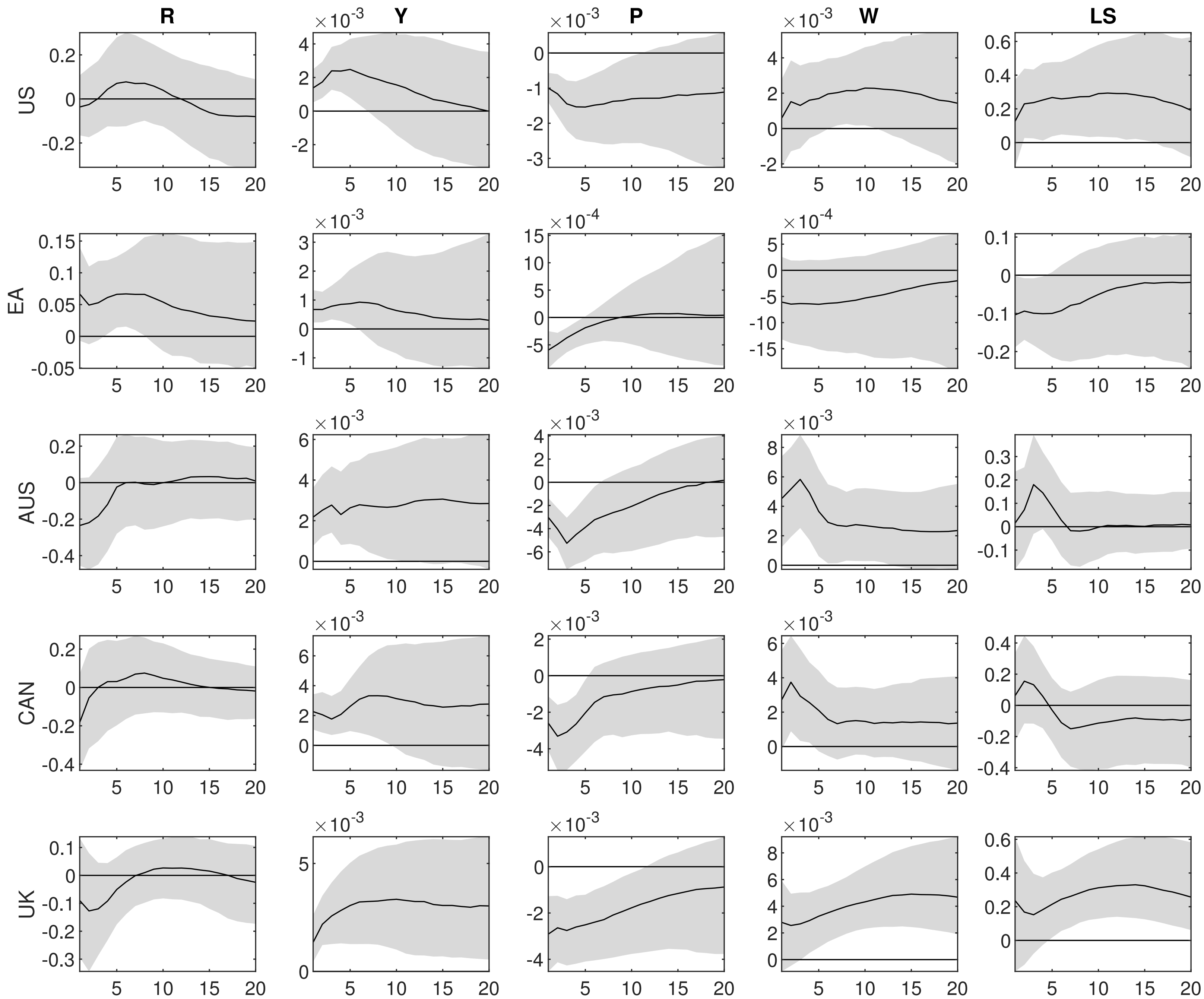


Figure F2: Impulse Response Function to a supply side shock (sign restrictions).

G Wage-price stickiness and the response of the labor share: derivation

Here, we show the full derivation of the analytical results of the NK model with price and wage rigidity in Section 2. To make the derivation easier to follow, we reproduce the model equations below. Note that, since we only care about MP shocks, we assume a constant TFP level (fixed to one, zero in logs). The set of equations describing the model are:

$$y_t = E_t[y_{t+1}] + (i_t - E_t[\pi_{t+1}]) \qquad \text{(IS Curve)}$$

$$y_t = (1-\alpha)n_t \qquad \text{(Production function)}$$

$$\pi_t = \beta E_t[\pi_{t+1}] + \lambda_p y_t + \kappa_p w_t \qquad \text{(Price Phillips Curve)}$$

$$\pi_t^w = \beta E_t[\pi_{t+1}^w] + \lambda_w y_t - \kappa_w w_t \qquad \text{(Wage Phillips Curve)}$$

$$lsh_t \equiv w_t + n_t - y_t \qquad \text{(Labor share definition)}$$

Here, y_t is the output gap (deviations from the flexible economy), w_t is the real wage gap, π_t and π_t^w are price and nominal wage inflation respectively, n_t is the employment gap, and i_t is the *interest rate in deviation from the natural real rate of interest (r^n).* β is the discount factor, α is the degree of DRS in production, and λ_p, λ_w, κ_p, and κ_w are slope coefficients of the Phillips Curves that are a function of deep parameters of the model as follows:

$$\kappa_p = \frac{(1-\theta_p)(1-\beta\theta_p)}{\theta_p} \tag{1}$$

$$\kappa_w = \frac{(1-\theta_w)(1-\beta\theta_w)}{(1+\eta\epsilon_w)\theta_w} \tag{2}$$

where $(1-\theta_p)$ is the fraction of firms that readjust prices, $(1-\theta_w)$ the fraction of workers that readjust wages, ϵ_w is the elasticity of substitution of differentiated labor inputs, and η is the inverse Frisch elasticity. Finally:

$$\lambda_p = \frac{\alpha}{1-\alpha}\kappa_p \tag{3}$$

$$\lambda_w = \left(\sigma + \frac{\alpha}{1-\alpha}\right)\kappa_w \tag{4}$$

where σ is the degree of risk aversion.

As mentioned in the main text, we are interested in the impact response of real wages and the labor share to a MP shock. To obtain that, we assume that the monetary authority is able to set the interest rate to track the natural real rate of interest (and hence make the gaps zero) in every period except for the initial period in which it deviates by an amount ε_t^{MP}, the MP shock. Written in terms of deviations from r^n, this then implies:

$$\begin{aligned} i_t &= E_t[\pi_{t+1}] + \varepsilon_t^{MP} \\ i_{t+j} &= E_{t+j}[\pi_{t+1+j}] \text{ for } j > 0 \end{aligned} \qquad \text{(MP rule)}$$

Finally, we have the definition of the change in the real wage gap as:

$$w_t \equiv w_{t-1} + \pi_t^w - \pi_t + \Delta w_t^n \qquad \text{(Real wage gap change)}$$

where w_t^n is the flexible price/flexible wage economy real wage. Note that w_t^n only responds to supply shocks and hence $\Delta w_t^n = 0$ in our model. Since we assume that the economy starts in period $t-1$ from an equilibrium with zero gaps, $w_{t-1} = 0$ too, and we have that:

$$w_t \equiv \pi_t^w - \pi_t. \tag{5}$$

Iterating the IS curve forward, we obtain an expression for the output gap as the sum of expected deviations of the real interest rate from its natural level. And given the MP rule above, this implies that the output gap at time t is just the negative of the MP shock:

$$y_t = \sum_{j=0}^{\infty}(i_{t+j} - E_t[\pi_{t+j+1}]) = -\varepsilon_t^{MP} \tag{6}$$

Using (5), (6), the price and wage Phillips Curves and, since MP sets all gaps to zero beyond time t then $E_t[\pi_{t+1}] = E_t[\pi_{t+1}^w] = 0$, we can obtain an expression for the real wage gap as a function of the shock:

$$w_t = \frac{\lambda_p - \lambda_w}{1 + \kappa_w + \kappa_p}\varepsilon_t^{MP} \tag{7}$$

To obtain the response of the labor share, we use the definition of the labor share and the production function to obtain:

$$lsh_t = \left(\frac{\lambda_p - \lambda_w}{1 + \kappa_w + \kappa_p} - \frac{\alpha}{1-\alpha}\right)\varepsilon_t^{MP} \tag{8}$$

which, given that $\alpha > 0$, is always going to be more negative than the response of real wages.

We now have an expression for the impact responses to a MP shock of real wages and the labor share. Quantitatively, the response will depend on the degree of price and wage rigidity through parameters κ_p and κ_w (and, by implication, λ_p and λ_w). A numerical example can visually illustrate this point. We pick certain common values in the literature for the deep parameters fixing θ_p and varying θ_w and show the response of the labor share for different degrees of wage rigidity. We set $\beta = 0.99$, $\alpha = 0.1$, $\sigma = 1$, $\eta = 0.4$, $\epsilon_w = 8$, $\theta_p = 0.6$, and allow θ_w to vary between 0.1 and 0.99. Figure G1 shows the response of the real wage gap and the labor share. As it is clear, both responses are increasing in θ_w. The real wage response turns positive, for this parameterization, for a value slightly above 0.7. The labor share response is always negative. As discussed in the main body of the paper, the higher the degree of wage rigidity relative to price rigidity, the higher the response of real wages and the labor share.

The responses of both variables will be negative when the production function has CRS. It is easy to see that, if we set $\alpha = 0$, then the expressions above collapse to:

$$w_t = -\frac{\lambda_w}{1 + \kappa_w + \kappa_p}\varepsilon_t^{MP} \tag{9}$$

$$lsh_t = -\frac{\lambda_w}{1 + \kappa_w + \kappa_p}\varepsilon_t^{MP} \tag{10}$$

which will always be negative regardless of the values of θ_p and θ_w. This is intuitive as, in this case, the labor share is equal to the real wage which, in turn, is equal to the marginal cost. Hence, any policy that reduces current inflation relative to future inflation must decrease marginal costs and hence real wages and the labor share.

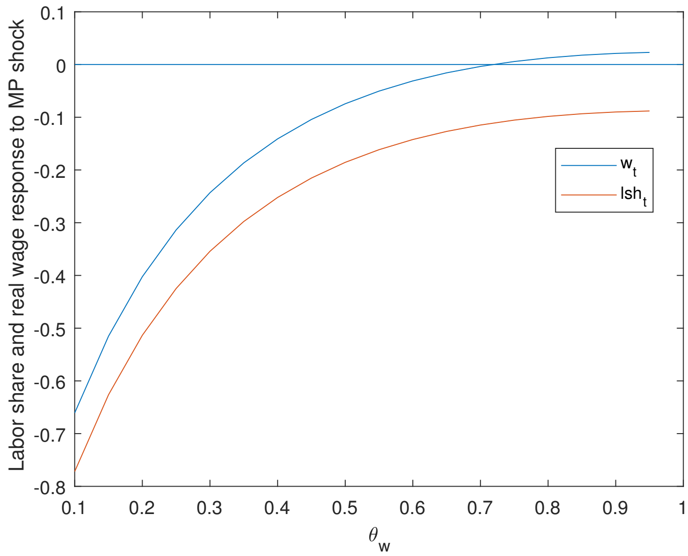


Figure G1: Response of real wages and the labor share for different values of wage rigidity. $\theta_p = 0.6$.

Furthermore, we can show that, as long as κ_w is positive (which must be the case) then the response of the labor share will always be negative. To see this, we find the value of κ_w in (8) that would make the expression in parenthesis zero. We call this value κ_w^0. It is easy to show that:

$$\kappa_w^0 = -\frac{\frac{\alpha}{1-\alpha}}{\sigma + 2\frac{\alpha}{1-\alpha}}, \tag{11}$$

which, given that $0 \leq \alpha < 1$ and $\sigma > 0$, would imply a negative κ_w. Thus, whatever the degree of wage stickiness, the labor share and, by implication, marginal costs must decrease after a MP contraction.

H Theory

As discussed in the main body of the paper, we discuss possible extensions of the standard NK framework that can break up the one-to-one relationship between the labor share and marginal costs (inverse of the markup) and therefore help the model match the empirical evidence.

In what follows, for ease of exposition, we will assume that the production function is linear in labor.[1] Given a linear production function with labor as the only variable input ($y_t = n_t$) now the real wage is also equal to the labor share and real marginal costs mc_t:

$$w_t = lsh_t = mc_t. \tag{1}$$

H.1 The labor share and fixed costs in production

Nekarda and Ramey (2019), among others, discuss two production function generalizations that are able to break the r.h.s. equality of (1): overhead and overtime labor. Both

[1] Assuming a decreasing returns to scale production function $y_t = \alpha n_t$ does not change the results.

specifications introduce a wedge between the average wage and the marginal product of labor, which is a necessary condition to be able to generate impulse responses in line with our empirical evidence.

However the procyclicality of marginal costs still dominates quantitatively the response of the labor share to a MP shock. Moreover, it can be shown that the inclusion of fixed costs in production to ensure no entry in steady state, as usually assumed in DSGE models, acts in the same way as the presence of overhead labor in production. Consider a NK economy with a simple linear production in labor with the presence of fixed costs F: $Y_t = N_t - F$. In log deviations from the steady state the labor share is now:

$$lsh_t = mc_t - n_t \frac{F}{Y}. \tag{2}$$

Given that hours (output) responds procyclically to a MP shock then the higher $\frac{F}{Y}$ the higher the wedge between labor share and marginal costs.[2] Numerical results (not reported here) show that this might work only on impact and for implausibly high values of $\frac{F}{Y}$.

H.2 The cost-push channel of Monetary Policy

The cost-push channel introduces a direct effect of the nominal interest rate (i_t) on the marginal cost and it has been used in the literature in order to explain the well-known *price puzzle* after a MP shock and to reproduce the pro-cyclical price markup documented by Nekarda and Ramey (2019).

Following the set up of Ravenna and Walsh (2006), we can augment the basic NK model with Calvo pricing by adding a credit channel and the cost of working capital by assuming a cash in advance constraint for the firms. The need to finance in advance their working capital (wage bill) induces a need for credit from financial intermediaries.

In this set up, the real wage is now given by

$$w_t = mc_t + y_t - n_t - i_t.\text{[3]} \tag{3}$$

This implies that, in this model, the labor share is given by

$$w_t = lsh_t = mc_t - i_t. \tag{4}$$

This channel is thus able to break the link between the labor share and the price markup. Because the marginal cost now depends on the cost of financing working capital, as shown in Phaneuf, Sims, and Victor (2018), the markup can become pro-cyclical consistent with the evidence in Nekarda and Ramey (2019). However, as the nominal interest rate moves counter-cyclically by definition, the direct effect of i_t in (4) reinforces the pro-cyclicality of the labour share. Hence, one needs to rely on numerical analysis to check which of the two competing effects dominates. The Monte Carlo Filtering results presented in Appendix J show how the working capital fraction is in principle a parameter that might be able to generate a switch in the sign of the labor share after a few quarters from a MP shock. However the quantitative analysis in section 3 of the paper shows that this is not enough to generate IRFs in line with the empirical evidence in the Christiano, Eichenbaum, and Trabandt 2016 model.

[2] This is also the reason why sometimes estimated DSGE models find a very large proportion of fixed costs in production (see Smets and Wouters (2007)).

[3] This follows the log-lnearization of equation (6) in Ravenna and Walsh (2006).

H.3 Search and Matching

We now turn our attention to labor market frictions in the form of search and matching. While in the paper we use the model of Christiano, Eichenbaum, and Trabandt (2016) that uses alternate offer bargaining, it is easier to present here the intuition of this channel using the more standard Nash bargaining model as in Galí (2010). In this set up, real wages are not set competitively but are the result of a bilateral Nash bargaining process between workers and firms, while an aggregate matching function explains the evolution of aggregate employment. Hence now real wages are not set anymore equal to a markup over labor productivity (lp_t). If $w_t \neq mc_t + lp_t$, it follows then that $lsh_t \neq mc_t$. The dynamics of the labor share will differ since now wages and marginal product of labor behave differently. Considering only the extensive margin here and again a linear production function $y_t = n_t$ we can see how the labor share is now given by:

$$lsh_t = w_t \neq mc_t. \tag{5}$$

Hence to generate an increase in the labor share the only possibility is to have a counter-factual response of wages to a monetary policy shock. Without wage rigidities, it would be difficult for wages to display a positive response given that the bargaining power of workers is bounded by one. The combination of both nominal wage and labor market rigidities, instead, proves to be enough to generate a positive response of real wages. Of course the introduction of capital and further real rigidities might overturn this result in larger DSGE model. Once again this can only be checked using numerical techniques as we do in the main body of the paper.

H.4 Open economy

Consider the small open economy NK model of Galí and Monacelli (2005), also discussed in chapter 8 in Galí (2015).[4] In this set up the (log-linear) Phillips curve for domestic inflation, production function and real marginal costs are:

$$\pi_{H,t} = \beta E_t(\pi_{H,t+1}) + \lambda mc_t \tag{6}$$

$$y_t = a_t + (1-\alpha)n_t \tag{7}$$

$$mc_t = w_t - p_{h,t} - a_t + \alpha n_t \tag{8}$$

where $\pi_{H,t}$ is domestic inflation, mc_t real marginal costs, β the discount factor, α the degree of decreasing returns in production, λ the slope of the Phillips curve, w_t nominal wages, $p_{h,t}$ the domestic price level, y_t is real output, a_t exogenous tfp, and n_t is employment. It follows straight away from 8 that the labor share in this economy is equal to the real marginal costs plus the difference between domestic and overall price level:

$$lsh_t = mc_t + p_{h,t} - p_t.$$

Hence it follows that the open economy setting introduces a wedge between marginal costs and labor share that could be affected by the degree of complementarity/susbstitutability in consumption between domestic and foreign goods (η in Galí (2015) terminology).

[4] Throughout we assume that the central bank reacts to CPI and not to domestic inflation. However results are not sensitive to this assumption and we checked all the alternative Taylor rule specification present in the Galí (2015).

Moreover we note that, given that the consumption is a CES aggregator of domestic and foreign goods, the linearised price level can also be written as:

$$p_t = \upsilon p_t^h + (1-\upsilon)p_t^f, \tag{9}$$

where υ is the degree of home bias in consumption (share of domestic consumption when relative prices are 1). This then leads to an expression for the labor share as:

$$lsh_t = mc_t + (1-\upsilon)(p_t^h - p_t^f), \tag{10}$$

where the last term in parenthesis is just the terms of trade. Therefore, the reaction of the labor share will depend on η and υ.

For this reason we checked how both parameters affect the IRFs of the labor share and it's components, which in this context are the marginal costs and the log difference between domestic price and overall price level. Using the same calibration as in Galí (2015) we show how the impact response of the labor share and its components change when varying in turn η and υ. The top three panels of Figure H1 show the case when varying η from 0.1 to 10. The lower the elasticity η the larger the effect of the terms of trades that goes in the right direction of pushing the labor share up. However we see how the procylical movement of marginal costs, driven by the phillips curve on domestic inflation, still dominates and even in the case of a almost Leontieff aggregate consumption aggregator the labor share response is still negative.

The bottom three panels of the figure repeat the same exercise by changing the degree of openness υ from 0 to 1 and show that the terms of trade have a positive effect on the labor share the higher the value of υ. Once again however this is not enough the turn the labor share response into positive territory due to the fact that the marginal costs response always dominates. We show this also in figure H2 where we compare IRFs using the standard calibration as in Galí (2015) with the ones produced by setting $\eta = 0.01$ and $\upsilon = 1$.

In summary a low elasticity of substitution and/or a low degree of home bias do increase the effect of the terms of trade on the labor share which goes in the 'right' direction but is not enough to switch the sign of the labor share response. We have also looked if the combination of these parameters with alternative calibrations of all the others in the model could deliver the right sign of the labor share by running a PSA on the whole parameter space of the model. Results show that there is no combination of parameters in the model that can produce a positive response of the labor share at any quarter from 2 to 8 after a monetary policy shock.

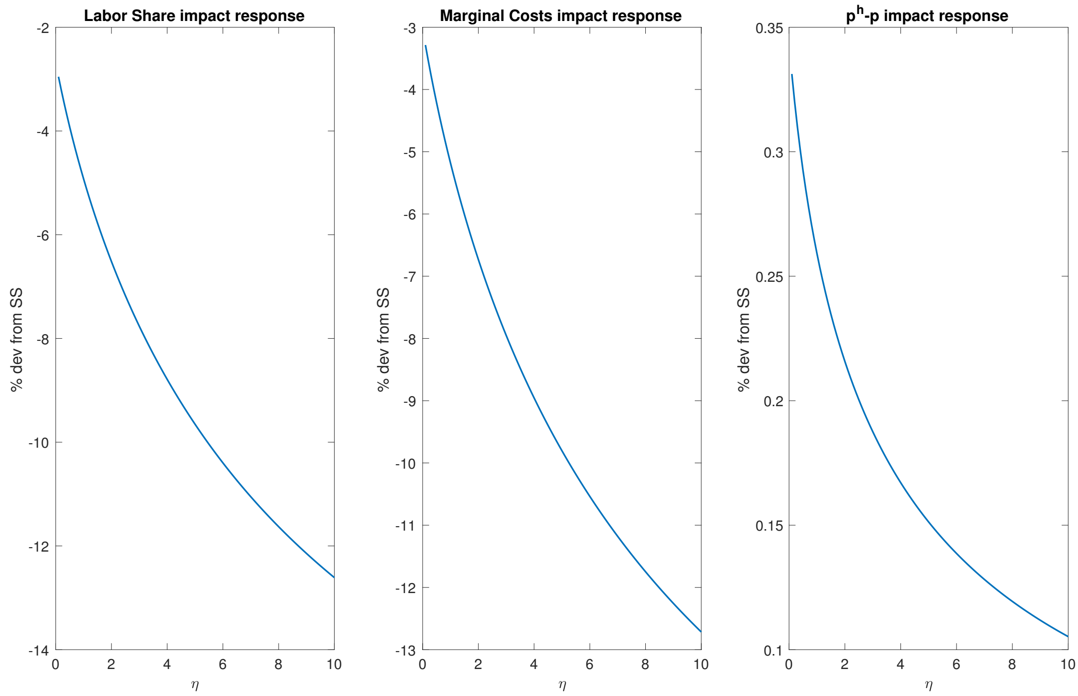
H.5 The labor share and CES production

Extending the NK model with investment and capital accumulation and assuming a CES production function[5] provides a simple way of introducing a wedge between the labor share and the marginal costs (mc_t) :

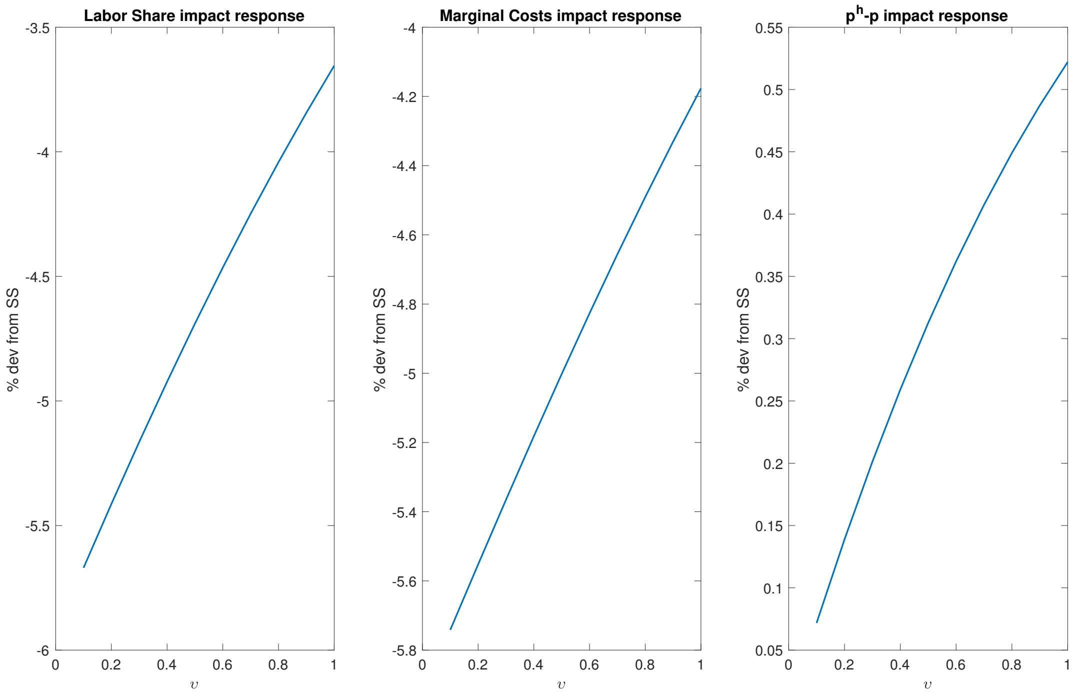
$$lsh_t^{CES} = mc_t + \frac{1-\sigma}{\sigma}(y_t - n_t), \tag{11}$$

where σ is the elasticity of substitution between capital and labor. As we show in previous versions of the paper, for any reasonable parameterization of the elasticity of substitution

[5] See Galí, Gertler, and López-Salido (2007) and Nekarda and Ramey (2019) for details and Cantore et al. 2015 for a medium scale DSGE model with CES production



(a) η



(b) υ

Figure H1: Change in the impact IRFs of selected variables when varying η or υ.

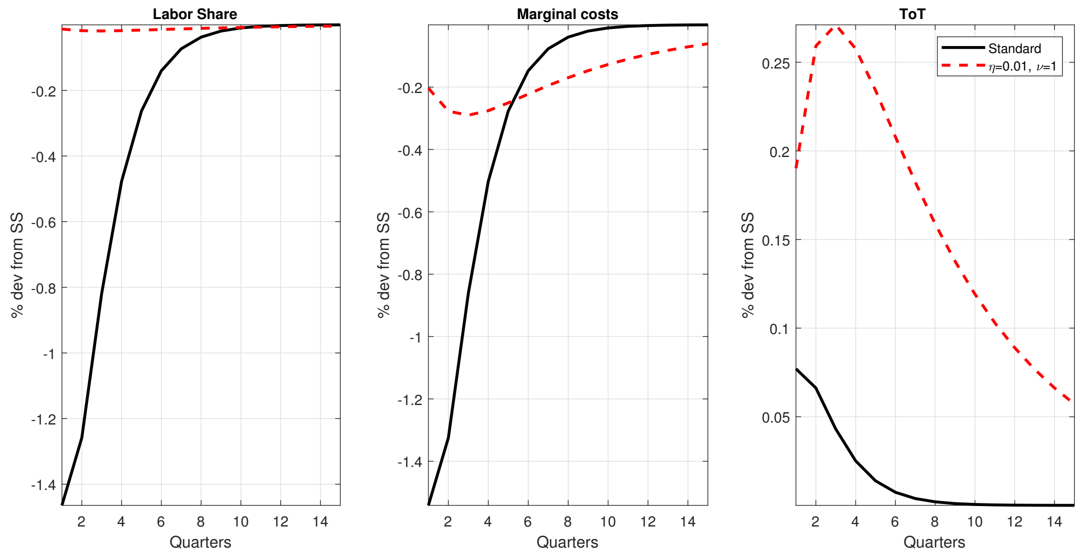


Figure H2: Change in the impact IRFs of selected variables when varying η or υ.

(σ), the reaction of mc_t to an MP shock always dominates, and the CES assumption does not change significantly the reaction of the labor share, which is always strongly correlated with marginal costs.

I SVAR with model simulated data

We quantitatively analyze the ability of the recursive SVAR to reproduce impulse responses to a MP shock generated by the model. To do so, we follow Erceg, Guerrieri, and Gust (2005), and generate samples of 150 observations of simulated data from the model for the interest rate, output, price, real wage, and the labor share using the estimated posterior modes of Christiano, Eichenbaum, and Trabandt (2016). We generate 150 different simulations from the model each of which is then used to estimate a recursive SVAR. We then compare the IRFs arising from the SVAR to those arising directly from the DSGE model. Specifically, we compare the median (true) IRF from the model to that in the SVAR for the repeated samples.

To allow for the invertibility of the VAR, we simulate the model with 5 shocks.[1] We set the standard deviation of the MP shock to 1% and for the rest of the shocks to 0.01%. Note that the aim of this exercise is to check whether the SVAR is able to identify the key shock for our analysis and, thus, we are not inferring anything about the identification of other structural shocks.

The comparison between SVAR and model IRFs is presented in figure I1, where the blue line is the model IRF and SVAR IRF is presented with 68% confidence sets. Clearly, the MP shock is neatly identified in the SVAR and especially so for the labor share and real wages.

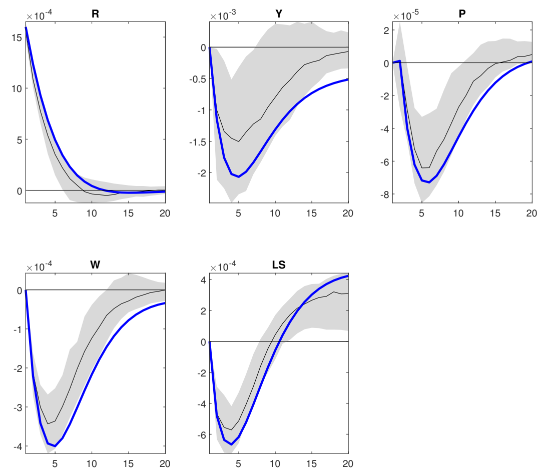


Figure I1: Blue line true (model) IRF, black line median SVAR IRF, grey area 68% confidence sets.

[1]As the original model has only three shocks we add two ad hoc iid shocks to the Euler equation and the resource constraint, but this does not affect the comparison for MP shocks.

J Monte Carlo Filtering

As in the prior predictive analysis, a random sample of the prior[1] is drawn and the associated model-implied statistics of interest are computed. Then, based on a set of constraints (e.g. rank conditions or signs of impulse responses), a categorization is defined for each MC model realization as lying either within or outside the target region. The terms behavior (B) or non-behavior ($\bar{B}$) are used in the MCF literature. The $B - \bar{B}$ categorization is mapped back onto the input structural parameters, each of which is thus also partitioned into a B and $\bar{B}$ sub-sample. Given a full set of N Monte Carlo runs, one obtains two subsets: $(\Psi_i|B)$ of size n and $(\Psi_i|\bar{B})$ of size $\bar{n}$, where $n + \bar{n} = N$ and Ψ_i, for $i = 1, .., k$, are model parameters. In general, the two sub-samples will come from different unknown probability density functions: $f_n(\Psi_i|B)$ of size n and $f_{\bar{n}}(\Psi_i|\bar{B})$ of size $\bar{n}$.

In order to identify the parameters that mostly drive the DSGE model into the target behavior, the distributions f_n and $f_{\bar{n}}$ are compared for each parameter independently. The Montecarlo sampling allows us to avoid computing analytical integration over the remaining parameters. If for a given parameter Ψ_i the two distributions are significantly different, then Ψ_i is a key factor driving the model behavior and there will be clearly identifiable subsets of values in its predefined range that are more likely to fall under B than under $\bar{B}$. If the two distributions are not significantly different, then Ψ_i is unimportant and any value in its predefined range is likely to fall either in B than under $\bar{B}$. Ideally, we are comparing the supports of the conditional cumulative distribution functions (CDF) of a parameter and compute the distance under standard statistical metrics. The Smirnov two-sample test (two-sided version) provides us with a statistical concept of distance. The lower the α associated to the Smirnoff test, the more likely is to reject the null hypothesis that the $CDF(\Psi_i|B)$ is equal to the $CDF(\Psi_i|\bar{B})$. The B and $\bar{B}$ subsets can be further inspected through bi-dimensional projections, in order to detect patterns characterizing two-way interactions. The standard procedure consists of computing the correlation coefficients ρ_{ij} between all parameters under the B and $\bar{B}$ subsets, and plotting the bi-dimensional projections of the sample for the couples having $|\rho_{ij}|$ larger than a significance threshold.

Table J1 below summarizes the results of applying this analysis to the calvo-sticky-wage model of Christiano, Eichenbaum, and Trabandt 2016 as discussed in section 3.3.2 of the paper. Parameters analized and respective priors are shown in table 2 of the paper.

[1] Same priors as above are used, see table 2.

2:5 quarters								
ls (+)			w (-)			ls (+); w (-)		
Parameter	D-Stat	P-value	**Parameter**	D-Stat	P-value	**Parameter**	D-Stat	P-value
Wage stickiness	0.292	0.000	Price stickiness	0.541	0.000	Wage stickines	0.502	0.000
Price stickiness	0.287	0.000	Wage stickiness	0.222	0.000	Price markup	0.389	0.000
Price markup	0.251	0.000	AR(1) MP shock	0.165	0.000	Interest rate smoothing	0.216	0.000
AR(1) MP shock	0.238	0.000	Interest rate smoothing	0.142	0.000	Working capital fraction	0.213	0.000
Habits in consumption	0.167	0.000	Wage indexation	0.081	0.000	Wage indexation	0.210	0.000
Wage indexation	0.141	0.000	Habits in consumption	0.076	0.000	Investment adjustment costs	0.193	0.000
Working capital fraction	0.132	0.000	Price indexation	0.071	0.000	Habits in consumption	0.170	0.000
Investment adjustment costs	0.126	0.000	Taylor rule response to inflation	0.051	0.000	Taylor rule response to output	0.106	0.000
Price indexation	0.115	0.000	Price markup	0.050	0.000	AR(1) MP shock	0.100	0.000
Interest rate smoothing	0.094	0.000	Taylor rule response to output	0.049	0.000			
Taylor rule response to inflation	0.087	0.000						

5:8 quarters								
ls (+)			w (-)			ls (+); w (-)		
Parameter	D-Stat	P-value	**Parameter**	D-Stat	P-value	**Parameter**	D-Stat	P-value
Price stickiness	0.486	0.000	Price stickiness	0.485	0.000	Wage stickiness	0.434	0.000
AR(1) MP shock	0.120	0.000	Price indexation	0.235	0.000	Price markup	0.283	0.000
Investment adjustment costs	0.110	0.000	Wage stickiness	0.219	0.000	Investment adjustment costs	0.265	0.000
Wage stickiness	0.094	0.000	Interest rate smoothing	0.095	0.000	Working capital fraction	0.216	0.000
Working capital fraction	0.087	0.000	AR(1) MP shock	0.087	0.000	Interest rate smoothing	0.164	0.000
Price markup	0.083	0.000	Working capital fraction	0.081	0.000	Wage indexation	0.153	0.000
Price indexation	0.071	0.000	Wage indexation	0.055	0.000	Price indexation	0.152	0.001
Inverse of Frish Elasticity	0.053	0.000	Price markup	0.053	0.000	AR(1) MP shock	0.150	0.000
Taylor rule response to inflation	0.052	0.000	Taylor rule response to output	0.052	0.000	Price stickiness	0.131	0.000
Interest rate smoothing	0.042	0.000	Habits in consumption	0.046	0.000	Taylor rule response to output	0.083	0.000

Table J1: Smirnov statistics in driving prior restrictions.

K Alternating offer bargaining model

This section shows robustness results by using the alternate offer bargaining model of Christiano, Eichenbaum, and Trabandt 2016 as opposed to the one with sticky wages a la Calvo used in the paper.

Description	
Investment adjustment costs	$U[1,20]$
Habits in Consumption	$U[0,1]$
Capacity utilization costs	$U[0,1]$
price stickiness	$U[0,1]$
Price markup	$U[1.1,2]$
Interest rate smoothing	$U[0,1]$
Taylor rule response to inflation	$U[1.01,5]$
Taylor rule response to output	$U[0,1]$
Working capital fraction	$U[0,1]$
Technology diffusion	$U[0,1]$
AR(1) MP shock	$U[0,1]$
Replacement ratio	$U[0,1]$
Prob. of barg. session determination	$U[0,1]$
Hiring fixed cost relative to output %	$U[0,2]$
Search cost relative to output %	$U[0,2]$
Matching function share of unemployment	$U[0,1]$
Job survival rate	$U[0,1]$
Vacancy filling rate	$U[0,1]$

Table H1: Uniform Distribution bounds for PSA and MCF, AOB model.

Restrictions					
2:5 quarters			5:8 quarters		
ls (+)	w (-)	ls (+); w (-)	ls (+)	w (-)	ls (+); w (-)
42.5%	9.1%	0.2%	29.1%	17.6%	0.9%

Table H2: Results from prior sensitivity analysis AOB model. Percentage of the prior support that matches all the restrictions.

2:5 quarters								
ls (+)			w (-)			ls (+); w (-)		
Parameter	D-Stat	P-value	**Parameter**	D-Stat	P-value	**Parameter**	D-Stat	P-value
Price stickiness	0.391	0.000	Price stickiness	0.387	0.000	Job survival rate	0.579	0.000
Price markup	0.226	0.000	AR(1) MP shock	0.296	0.000	Interest rate smoothing	0.379	0.000
Job survival rate	0.183	0.000	Interest rate smoothing	0.275	0.000	Price markup	0.323	0.000
Matching function share	0.128	0.000	Working capital fraction	0.232	0.000	Price stickiness	0.312	0.000
Investment adjustment costs	0.096	0.000	Matching function share	0.108	0.000			
Interest rate smoothing	0.093	0.000	Price markup	0.099	0.000			
AR(1) MP shock	0.069	0.000	Taylor rule response to inflation	0.096	0.000			
Habits in Consumption	0.068	0.000	Taylor rule response to output	0.085	0.000			
Replacement ratio	0.056	0.000						
Hiring fixed cost relative to output %	0.053	0.000						

5:8 quarters								
ls (+)			w (-)			ls (+); w (-)		
Parameter	D-Stat	P-value	**Parameter**	D-Stat	P-value	**Parameter**	D-Stat	P-value
Price stickiness	0.338	0.000	AR(1) MP shock	0.381	0.000	Job survival rate	0.405	0.000
Price markup	0.181	0.000	Price stickiness	0.329	0.000	AR(1) MP shock	0.309	0.000
Job survival rate	0.115	0.000	Job survival rate	0.170	0.000	Price stickiness	0.283	0.000
Investment adjustment costs	0.105	0.000	Matching function share	0.164	0.000	Habits in Consumption	0.202	0.000
Matching function share	0.103	0.000	Working capital fraction	0.140	0.000	Interest rate smoothing	0.189	0.000
AR(1) MP shock	0.079	0.000	Hiring fixed cost relative to output %	0.073	0.000	Price markup	0.182	0.000
Habits in Consumption	0.056	0.000	Interest rate smoothing	0.064	0.000	Replacement ratio	0.152	0.000
Interest rate smoothing	0.055	0.000	Habits in Consumption	0.061	0.001			
Working capital fraction	0.054	0.000						

Table H3: Smirnov statistics in driving prior restrictions, AOB model.

Description	Priors	Posteriors
Investment adjustment costs	$\Gamma(8,2)$	7.10 (3.75,10.77)
Habits in Consumption	$B(0.5,0.15)$	0.61 (0.36,0.84)
Capacity utilization costs	$\Gamma(0.5,0.3)$	0.53 (0.05,1.14)
Price stickiness	$B(0.66,0.1)$	0.64 (0.50,0.77)
Price markup	$\Gamma(1.2,0.05)$	1.24 (1.14,1.33)
Interest rate smoothing	$B(0.7,0.15)$	0.67 (0.48,0.83)
Taylor rule response to inflation	$\Gamma(1.7,0.15)$	1.73 (1.45,2.02)
Taylor rule response to output	$\Gamma(0.1,0.05)$	0.05 (0.01,0.11)
Working capital fraction	$B(0.8,0.1)$	0.77 (0.56,0.96)
MP shock stdev	$\Gamma(0.27,0.05)$	0.30 (0.25,0.34)
AR(1) MP shock	$\Gamma(0.5,0.15)$	0.43 (0.18,0.72)
Replacement ratio	$B(0.4,0.1)$	0.41 (0.22,0.61)
Prob. of barg. session determination	$\Gamma(0.5,0.4)$	0.33 (0.01,0.81)
Hiring fixed cost relative to output %	$\Gamma(1,0.3)$	0.98 (0.44, 1.56)
Search cost relative to output %	$\Gamma(0.1,0.07)$	0.10 (0.00, 0.23)
Matching function share of unemployment	$B(0.5,0.1)$	0.50 (0.30, 0.69)
Job survival rate	$B(0.8,0.1)$	0.74 (0.55,0.90)

Table H4: AOB model: Priors and posterior means the parameters (95% HDP interval in parenthesis) - Bayesian Impulse Response Matching as in Christiano, Trabandt, and Walentin (2010). Distributions: Γ *Gamma*, B *Beta*.

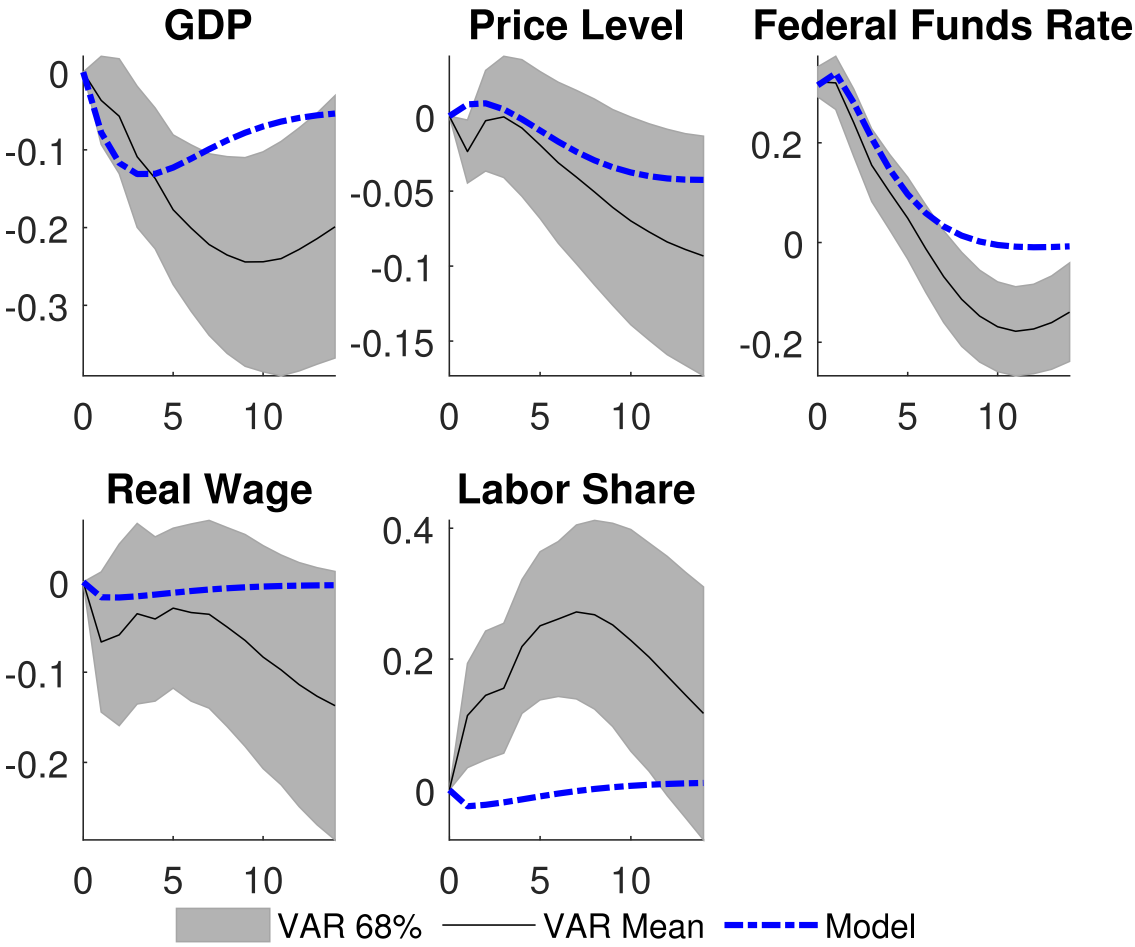


Figure H1: AOB Model: Bayesian Impulse Responses Matching - SVAR vs DSGE model

L Bayesian Impulse Responses

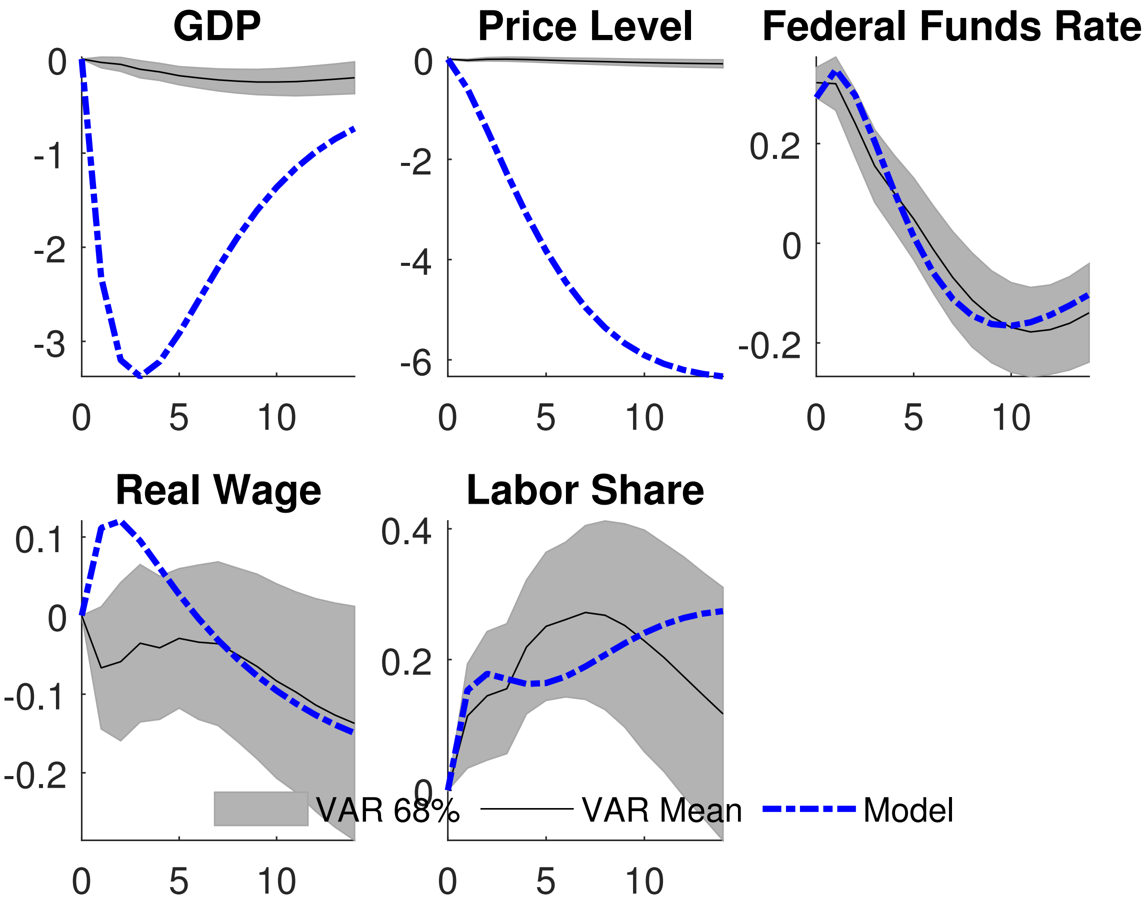


Figure L1: Bayesian Impulse Responses Matching - Matching only Federal Funds Rates and the Labor share.

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