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JEL Classification: E23, E32, C52

Keywords: Labor Share, monetary policy shocks

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The Missing Link: Monetary Policy and The Labor Share*

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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 components of the labor share, namely real wages and labor productivity. 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, real wages, and productivity? 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 and labor productivity. 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 a recursive Cholesky ordering, sign restrictions, and several external instruments in the spirit of Stock and Watson (2012) and Mertens and Ravn (2013) to identify MP surprises.

To analyze whether theories are consistent with these robust stylized facts, we study the properties of different families of models commonly used in macroeconomics for the analysis of monetary policy. We first briefly discuss the intuition behind some canonical models to understand the margins affecting the labor share. We then look at the quantitative properties of larger models incorporating a combination of different rigidities. We derive measures of the labor share from the models 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 these models 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, real wages, and productivity using Monte Carlo Filtering (MCF) techniques. Third, once these key parameters are identified, we estimate them by matching the models' impulse responses to those of the VAR.

[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.

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 search and matching frictions. We also consider the role played by wage rigidities and fixed production costs. In other words, we look at different families of models 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 of models, 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 a frictionless labor markets model, high nominal wage inertia is able to reproduce the response of the labor share to an unexpected MP shock. At first sight, this would be an obvious solution to the puzzle. However, this comes at the cost of obtaining counter-factual (counter-cyclical) responses of real wages. Our impulse response matching estimates show that several models do a reasonable job at matching the responses of standard macroeconomic variables to an identified MP shock, but they are 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.[3] The conditional correlation of the labor share to demand shocks is still empirically and theoretically an open question. It has to be noted, however, that most of the 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. In our approach, 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 below 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 stickiness.

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.[4] Nevertheless, the response of wages is typically not significant in most of the literature. Using individual-level data, Basu and House (2016) find that wages of newly hired workers and the *user cost of labor* respond strongly and pro-cyclically to MP innovations. The reason is that aggregate data on wages and productivity might be subject to biases due to systematic changes in the

[3]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 (forthcoming). However, our focus here is on the effects of MP innovations.

[4]It is worth pointing out that the difference between the responses of labor productivity and real wages in Christiano, Eichenbaum, and Evans (2005) and Altig et al. (2011), do not necessarily reflect the responses of the US labor share. This is because, as discussed below, real wages and productivity are constructed using different price deflators. Also, we would be ignoring the adjustments to proprietors' income, net taxes, and capital depreciation typically used to construct labor share series. See Section 2 and Appendix A.

composition of employed workers over the cycle. This *composition bias* that might affect aggregate measures of the real wage and labor productivity cancels out when combining them to construct the labor share measure.[5] This argument reinforces the advantage of using the labor share in aggregate empirical analyses. In our case, since we also find pro-cyclical aggregate responses of real wages and labor productivity, the composition bias can only reinforce our results (see section 2.1).

The relationship between the markup, the labor share, and their cyclicality is the focus of, amongst many others, Bils (1987), Bils, Klenow, and Malin (2018), Galí, Gertler, and López-Salido (2007), Hall (2012), Nekarda and Ramey (2013) and Rotemberg and Woodford (1999).

Rotemberg and Woodford (1999) studied extensively the cyclical behavior of real marginal costs and price markups. They found a pro-cyclical marginal labor cost and show that the implied counter-cyclicality of markups accounted for a substantial fraction of cyclical output movements. Galí, Gertler, and López-Salido (2007) expand on the resulting literature on counter-cyclical markups and present a theory-based measure of the gap between the marginal product of labor and the household consumption and leisure trade off, the 'labor wedge'. They show how this variable corresponds to the reciprocal of the markup of prices over 'social' marginal costs. Most of the variation of this wedge is associated with counter-cyclical movements in the wage markup. The price markup shows, at best, a weak contemporaneous correlation. More recently, Barattieri, Basu, and Gottschalk (2014), also find evidence of a greater importance of wage rigidities.

Karabarbounis (2014) also discusses the counter-factual requirement of NK models that, in order to have a counter-cyclical markup, a pro-cyclical labor share is necessary. He decomposes the labor wedge in two parts: a firm's wedge and a household wedge. Starting from the assumption that the firm's wedge is a decreasing function of the labor share, and that the labor share is counter-cyclical, he observes that the firm's first-order condition that the MPL equals the real wage needs to be augmented by a relatively smooth and pro-cyclical wedge for this condition hold in the data. Our findings also cast doubts on this counter-factual requirement of NK models.

Nekarda and Ramey (2013) 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. They also show a pro-cyclical response of the markup conditional on demand shocks. 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 its components and analyze the coherence between their responses to a MP shock and that obtained in the VARs. We make use of a wide variety of NK models where the relationship between the labor share and the price markup breaks down. While Nekarda and Ramey (2013) conclude that refocusing models around wage rigidity may resolve their empirical inconsistency, we show that, even with wage and labor market rigidities, models are unable to reproduce the joint behavior of the labor share and its components.

Bils, Klenow, and Malin (2018) revive the role of counter-cyclical markups and sticky prices. They note that criticisms of the counter-cyclicality of the markup are based on the observation that the gap between average hourly earnings and labor productivity is a-cyclical. They argue that average hourly earnings may not reflect the true marginal cost of labor to the firm. Hence, they look at the intra-temporal wedge for the self-employed and the product market wedge from intermediate inputs. Their finding is that product market

[5]The labor share is defined as $S^h = WH/Y = W/Y/H$, where W are real wages, Y is output, and H is hours worked.

distortions are at least as important as labor market distortions in recent recessions.

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.[6] 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.

There are several channels that can break the relationship between the labor share and the inverse of the markup. As discussed in Nekarda and Ramey (2013), for instance, CES production functions or the presence of fixed costs of production would imply that the labor share differs from the inverse of the markup. Another simple way of breaking this relationship is the cost channel of MP (see Ravenna and Walsh 2006). If firms need to borrow working capital to pay for variable inputs in advance of production, changes in interest rates would affect wage costs leading to a cost channel of MP. However, the inverse of the labor share and the price markup are not equal in these models because nominal interest rates have a direct effect on marginal costs. Hence, in the presence of working capital, there are two contrasting forces: pro-cyclical markups and counter-cyclical interest rates. Another important channel that breaks the relationship between markups and the labor share is search and matching frictions in the labor market (see Trigari 2006). In these models, wages are determined by a Nash bargaining process between firms and workers.

We show that it is possible to reproduce the observed response of the labor share to a monetary policy shock but only with a strong degree of nominal wage stickiness. If we allow the degree of wage stickiness to be stronger than price stickiness, in the presence of perfectly competitive labor markets, real wages will respond counter-cyclically to a monetary innovation and hence move the labor share in the right direction. This, however, comes to the cost of generating a counter-cyclical response of wages that is at odds with the evidence.

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.

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

[6] 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 procyclical.

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.[7]

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 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.

To this end, we explored various restrictions proposed in the literature. In particular, we considered: 1) timing restrictions (Cholesky), where we assume that the macroeconomic aggregates do not respond to the policy variable within the quarter; 2) 'reasonable' and quantitatively loose (sign) restrictions, where we assume that a monetary tightening depresses the price level and monetary base growth; and, 3) only for the US, instrumental variables restrictions, where we impose a correlation between the monetary policy shock in the VAR and a narrative monetary series counterpart based on FOMC minutes (see Romer and Romer (2004)) or between the VAR shock and the intra-day variation of the Federal Fund rate in a narrow window around the monetary policy action (see Gurkaynak et al. (2005), Gertler and Karadi (2015) and Miranda-Agrippino and Ricco (2017). For exposition purposes, we only report the results that we obtain with timing restriction identification. In section 2.2 we discuss briefly the findings of alternative identification schemes, whose results can be consulted in the Appendix.

More formally, we assume that the joint co-movements of our key macroeconomic vari-

[7] 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.

ables 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. y_t is a vector that contains the observable variables, which are the log of real GDP, the log of the GDP deflator, the log of an index of commodity prices, log of the CPI, the log of the labor share, short term interest rates, and M2 growth. 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 $E(\nu_t \nu_t') = I_n$. Our baseline strategy to retrieve the monetary policy 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 money growth. This implies that all the other variables do not react contemporaneously to changes in the interest rate. This implies also that the policy rate responds contemporaneously to all the macroeconomic shocks hitting prices, real variables and shares.[8] The sample spans used for each country VAR embrace the Great Moderation period. Since we are interested in the relationship between the labor share and monetary policy, we restrict the samples to periods where monetary policy was not constrained by the effective lower bound. 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. Lag selection is guided by the BIC criterion.[9] All the VARs presented in the paper were estimated using Bayesian methods with uninformative priors.

Figure 2 reports the responses of all the variables to a MP shock (tightening) normalized to a 1% increase in the short term interest rate. We report the median response from the posterior distribution as well as the 68% confidence set. All responses are expressed in percentage terms. First, we notice that the identified transmission reflects our priors about the dynamic transmission 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 (including the price puzzle). What is new is the response of the labor share. In every country it is positive and statistically significant. Empirically, an unexpected MP tightening increases the share of labor in total income. The increase in labor share also appears to be persistent and does not vanish within a few quarters with the possible exception of the 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, we observe that the median response of output after 10 quarters is almost -1% while the increase in the labor sharer reaches a peak of 1.4% at the same horizon. For the rest of the countries, instead, the labor share responses are about a half of the response of output.

2.1 Dissecting the labor share response to a monetary policy shock

A counter-cyclical response of the labor share conditional on monetary policy shocks can occur either because real wages are more counter-cyclical than labor productivity or because

[8]We checked whether ordering the labor share after the short term interest rate changes the results. It does not.

[9]We use 3 lags for Australia, 2 lags for US, UK and Canada, and one lag for the EA.

labor productivity is more pro-cyclical than real wages. The two scenarios have very different implications for the transmission mechanism of monetary policy and will prove to be crucial in evaluating the performance of business cycle theories as we show in the next section. Hence, here we focus on real wages and labor productivity. Furthermore, we look at output and hours separately to understand the determinants of the behavior of labor productivity.

We express the labor share (S^h) as the ratio between real hourly compensation (W^r), deflated using CPI, and labor productivity (LP) which is the ratio between real GDP, deflated using the GDP deflator, and a measure of hours adjusted for the relative price index:

$$S^h = \frac{W^n H}{Y^n} = \frac{W^n}{P^{CPI}} \frac{HP}{Y^n} \frac{P^{CPI}}{P} = \frac{W^r}{LP} \frac{P^{CPI}}{P}, \tag{1}$$

where W^n are nominal hourly wages, P^{CPI} is the CPI, H is hours, Y^n is nominal GDP and P the GDP deflator. In most of the theory models, instead, W^r and LP have, by construction, the same deflators and we need take this into account when comparing empirical and theoretical IRFs.

We use the same recursive identification approach as before and we run a VAR under two different information sets. The first experiment consists of the baseline VAR specification where we substitute the labor share with (the log of) real wages and labor productivity. In the second experiment, we substitute labor productivity with hours. For the US we consider the non-financial corporate sector counterparts of GDP, GDP deflator, CPI, and Labor Productivity.[10] As discussed by Gomme and Rupert (2004), in this sector there are no problems arising from the measurement of proprietors and rental income. The results using data for the aggregate economy show the same picture. For the rest of the countries, however, we do not have access to more granular data and consider the labor share components for the whole economy.

Figure 3 plots the individual impulse responses to a monetary tightening for each of the labor share components in the countries under analysis.[11] The first thing to notice from this figure is that the reduction in labor productivity is significant and persistent (second column). The magnitude of its decline is always larger than the sum of the effect on real wages and on the relative price. Hence, the labor share goes up. Regarding real wages, they fall for the US, Australia, and Canada while their response is not significant for the EA and the UK. The third column in the figure shows the response of the CPI relative to the GDP deflator (P^{CPI}/P). The relative price does not seem to follow any clear pattern in most countries with the exception of the US, where we observe a significant decline. The last two columns of the figure show what the driving force behind the reduction in labor productivity is that output declines more than hours.

The results from this decomposition show that the labor share falls because productivity falls more than real wages do, and the fall in productivity is driven by a larger fall in output than in hours worked. Real wages tend to fall on average, but the fall is not significant in some countries. That is, the results show that the response of real wages is at least non-positive.

We argued in the introduction that 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, in this section

[10]The ordering is then: Real GDP, GDP deflator, price of commodities, CPI, real wages, labor productivity (or hours), Federal Funds Rate and M2 growth. CPI in the non-financial corporate sector is constructed by from the data on real and nominal hourly wages in this sector.

[11]To make sure the decomposition is consistent with the dynamics of the original variables, we used the impulse responses of wages, productivity, output, and hours to construct the "implicit" impulse response of the labor share and labor productivity. In all cases, the "implicit" impulse responses matched the ones obtained directly when we introduce the labor share and labor productivity in the VAR. Also we used the response of the CPI and the GDP deflator to compute the "implicit" impulse responses of $\frac{P^{CPI}}{P}$ in the figures.

we have used them separately to uncover the components of the response in the labor share. It may be argued, then, that these results are compromised by reintroducing the composition bias. It is then important to analyze whether, given our results, the composition bias may invalidate our results.

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 above show that the response of aggregate labor productivity is negative and aggregate real wages respond *at least* non-positively (and negatively in most cases). From 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.[12]

As a second cross-check of this argument, we use data on composition bias corrected

[12]Note that this is not to say that, from our VAR results, we know the *value* 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.

measures of wages constructed by Haefke, Sonntag, and Van-Rens (2013) for the US. The results verify that the different measures of composition bias corrected wages are indeed more procyclical in response to a MP shock than the ones obtained using aggregate wages.[13]

2.2 Robustness

We carried out a number of experiments to check whether the empirical results are robust to alternative specifications. The key message here is that we find that the rise in the labor share 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. All proxies constructed generate similar impulse responses profiles.
- For the US, we studied different subsamples and a larger information set (where we included also the main components of aggregate expenditure). 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.
- We considered an alternative identification scheme based on sign restrictions to identify MP shocks (see Uhlig (2005)). We postulate that a monetary policy 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 4 plots the results for all the countries. While there are quantitative differences between 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.
- An alternative identification scheme that the VAR literature has proposed is 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 monetary policy shock in the structural VAR is identified as the predicted value in the population regression of the instrument on the reduced form VAR residuals. For this result to hold, the instrument needs to be valid; that is, it needs to be relevant (correlated with the unobserved monetary policy shock of the VAR) and exogenous (uncorrelated with the other shocks). This two stage regression

[13] Details available in section D of the Appendix.

allows to recover the the first column of the rotation matrix Ω, and thus to recover impulse responses and transmission mechanism. More formally, let m_t be the time series proxy for the unobserved monetary policy shock. Assume, without loss of generality, that the proxy is linked to the first shock as follows:

$$E(\nu_t m_t) = [\rho, 0, ..., 0]',$$
$$E(\Omega \nu_t m_t) = \Omega[\rho, 0, ..., 0]',$$
$$E(e_t m_t) = \rho[\Omega_{11}, \Omega'_{2:N,1}]'.$$

Assuming that the first reduced form shock is related to the observed proxy, we can partition the two sets of relationship and obtain:

$$E(e_{2,t} m_t) E(e_{1,t} m_t)^{-1} = \Omega_{11}^{-1} \Omega_{2:N,1},$$

where the second equation can be estimated using the sample analog since m_t is observable, e_t is observable conditional on Φ and Σ, and they are both stationary. This restriction coupled with the fact that $\Omega\Omega' = \Sigma$ gives rise to a set of equations that, up to a sign normalization, uniquely pin down the first column of the rotation matrix (see Mertens and Ravn (2013) for more details).

Our econometric approach works as follows. We draw the reduced-form VAR parameter values from the posterior distribution assuming a flat prior as in the previous sections. We then compute the implied reduced-form VAR residuals associated to this draw. We then isolate the variation in the reduced-form residual of the policy indicator that is attributable to the proxy. We then regress the remaining reduced-form VAR residuals on the fitted value of the first regression. This two stage regression allows us to recover the first column of the rotation matrix, and thus to recover impulse responses and transmission mechanism of the monetary policy surprises. We repeat this procedure 1,000 times and compute the 68% high probability density sets.

For the US we use five different proxies or instruments for monetary policy surprises.[14] The first instrument we use is the Romer and Romer (2004) narrative measure of monetary policy. The second instrument is the estimated monetary policy innovations in the Smets and Wouters (2007) model and spans the period 1959q1-2004q4. The third instrument is the "target" factor of Gürkaynak, Sack, and Swanson (2005), which measures surprise changes in the target Federal Funds Rate (quarterly sums of daily data, 1990Q1-2004Q4). The fourth instrument is the Gertler and Karadi (2015) measure of monetary policy surprises and spans the period 1991q1 - 2012q4. It is constructed as the surprise of the current Federal Funds Rate within a 30 minutes window of the FOMC announcement. The final instrument is constructed in Miranda-Agrippino (2016) as the component in market-based monetary surprises that is orthogonal to the central bank's forecasts about the current and future economic outlook (see also Miranda-Agrippino and Ricco (2017)).[15] Figure 5 reports the dynamic transmission of MP surprises to the US labor share and other macroeconomic aggregates. Our conclusions about the impact of MP shocks is unaffected: after a MP tightening, the labor share consistently increases. This result is, again, robust to the labor share measure used.

[14] We lack good instruments for other countries. For the Euro Area, Jardet and Monks (2014) constructed similar high frequency proxies starting from the 2002. Given the short sample we cannot use them here. For the UK Cloyne and Hürtgen (2016) developed a narrative measure while Miranda-Agrippino (2016) and Gerko and Rey (2017) obtain high frequency ones for UK and US. Although we experimented with these three measures for the UK, we were unable to recover innovations that resembled a MP shock in terms of the behavior of output and inflation. This may well be due to the fact that we focus on quarterly frequencies.

[15] Romer and Romer (2004) updated series are taken from Miranda-Agrippino and Rey (2015). We borrow the second and third instrument from the database of Stock and Watson (2012).

- 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.

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, real wages, and productivity?

Intuitively, it is well know that in standard NK models the labor share is equivalent to the inverse of the price markup (Galí, Gertler, and López-Salido (2007), Nekarda and Ramey (2013)). Rearranging the linear version of the New Keynesian Phillips curve as in Galí (2015), we have:

$$\theta_t = \frac{\pi_t - \beta \mathbb{E}_t \pi_{t+1}}{\lambda}, \tag{2}$$

where θ_t represents real marginal costs (inverse of the price markup), π_t is inflation, and λ 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, nominal wage rigidities, 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.

Several mechanisms commonly introduced in DSGE models can alter the relationship between the labor share and the markup. For instance, generalising the production function to the Constant Elasticity of Substitution (CES) family, as in Cantore et al. (2014), introduces a wedge between these two variables that depends on labor productivity and the elasticity of capital-labor substitution. 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 (2013)). This is usually implemented through the introduction of fixed costs in production. 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.[17]

Each of the channels described above could, in principle, help a New-Keynesian model match the impulse responses of interest. State of the art medium scale DSGE models widely

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

[17]Supplementary Appendix E provides a detailed discussion of each of these theoretical channels that can separate the labor share from the inverse of the markup.

used to study the quantitative consequences of monetary policy commonly contain a combination of these channels. Hence, we proceed by selecting families of DSGE models that include these ingredients plus the usual nominal and real rigidities present in standard NK models and compare them against the SVAR evidence from the previous section.

We start from the benchmark DSGE model developed in the seminal paper by CEE. This is a medium scale model that includes price and wage rigidities, variable capital utilization, habit formation in consumption, investment adjustment costs, and indexation in both prices and wages.[18] We label this model $\mathbb{NK}$. The second model extends $\mathbb{NK}$ by generalizing the production function to a CES as in Cantore et al. (2015). We label this model $\mathbb{NK\_CES}$. We then consider the role of working capital and hence the cost channel of monetary policy. We analyzed a version of the Christiano, Eichenbaum, and Evans (2005) model with working capital. However, because this channel is amplified when there are *firm networks* and the working capital channel extends to all inputs in production, we used the model by Phaneuf, Sims, and Victor (2018) which we label $\mathbb{NK\_WKN}$.[19] Finally, we consider a medium scale DSGE model with labor market frictions and alternate offer bargaining developed by Christiano, Eichenbaum, and Trabandt (2016) (labeled $\mathbb{NK\_SM}$). The last two models abstract from price and wage indexation usually included to match real wage and inflation inertia but that have been heavily criticised in the literature due to their lack of microfoundations. Moreover $\mathbb{NK\_SM}$ also abstracts from sticky wages and endogenously generates wage inertia.[20]

In order to ensure comparability, we assume the same Taylor type rule for monetary policy in each of this models:

$$r_t = \rho^r r_{t-1} + (1 - \rho^r)[\rho^\pi \pi_t + \rho^y y_t] + \varepsilon_t^r \tag{3}$$

where r_t is the interest rate set by the monetary authority, y_t is real output, π_t is inflation, ε^r is the monetary policy shock and variables are defined in deviations from their steady state values. ρ^r is the degree of interest rate smoothness while ρ^π and ρ^y represent the magnitude of the response of the interest rate to deviations of inflation and output respectively.

Moreover, we follow Christiano, Eichenbaum, and Trabandt (2016) and assume that, in each model, the monetary policy 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 Cholesky decomposition are comparable with the information set of the DSGE models.

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

3.1 Quantitative analysis: missing the link

Our objective here is to assess quantitatively the ability of the models discussed above to replicate the empirical responses of the labor share and its components to a monetary policy

[18]This model is essentially equivalent to the Smets and Wouters (2007) model abstracting from growth.

[19]Note that this model has more chances of producing the desired response of the labor share. With the Christiano, Eichenbaum, and Evans (2005) model augmented with working capital only, results obviously do not change our conclusions.

[20]For robustness, we also checked: all the models analyzed in Christiano, Eichenbaum, and Trabandt (2016), a model with *right to manage* as in Christoffel and Kuester (2008), and a sticky information model as in Mankiw and Reis (2007). Results are available upon request.

shock. The assessment is negative, as we do find a mismatch between the predictions of the VAR model and the predictions of New Keynesian models with various types of frictions. We arrive to this conclusion in three steps. We first ask whether there are combination of model frictions that can, at least a priori, replicate the response of the labor share and its components. Second, we single out the 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, which include both real and nominal quantities and the share of labor.[21] While the structural models do a decent job in matching the dynamic propagation of inflation and real quantities, they do not cope well in replicating the propagation of the labor share and its components.

3.1.1 Are New Keynesian models 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.[22] 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 the parameters of the models presented above. Table 2 shows the calibration of parameters held fixed while table 3 shows the bounds of the uniform distributions we attach to all the other parameters.[23] Basically, we allow for any economically meaningful value of the parameters, even for extreme values such as full price flexibility.[24] 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 4 summarizes the numerical analysis for each of the models. Numbers in the table represents the percentage of the prior support that matches all the restrictions imposed on the impulse response 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 add the same restriction, with opposite sign, to the real wage and labor

[21] 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. Only for the $\mathbb{NK}$ model, the persistence of the output and labor share responses are misrepresented to an extent in the SVAR, but they have similar signs and shapes. The results are presented in supplementary Appendix F.

[22] 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).

[23] For $\mathbb{NK}\_\mathbb{SM}$ model all the parameters not shown in table 2 are calibrated as in Christiano, Eichenbaum, and Trabandt (2016).

[24] The only exception to this is the share of intermediate goods in production in model $\mathbb{NK}\_\mathbb{WKN}$ which has a support up to 0.7. This is due to the fact that, beyond this value, the model does not have a stable solution.

productivity. We repeat the exercise by imposing the same restrictions from quarters five to eight.[25]

Looking at the second column we see that each model has a non-negligible portion of the parameter space able to reproduce the sign of the labor share from quarter two to five. Yet, for some models, this probability is quite low. This percentage increases 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. As discussed in section 2.4, the labor share can increase because real wages increase more than labor productivity or because labor productivity decreases more than real wages. Our empirical analysis suggests that the latter is the case. When we impose restrictions on wages and labor productivity, the probability of replicating the full array of sign patterns drops significantly, below 10% (15%) at short (medium) horizons (columns 3 and 5). 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.

In any case, the results show that there exist a non zero percentage of the parameter space that is able to match the sign of the impulse responses of the labor share and its components.

3.1.2 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/labor productivity) in response to a contractionary MP shock.

The literature has mainly focused on sensitivity exercises on calibrated parameters where the model objects of interest are computed by varying one parameter at a time. The MCF has clear advantages over calibration sensitivity exercises. First, unlike sensitivity calibration 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.[26]

Table 5 summarizes the results of this stage and 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 4.[27] Check marks in black identify parameters driving the restrictions over quarters two to five while red check marks identify the ones responsible over quarters five to eight. Parameters driving the restrictions over both horizons have a check mark in red and underlined. Few regularities emerge from this table. First of all, as expected, both price and wage stickiness are identified as crucial in all models except in $\mathbb{NK\_SM}$ where wage inertia is endogenized via labor market frictions generated by the alternate offer bargaining.

In particular, in frictionless labor market models, positive responses of the labor share to a MP shock arise typically when there is substantial wage rigidity and when wages are

[25]Note that these restrictions are quite favorable to the models 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.

[26]Details in supplementary Appendix G.

[27]Detailed results by model are presented in supplementary Appendix G.

less flexible than prices. The left panels of Figure 6 report the wage stickiness Cumulative Density Functions (CDF) in various models when the the labor share IRFs are positive for 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, the support of the blue CDF is between 0.2 and 1 with most of the probability mass located to the right of 0.8. This indicates that we need a lot of wage stickiness in order to generate a positive response of the labor share to a monetary policy shock.

Yet, this might not be enough. We also need prices to be more flexible than wages. This can be seen in the right panels of figure 6, 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 northeast corner of the plot, where both prices and wages are rigid, the response of the labor share to MP shocks tends to be negative (more red dots). As we move towards the northeast corner (more flexible prices), the likelihood of generating a positive response of the labor share to a monetary policy shock increases.

In sum, price and wage stickiness parameters are crucial for standard NK models without labor market rigidities to match the dynamics of the labor share. 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 statistically matter. The price markup parameter seems to be relevant in all models except $\mathbb{NK\_CES}$ 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 the price markup parameter. Also, the elasticity of substitution between capital and labor in the $\mathbb{NK\_CES}$ model is identified as an important parameter in driving the restriction in the first few quarters. The working capital fraction for labor inputs, the curvature of the investment adjustment costs function, and few parameters related to labor market frictions in $\mathbb{NK\_SM}$ are also key. Other relevant parameters identified are habits in consumption and the interest rate smoothing parameter in the Taylor rule. These do not always show up as crucial in all models. However, we adopt the conservative approach that, if any of the parameters has a significant Smirnov statistic in at least one of the models, it will be estimated in step 3 for all the models in which that parameter is present. The wage and price indexation parameters are also estimated as they appeared to be relevant in versions of the working capital model without firm networking.

In summary, all the channels we had identified as relevant for breaking the relationships between the labor share and the price markup show up in the MCF analysis. The relative importance of each of these frictions or mechanisms is crucial also for the transmission of shocks to variables other than the labor share and its components. This will be important for next section when we estimate the models to replicate the empirical IRFs.

3.1.3 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 we identify in the SVAR analysis. The final question is then: are any of these models 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. To do so, we estimate the model parameters using the Bayesian IRF matching approach advocated in Christiano, Trabandt, and Walentin (2010) and Christiano, Eichenbaum, and Trabandt (2016).

A few things are worth emphasising here. First, we extend our baseline Cholesky specification by adding the relative price of investment, capacity utilization, real consumption, and investment to the set of observables since we want to assess the ability of the model to reproduce the responses of important macro variables. Second, we do not enter real variables and price indices in levels as we do in section 2 because here we need to match the IRFs from stationary models. Moreover, the price level cannot be pinned down in the structural models and hence we have to match inflation instead. Third, for reasons of collinearity with the labor share, we cannot include hours, real wage, and labor productivity as in Altig et al. (2011) or Christiano, Trabandt, and Walentin (2010). Hence, the information set of the estimated SVAR for IRF matching is the following: Δ log of the relative price of investment, Δ log of Real GDP, Δ log of GDP deflator, Δ log of price of commodities, Δ log of CPI, capacity utilization, Δ log of consumption, Δ log of investment, log of the labor share, Federal Funds Rate, Δ M2. Data on capacity utilization and relative price of investment come from Altig et al. (2011). Since we are interested only in the dynamic transmission of monetary policy shocks, we do not specify a trending process for the real variables in the structural model, e.g. a permanent neutral technology shock. The latter generates co-integrating relationships among output, investment, and consumption, which can be accounted for in the SVAR by considering the (nominal) great ratios of consumption and and investment to output (as in Christiano, Trabandt, and Walentin (2010) and Altig et al. (2011)). As our model abstracts from permanent shocks, we are not constrained to impose any co-integration relationship and we treat real variables in growth rates (or level) without imposing any structure on their long run relationships. As monetary policy shocks are orthogonal to permanent technological shifts, including real variables in growth rates or using their nominal great ratios in the empirical model does not make a difference for the dynamic transmission of monetary policy shocks.[28] Finally, because the VAR contains a larger set of 11 variables, and hence parameters, we increase the sample period and use all the available data. Since some of the observables are not available for other countries, we restrict this analysis to the US economy for the sample period 1959Q2 to 2008Q4.[29] With this specification, we estimate a Bayesian SVAR with 2 lags and identify a MP shock following the same Cholesky recursive identification approach as before where the Federal Funds Rate is ordered just before money growth.[30]

We then estimate each DSGE model by choosing the values of the selected parameters that minimize a measure of the distance between the SVAR impulse responses and the DSGE model-based ones. As mentioned above, we use the Bayesian Impulse Responses matching approach developed in Christiano, Trabandt, and Walentin (2010) to impose economically meaningful priors on the structural parameters. 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. The structural models are estimated by matching the IRFs of the following variables: output, inflation, federal funds rates, consumption, investment, capacity utilization, and the labor share.

Each 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

[28]This is actually what we find using either SVAR specification. The results following exactly the same specification as in Christiano, Trabandt, and Walentin (2010) and Altig et al. (2011) are available upon request.

[29]It is important to note that we carried out several sensitivity tests with this specification of the VAR and, as before, the positive response of the labor share to a MP contraction remains robust.

[30]For details see Appendix H.

exercise are the same as in table 2.[31] Table 6 summarizes the priors used in estimation. We use a Beta distributions for probabilities, habits, interest rate smoothness, working capital fractions, intermediate shares in production, and matching function share of unemployment. A Gamma distribution is used for investment adjustment costs, capital utilization, price markup, Taylor rule responses to inflation and output, and hiring and search costs. Finally, a Normal distribution is used for the elasticity of capital-labor substitution.[32] All priors are centred around values chosen in line with the literature on Bayesian estimation of DSGE models.

In Table 7 we report the parameters estimates and 95% confidence intervals. A few regularities emerge from this table. First, most of the parameter estimates are similar across models. This is true for habits in consumption, price markup in steady state[33] and Taylor rule coefficients. Variable capital utilization changes substantially across models. Calvo price parameters show substantially more stickiness in models without the working capital channel. What appears to be a common pattern is the higher relative stickiness of wages compared to prices that the estimation produces across all models with Calvo sticky wages. Moreover, all except the $\mathbb{NK\_WKN}$ model present an implausibly high degree of wage stickiness in order to minimize the distance with the SVAR and the DSGE IRFs. It is also interesting to note that the fraction of working capital is estimated to be large in the $\mathbb{NK\_WKN}$ model and that, in the model with non competitive labor markets, we estimate a high replacement ratio of 60%.

Figure 7 plots the resulting IRFs. It reports, in grey, the 68% confidence bands and in black the median response from the SVAR while the IRFs from each estimated model are presented with different colors. All the models are able to reproduce fairly well the responses of real variables with the possible exception of investment in the first two quarters. Moreover, inflation persistence is underestimated in all models. What is striking, however, is the inability *all models* to reproduce the response of the labor share and capacity utilization, with the two clearly linked via the effect of MP shocks on labor productivity.[34] Only $\mathbb{NK\_CES}$ and $\mathbb{NK\_WKN}$ are able to produce a small positive response of the labor share after a couple of quarters following the MP tightening. However, the magnitude of the response and the profile of the IRF is far off the ones estimated in the SVAR.

The results in figure 7 are in line with the intuitive discussion of the mechanisms present in these DSGE models. Although these models, with the exception of $\mathbb{NK}$, are able to split the dynamics of the labor share and 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 in these models 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 variables cannot simultaneously match the dynamics of the labor share.[35] This fact sheds doubts on the transmission mechanism of MP in these models. Furthermore, in estimated DSGE models for policy analysis, it is common

[31]With the addition of the the inverse of the Frisch elasticity of labor supply and the wage markup that, where applicable, are now calibrated to value equal 1 and 1.2 respectively. Both parameters were not flagged up as relevant in the MCF analysis.

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

[33]Which determines the proportion of fixed costs in production.

[34]The associated responses of real wages and labor productivity in each model are not reported here but are in line with the evidence presented in section 2.1.

[35]To confirm this, we also estimated the DSGE models by matching *only* the labor share and Fed Funds rate. In this case, most models can obviously match the labor share, but the response of real variables and inflation is grossly out of line with the data. See figure I1 in the supplementary Appendix.

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 robust evidence presented in Section 2 at face value, then the transmission mechanism assumed with this practice is at odds with the data behavior which can have important consequences for the 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 monetary policy 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 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 monetary policy 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 its components (the real wage and labor productivity) 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 monetary policy 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 widely used models for monetary policy analysis to reproduce these important stylized 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 its components from models and analyze whether their response to monetary policy shocks is consistent with the one observed in the data. We analyze standard NK DSGE models and versions of this model augmented with a working capital channel, different production functions, and with search and matching frictions. 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 models that is qualitatively consistent with the responses obtained in the SVAR. We then select the subset of parameters that are important drivers of the response of the labor share and its components. Finally, we estimate these parameters in the different models using impulse response matching and compare the response of the labor share to an MP shock in the estimated DSGEs with that obtained in the SVAR.

We show that, in the models considered, 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. From steps one and two of our numerical analysis, we show that it is possible to obtain positive labor share responses to a monetary policy contraction when the degree of wage stickiness is higher than price stickiness. But this comes at the cost of obtaining counter-factual (countercyclical) responses of real wages. I.e., the labor share moves in the "right direction for the wrong reasons". When we estimate the models using impulse response matching, we show that the models do a reasonable job at matching the response of a set of real variables but they cannot match the response of the labor share. That is, models that can do well at reproducing the dynamic responses of real variables cannot simultaneously match the dynamics of the labor share in response to a monetary policy shock.

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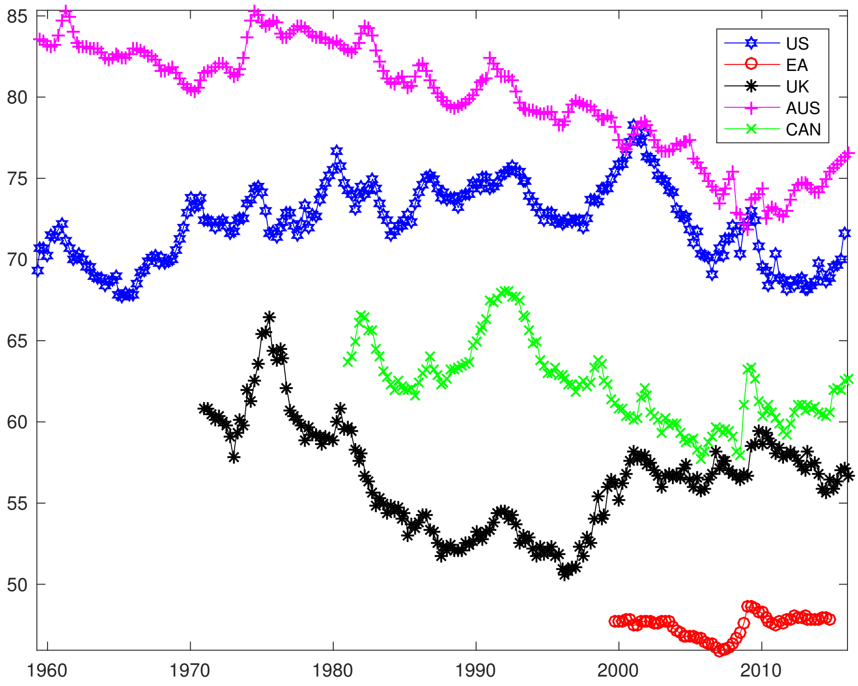

Figure 1: Cross Country Labor Share

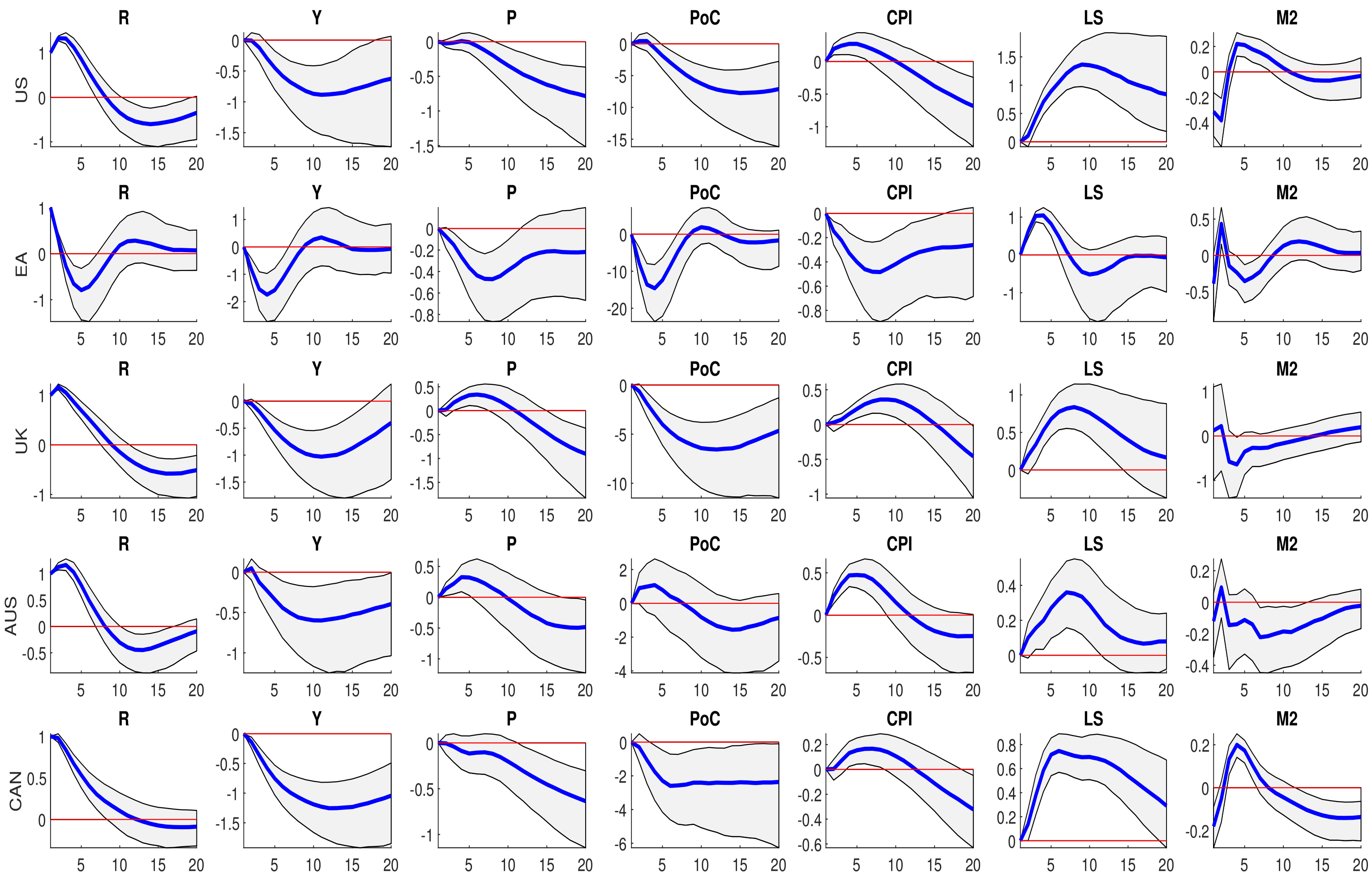

Figure 2: Impulse Response Function normalized to a 1% increase in the short term interest rate using **recursive Cholesky**.

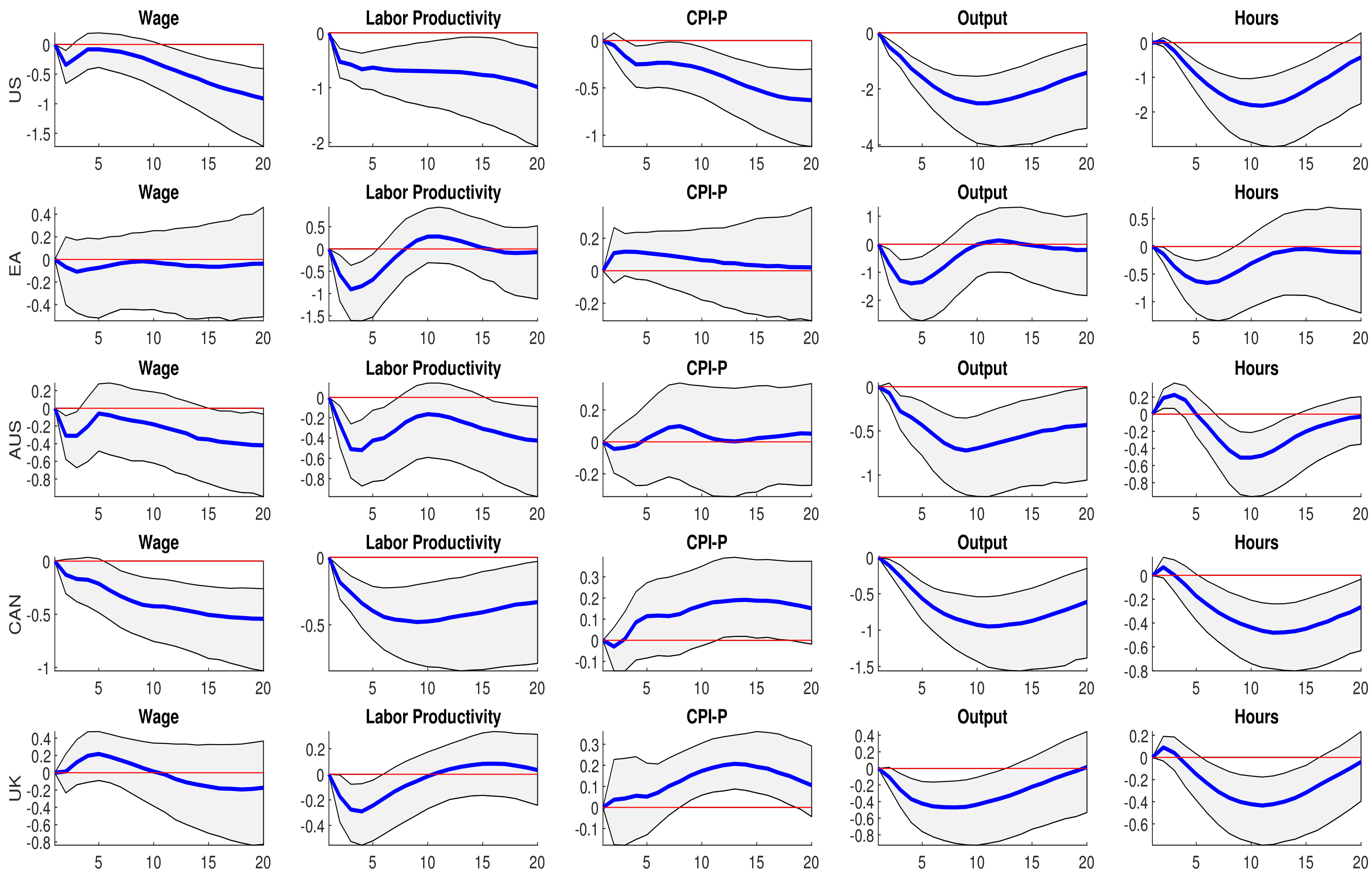

Figure 3: Impulse Responses of labor share components normalized to a 1% increase in the short term interest rate using recursive Cholesky.

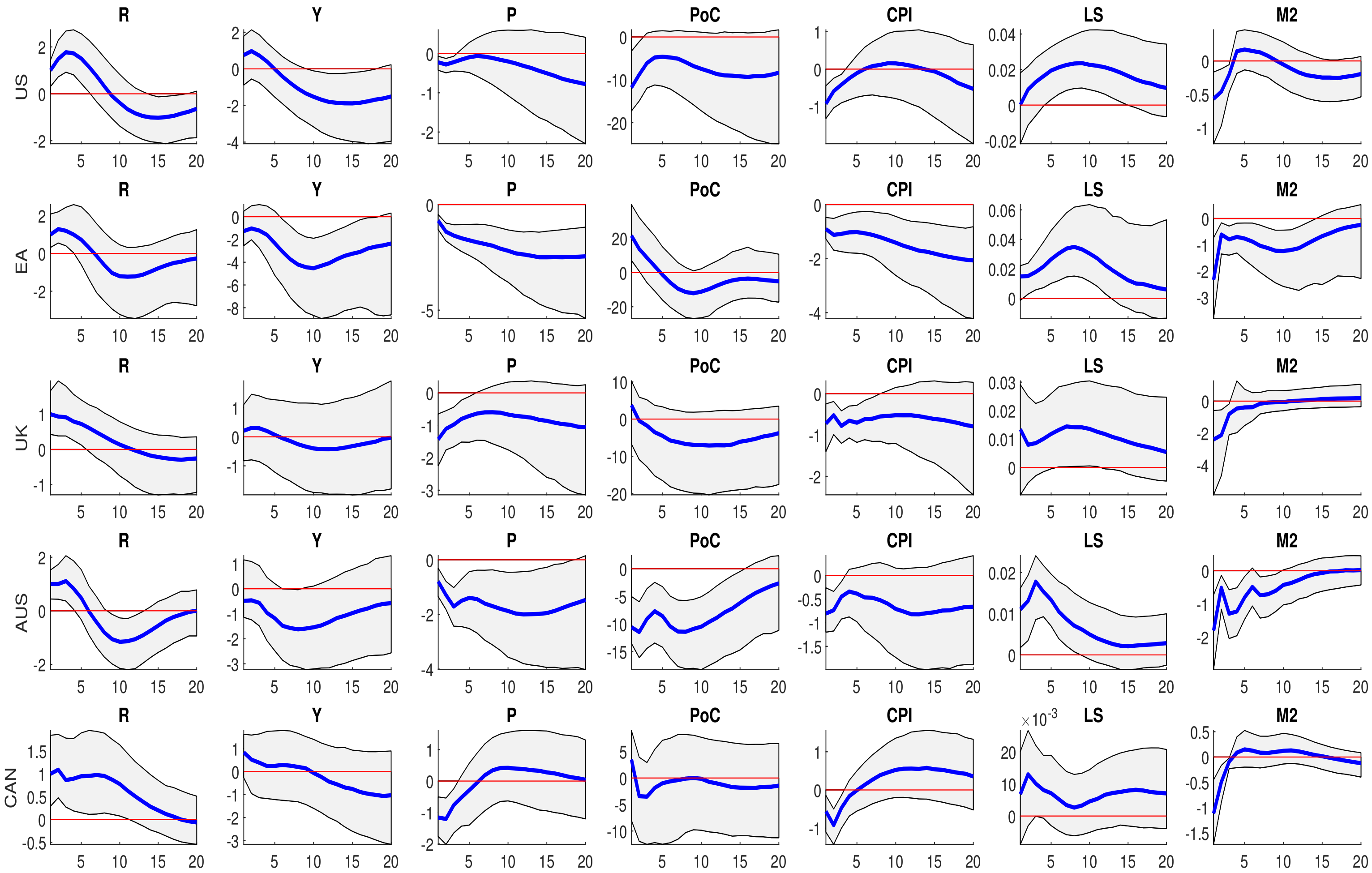

Figure 4: Impulse Response Functions normalized to a one percent increase in the short term nominal interest rate using an identification scheme based on **sign restrictions**.

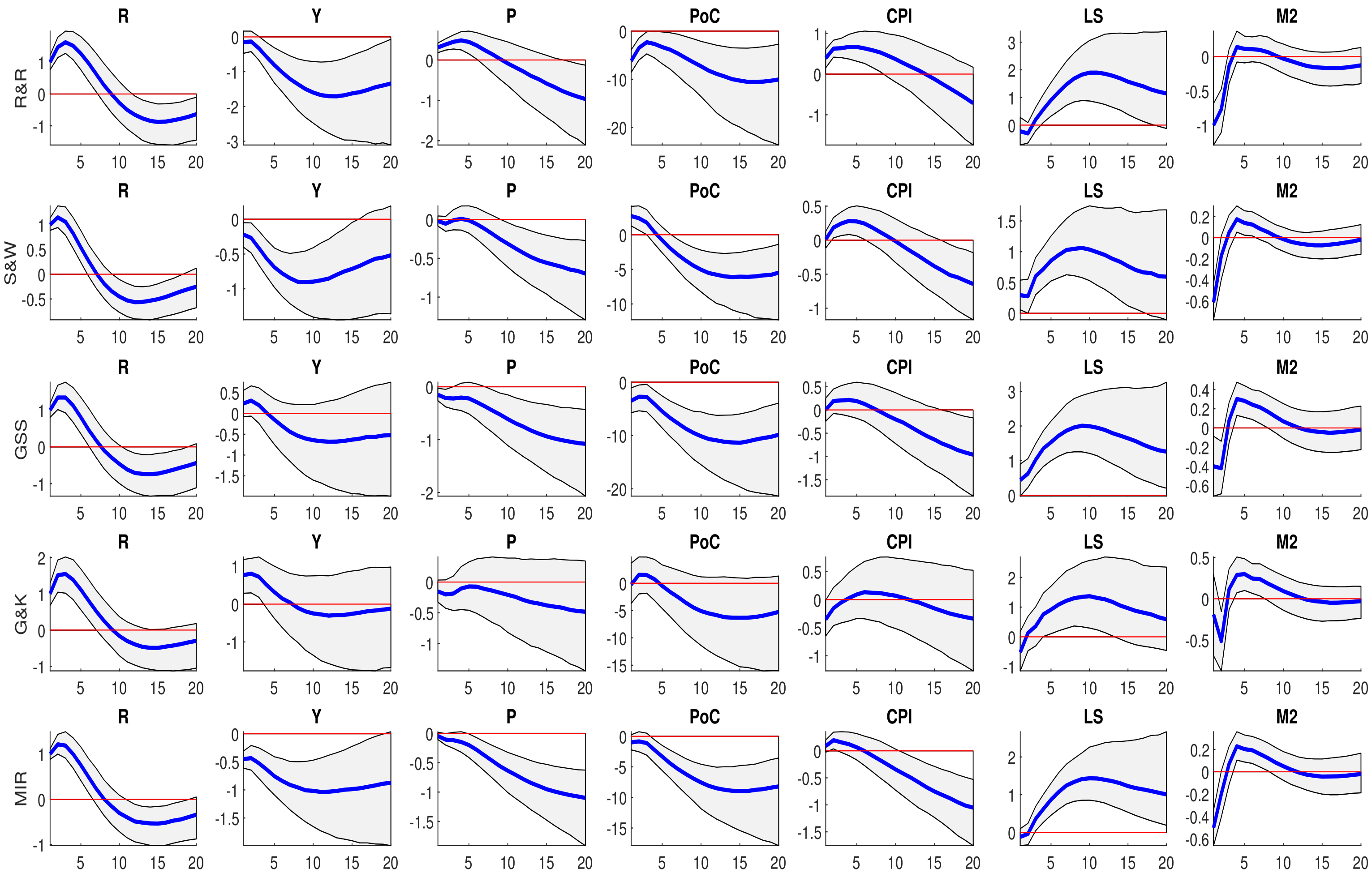

Figure 5: Impulse Response Functions normalized to a one percent increase in the short term nominal interest rate using an identification scheme based on the **Instrumental Variable VAR**. [$R\&R$]: Romer and Romer; [$S\&W$]: Smets and Wouters; [GSS]: Gürkaynak et al.; [$G\&K$]: Gertler and Karadi; [MIR]: Miranda-Agrippino.

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	NK	NK_CES	NK_WKN	NK_SM
Discount Factor	0.99	0.99	0.99	0.99
Capital depreciation	0.025	0.025	0.025	0.025
Steady State Hours	0.330	0.330	0.33	-
Unemployment rate	-	-	-	5.5%
Steady State Labor Share	0.670	0.670	0.670	0.670
Fixed cost in production	calibrated to ensure 0 profits in steady state			
Relative Risk Aversion	1	1	1	1

Table 2: Calibration of parameters held constant in PSA and MCF.

Description	NK	NK_CES	NK_WKN	NK_SM
Inverse of Frish Elasticity of Labor Supply	$U[1,10]$	-	$U[1,10]$	$U[1,10]$
Investment adjustment costs	$U[1,10]$			
Habits in Consumption	$U[0,1]$			
Variable Capital Utilization	$U[0,1]$			
Calvo price stickiness	$U[0,1]$			
Calvo wage stickiness	$U[0,1]$	$U[0,1]$	$U[0,1]$	-
price markup	$U[1,1.2]$			
wage markup	$U[1,1.2]$	$U[1,1.2]$	$U[1,1.2]$	-
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	$U[0,1]$	$U[0,1]$	-	-
Wage Indexation	$U[0,1]$	$U[0,1]$	-	-
K/L elasticity of substitution	-	$U[0.01,5]$	-	-
working capital fraction (labor)	-	-	$U[0,1]$	$U[0,1]$
Intermediate inputs share in production	-	-	$U[0,1]$	-
working capital fraction (capital)	-	-	$U[0,1]$	-
working capital fraction (intermediate inputs)	-	-	$U[0,0.7]$	-
technology diffusion	-	-	-	$U[0,1]$
prob. of barg. session determination	-	-	-	$U[0,1]$
replacement ratio	-	-	-	$U[0,1]$
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 3: Uniform Distribution bounds for PSA and MCF.

	Restrictions			
	2:5 quarters		5:8 quarters	
Model	ls (+)	ls (+); lp (-); w (-)	ls (+)	ls (+); lp (-); w (-)
NK	30.9%	1.7%	59.7%	13.9%
NK_CES	11.2%	0.7%	55.1%	4.6%
NK_WKN	26.5%	9.2%	54.4%	13.3%
NK_SM	6.2%	2.8%	46.0%	13.5%

Table 4: Results from prior sensitivity analysis. Percentage of the prior support that matches all the restrictions.

Description	NK	NK_CES	NK_WKN	NK_SM
Relative Risk Aversion				
Inverse of Frish Elasticity of Labor Supply				
Investment adjustment costs	$\color{red}\underline{\checkmark}$	$\color{red}\checkmark$	$\color{red}\checkmark$	$\color{red}\checkmark$
Habits in Consumption		$\color{red}\checkmark$	$\checkmark$	
Variable Capital Utilization				
Calvo price stickiness	$\color{red}\underline{\checkmark}$	$\color{red}\underline{\checkmark}$	$\color{red}\underline{\checkmark}$	
Calvo wage stickiness	$\checkmark$	$\color{red}\underline{\checkmark}$	$\color{red}\underline{\checkmark}$	
price markup	$\color{red}\underline{\checkmark}$		$\color{red}\underline{\checkmark}$	$\color{red}\underline{\checkmark}$
wage markup				
Interest rate smoothing	$\color{red}\checkmark$	$\color{red}\checkmark$	$\color{red}\underline{\checkmark}$	
Taylor rule response to inflation				
Taylor rule response to output				
Price Indexation				
Wage Indexation				
K/L elasticity of substitution		$\checkmark$		
working capital fraction (labor)			$\checkmark$	$\color{red}\underline{\checkmark}$
Intermediate inputs share in production			$\color{red}\underline{\checkmark}$	
working capital fraction (capital)				
working capital fraction (intermediate inputs)				
technology diffusion				
prob. of barg. session determination				
replacement ratio				$\color{red}\underline{\checkmark}$
hiring fixed cost relative to output %				
search cost relative to output %				
matching function share of unemployment				$\color{red}\underline{\checkmark}$
job survival rate				$\underline{\checkmark}$
vacancy filling rate				

Table 5: Parameters responsible for matching prior restrictions over quarters 2:5 (black checkmark), 5:8 (red checkmark) and 2:8 (red underlined checkmark).

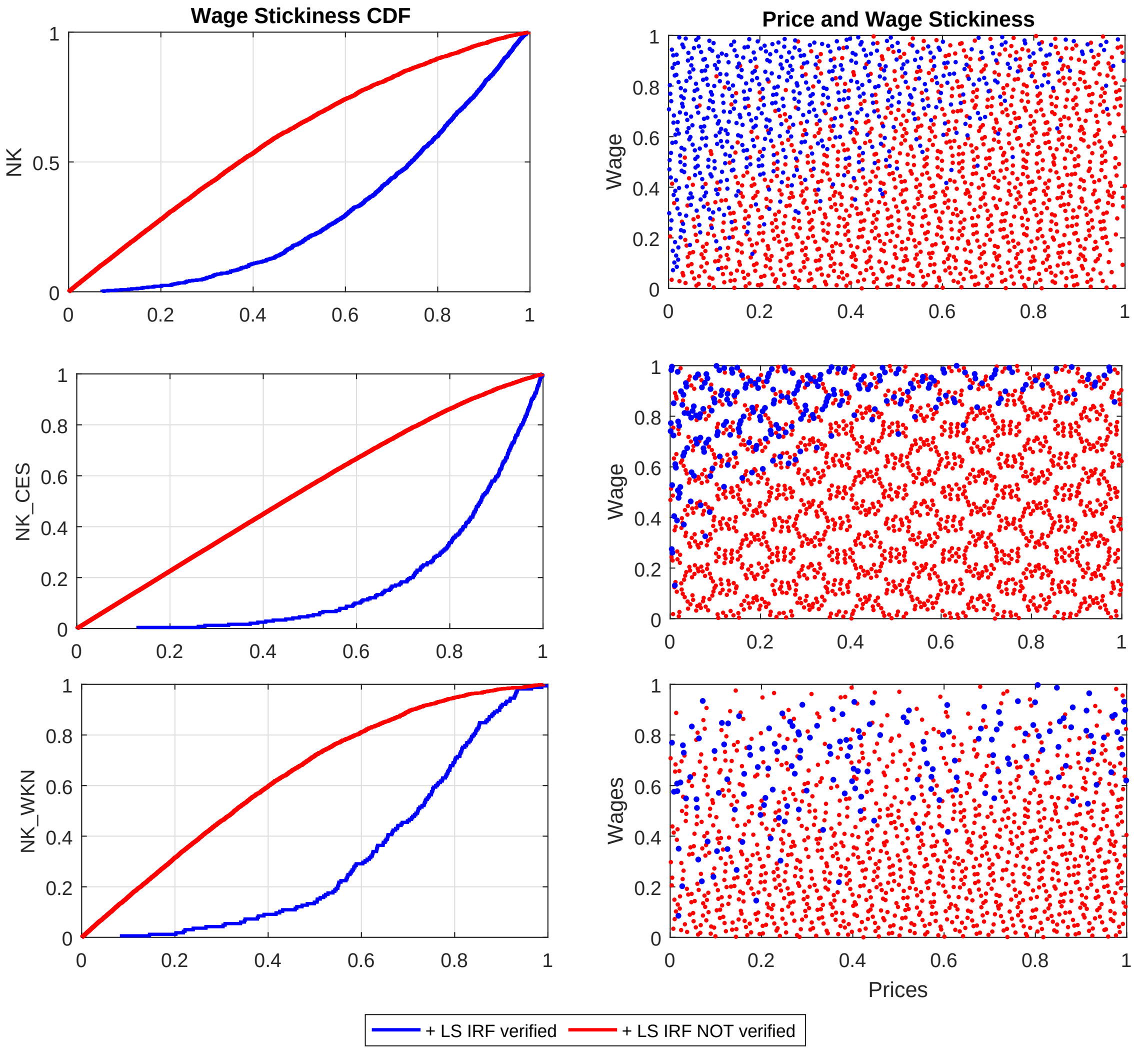

Figure 6: The wage stickiness Cumulative Density Function (CDF) on the left panels; in blue (red) the CDF that does (not) generate a positive response of the labor share. On the right panels, the combination of random draws from price and wage stickiness that do (not) verify the labor share IRF in blue (red). From top to bottom, the $\mathbb{NK}$ model, the $\mathbb{NK}$_$\mathbb{CES}$ model, and the $\mathbb{NK}$_$\mathbb{WKN}$ model.

Description	NK	NK_CES	NK_WKN	NK_SM
Investment adjustment costs		$\Gamma(8,2)$		
Habits in Consumption		$B(0.5,0.15)$		
Variable Capital Utilization		$\Gamma(0.5,0.3)$		
Calvo price stickiness		$B(0.66,0.1)$		
Calvo wage stickiness	$B(0.66,0.1)$	$B(0.66,0.1)$	$B(0.66,0.1)$	-
price markup		$\Gamma(1.2,0.05)$		
Interest rate smoothing		$B(0.7,0.15)$		
Taylor rule response to inflation		$\Gamma(1.7,0.15)$		
Taylor rule response to output		$\Gamma(0.1,0.05)$		
Price Indexation	$B(0.5,0.15)$	$B(0.5,0.15)$	-	-
Wage Indexation	$B(0.5,0.15)$	$B(0.5,0.15)$	-	-
K/L elasticity of substitution	-	$N(1,0.3)$	-	-
working capital fraction (labor)	-	-	$B(0.8,0.1)$	$B(0.8,0.1)$
Intermediate inputs share in production	-	-	$B(0.5,0.1)$	-
working capital fraction (capital)	-	-	$B(0.8,0.1)$	-
working capital fraction (intermediate inputs)	-	-	$B(0.8,0.1)$	-
technology diffusion	-	-	-	$B(0.5,0.2)$
prob. of barg. session determination	-	-	-	$\Gamma(0.5,0.4)$
replacement ratio	-	-	-	$B(0.4,0.1)$
hiring fixed cost relative to output %	-	-	-	$\Gamma(1,0.3)$
search cost relative to output %	-	-	-	$\Gamma(0.1,0.07)$
matching function share of unemployment	-	-	-	$B(0.5,0.1)$
job survival rate	-	-	-	$B(0.8,0.1)$
MP shock stdev		$\Gamma(0.74,0.05)$		

Table 6: Priors for Bayesian IRF Matching. Distributions: Γ *Gamma*, B *Beta*, N *Normal*.

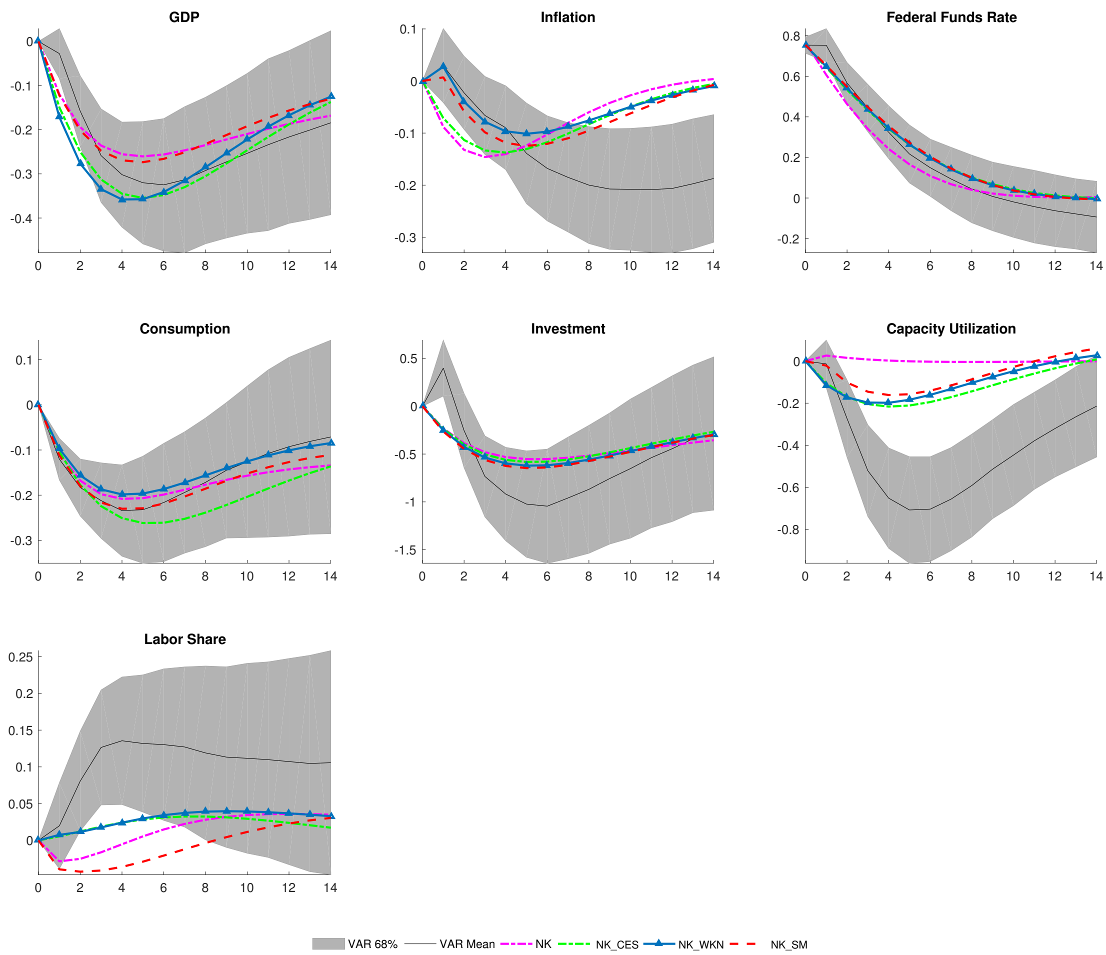

Figure 7: Bayesian Impulse Responses Matching - SVAR vs DSGE models

Description	NK	NK_CES	NK_WKN	NK_SM
Investment adjustment costs	9.22 (5.78-12.84)	12.3 (6.56-18.9)	10.1 (6.55-13.8)	9.93 (6.39-13.6)
Habits in Consumption	0.78 (0.70-0.86)	0.88 (0.83-0.93)	0.81 (0.75- 0.87)	0.81 (0.74-0.87)
Variable Capital Utilization	0.63 (0.13-1.25)	0.93 (0.15-1.81)	0.73 (0.10-1.49)	0.18 (0.02-0.40)
Calvo price stickiness	0.79 (0.70-0.88)	0.78 (0.66-0.89)	0.66 (0.55-0.77)	0.60 (0.50-0.71)
Calvo wage stickiness	0.89 (0.85-0.94)	0.93 (0.90-0.96)	0.77 (0.66-0.86)	-
price markup	1.27 (1.18-1.37)	1.20 (1.10-1.30)	1.25 (1.17-1.34)	1.28 (0.19-1.37)
Interest rate smoothing	0.83 (0.80-0.87)	0.87 (0.84-0.91)	0.86 (0.83-0.89)	0.87 (0.83-0.90)
Taylor rule response to inflation	1.73 (1.45-2.02)	1.70 (1.41-2.00)	1.76 (1.49-2.03)	1.74 (1.47-2.03)
Taylor rule response to output	0.10 (0.01-0.19)	0.07 (0.01-0.14)	0.03 (0.01-0.05)	0.04 (0.01-0.07)
Price Indexation	0.63 (0.35-0.90)	0.59 (0.28-0.87)	-	-
Wage Indexation	0.47 (0.19-0.75)	0.51 (0.22-0.80)	-	-
K/L elasticity of substitution	-	0.67 (0.03-1.23)	-	-
working capital fraction (labor)	-	-	0.71 (0.40-1.00)	0.82 (0.66-0.97)
Intermediate inps share in prod.	-	-	0.58 (0.44-0.70)	-
working capital fraction (capital)	-	-	0.81 (0.53-1.00)	-
working capital fraction (intermediates)	-	-	0.82 (0.56-1.00)	-
technology diffusion	-	-	-	0.50 (0.12-0.87)
prob. of barg. session determination	-	-	-	0.50 (0.002-1.27)
replacement ratio	-	-	-	0.60 (0.39-0.80)
hiring fixed cost relative to output %	-	-	-	1.07 (0.52-1.67)
search cost relative to output %	-	-	-	0.05 (0.001-0.14)
matching function share of unemp.	-	-	-	0.46 (0.27-0.65)
job survival rate	-	-	-	0.33 (0.19-0.48)
MP shock stdev	0.77 (0.71-0.83)	0.76 (0.70-0.81)	0.75 (0.69-0.81)	0.75 (0.70-0.81)

Table 7: Posterior mean of the parameters - Bayesian Impulse Response Matching as in Christiano, Trabandt, and Walentin (2010). 95% HDP interval in parenthesis.

Appendix

The Missing Link: Monetary Policy and The Labor Share

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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:

$$\textbf{Labor Share 2}: LS_t = 1 - \frac{CP_t^{gva} + NI_t^{gva} - Tax_t^{gva}}{NVA_t}.$$

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

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

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.

8. *Real wage*: Wages and Salaries from NIPA 1.12 deflated by CPI and divided by hours worked in the total economy from Valery Ramey dataset.

9. *Labor productivity*: Ratio between GDP and total hours from Ramey.

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. Money growth 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. We have also performed sensitivity analysis using GDP and deflator from the Non-Farm business sector and Non-Financial corporate sector and core CPI of all items excluding energy and we get similar results for the response of the labor share.[2] In section 2.1 we also use data on real wages and labor productivity. Real wages are computed by dividing Wages and Salaries from NIPA 1.12 (A4102C1Q027SBEA) by hours worked in the total economy from Ramey dataset and the CPI. Labor productivity is computed as the ratio between GDP and total hours from Ramey. Using real hourly compensation and hours worked in the non-farm business sector and/or the non-financial corporation sector does not affect the results. Data used in section 2.1 different from the ones above are the following. For GDP we use Nonfinancial Corporations Sector: Real Output (PRS88003043). GDP deflator is the Nonfinancial Corporations Sector: Implicit Price Deflator (PRS88003143). Instead of CPI here we use the implicit priced deflator constructed implicitly from Nonfinancial Corporations Sector: Real Hourly Compensation (PRS88003153) and Nominal Hourly Compensation (PRS88003103). Labor productivity is Nonfinancial Corporations Sector: Real Output Per Hour (PRS88003093) and Hours Worked in the Nonfinancial Corporations Sector (PRS88003033). Finally, data on Capacity utilization and relative price of investment are the same used in Altig et al. (2011).

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 wages we divide nominal compensation of employees by the CPI (from Australian Bureau of Statistics) and the measure of total hours worked constructed by Ohanian and Raffo (2012). Labor productivity is computed as the ratio between real GDP and total hours from Ohanian and Raffo (2012). 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 is constructed using money supply downloaded from datastream. In section 2.1 we constructed, from OECD national accounts, a proxy for real wages by dividing nominal compensation of employees by the CPI and the measure of total hours worked. Labor productivity is computed as the ratio between real GDP and total hours. Time span for the VAR analysis is 1985:Q1-2009:Q4 .

[2]Results available upon request.

A.3 Canada

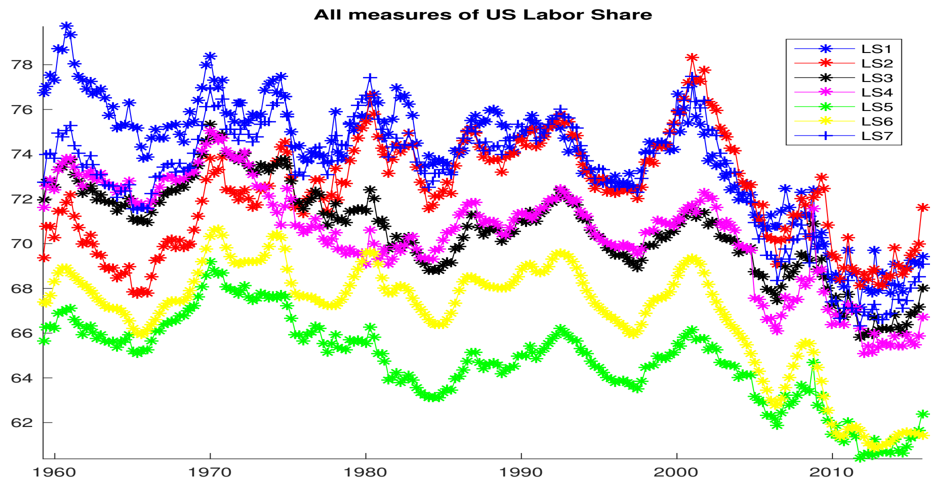
We consider quarterly data for the 1981:Q2-2016:Q1 period from Statistics Canada. We used two alternative measures. First, compensation of employees over total factor income (GDP corrected by taxes and subsidies) (CAN_LS1) . Second, we imputed mixed income in the same proportion as unambiguous labor and capital income, and added it to the previous measure of labor income (CAN_LS2) . For real wages we divide nominal compensation of employees by the CPI (from Statistics Canada) and the measure of total hours worked constructed by Ohanian and Raffo (2012). Labor productivity is computed as the ratio between real GDP and total hours from Ohanian and Raffo (2012). 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 is constructed using money supply downloaded from datastream.In section 2.1 we constructed, from OECD national accounts, a proxy for real wages by dividing nominal compensation of employees by the CPI and the measure of total hours worked constructed by Ohanian and Raffo (2012). Labor productivity is computed as the ratio between real GDP and total hours from Ohanian and Raffo (2012). Time span for the VAR analysis is 1985:Q1-2011:Q1.

A.4 UK

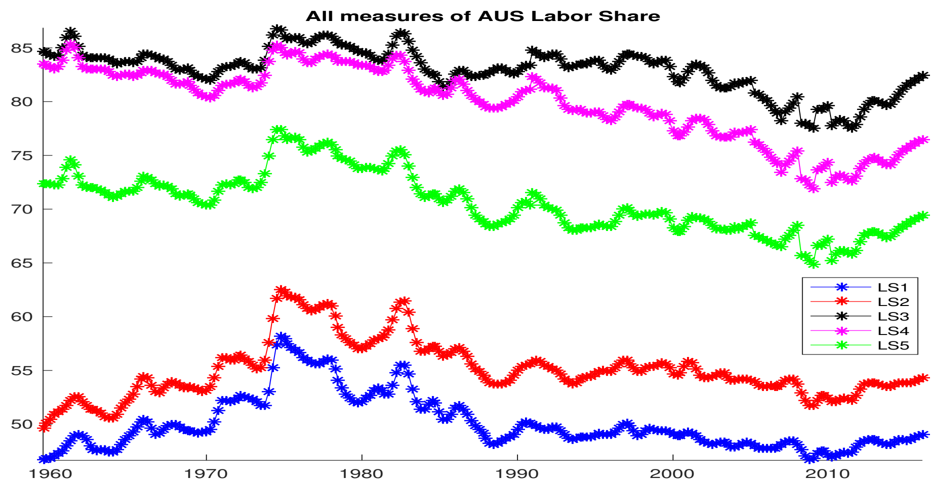
Quarterly data for the 1971:Q1-2016:Q1 period from the Office for National Statistics (ONS). We used one measure of the labor share: compensation of employees (DTWM) over gross value added at factor costs (CGCB) (UK_LS). For real wages we divide nominal compensation of employees by the CPI (from ONS) and the measure of total hours worked constructed by Ohanian and Raffo (2012). Labor productivity is computed as the ratio between real GDP and total hours from Ohanian and Raffo (2012). 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 is constructed using money supply downloaded from datastream (UKCMS2..B). In section 2.1 we constructed a proxy for real wages by dividing nominal compensation of employees by the CPI and the measure of total hours worked constructed by Ohanian and Raffo (2012). Labor productivity is computed as the ratio between real GDP and total hours from Ohanian and Raffo (2012). Time span for the VAR analysis is 1986:Q1-2008:Q1.

A.5 EA

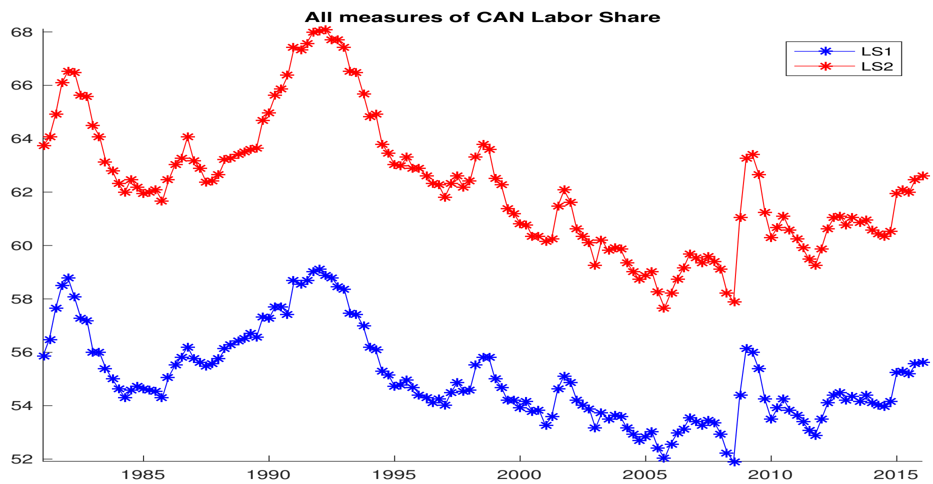
We take most of the data from the AWM database, where we use the following variables, real GDP and the GDP deflator, HICP excluding energy (seasonally adjusted) and the Short-term interest. The price of commodity index is the same used for the US. Money growth is taken from the IMF database on FRED (MYAGM2EZQ196N). 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 divided by the CPI (both from OECD Quarterly National Accounts) and the measure of total employment from the New Area Wide Model Database. For labor productivity we take the ratio between real GDP and total employment from the New Area Wide Model Database. In section 2.1 we also use as a proxy for real wages nominal compensation of employees from the OECD divided by HICP excluding energy and the measure of total employment from AWM. For labor productivity we take the ratio between real GDP and total employment from AWM. Time span of the VAR analysis is 1999Q1 to 2011Q3.



(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 D1.

Country	Info set	Sample	Identification	Reference	Positive Response of LS
US	Baseline	84-07	Cholesky	Figure D1	All Proxies
	Extended		Cholesky	Figure D2	All Proxies
	Baseline		Signs	Figure D7	All Proxies
	Baseline		Instruments	Figures D10-D15	All Proxies
	Baseline	65-07	Cholesky	Figure D4	All Proxies
	Baseline	65-95	Cholesky	Figure D3	All Proxies
EA	Baseline	99-11	Cholesky	Figure 2	Yes
	Baseline		Signs	Figure 4	Yes
UK	Baseline	86-08	Cholesky	Figure 2	Yes
	Baseline		Signs	Figure 4	Yes
CAN	Baseline	85-11	Cholesky	Figure D6	All Proxies
	Baseline		Signs	Figure D9	All Proxies
AUS	Baseline	85-09	Cholesky	Figure D5	All Proxies
	Baseline		Signs	Figure D8	All Proxies

Table D1: Summary of the robustness exercises with the VAR specification. Baseline = log of real GDP, the log of the GDP deflator, the log of an index of commodity prices, log of the CPI, the log of the labor share, short term interest rates, and M2 growth. Extended = Baseline and real consumption and investment.

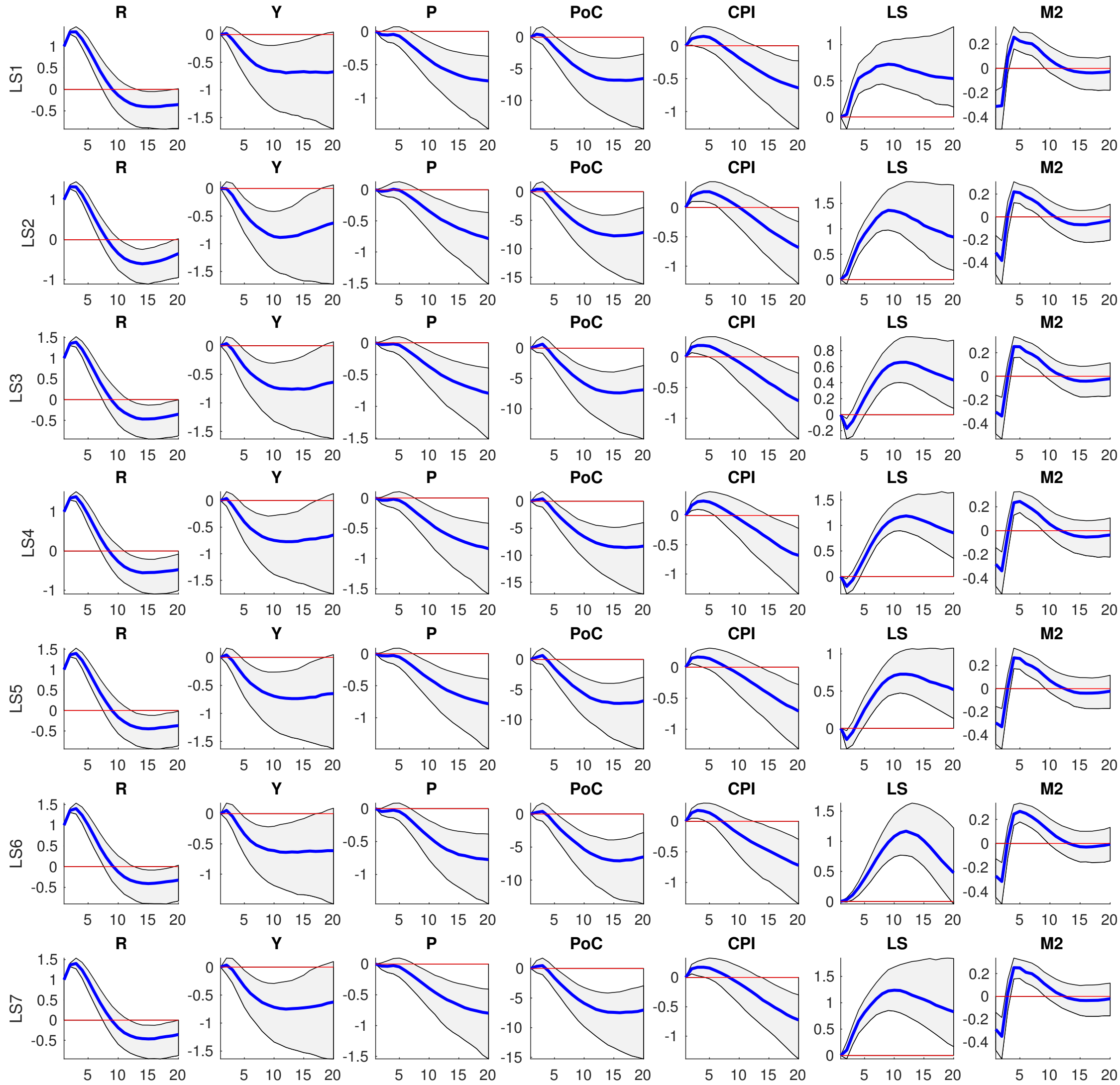


Figure D1: Impulse Response Function normalized to a 1% increase in the short term interest rate using recursive Cholesky. All Labor Share proxies US. 1984Q1-2007Q4

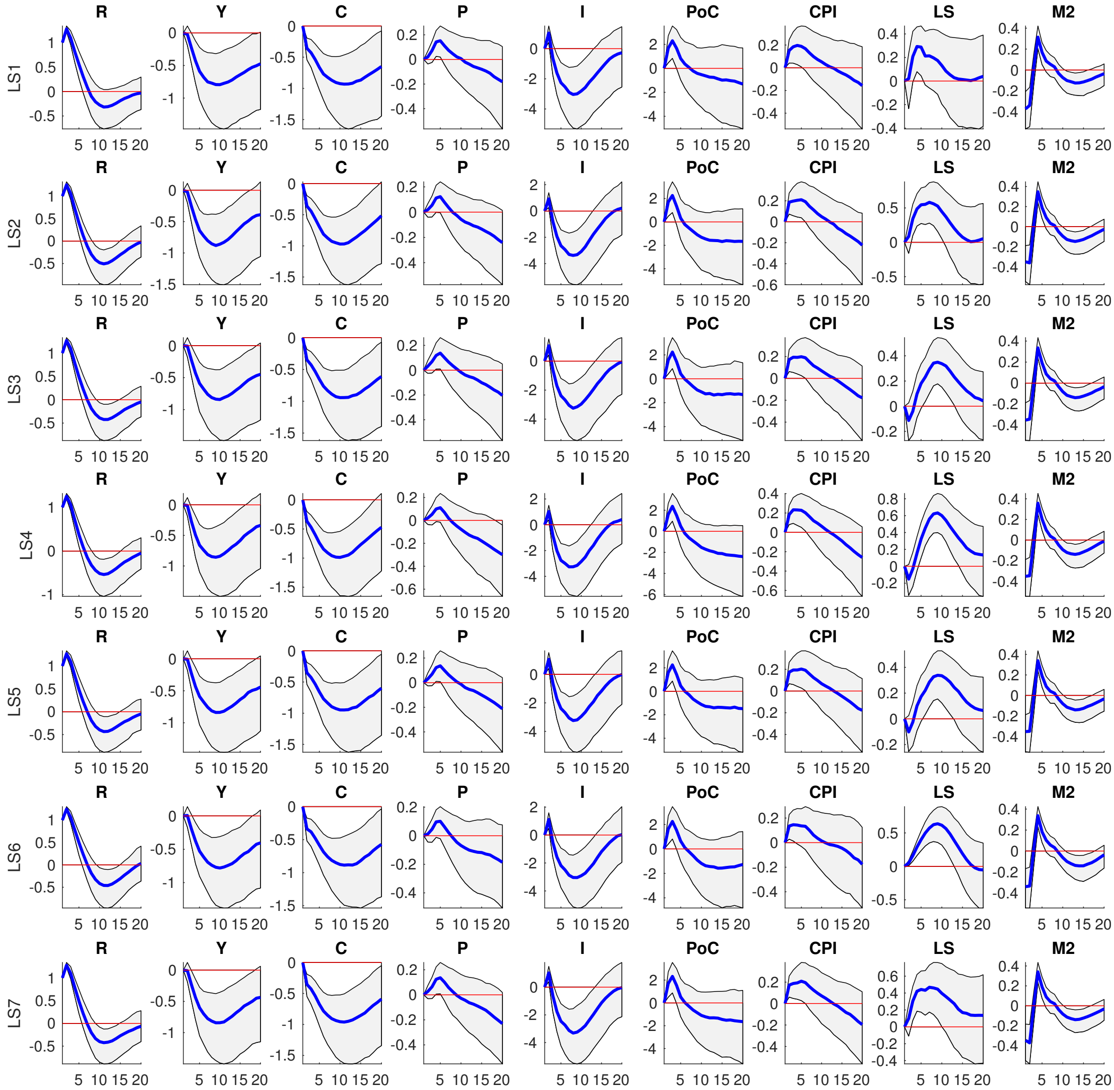


Figure D2: Impulse Response Function normalized to a 1% increase in the short term interest rate using recursive Cholesky and Extended Information Set (including real consumption and investment). All Labor Share proxies US. 1984Q1-2007Q4.

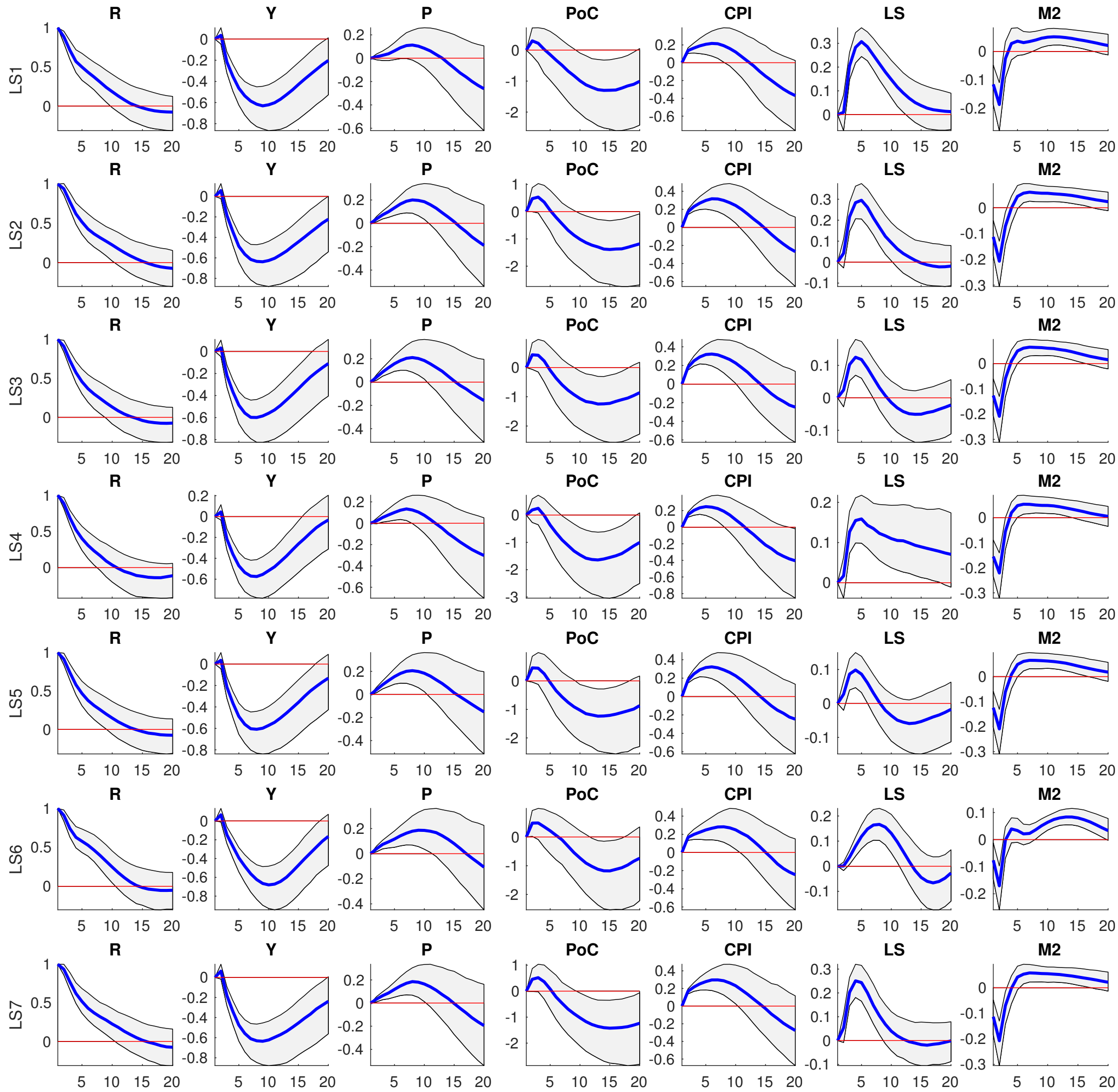


Figure D3: Impulse Response Function normalized to a 1% increase in the short term interest rate using recursive Cholesky. Baseline information set. All Labor Share proxies US. 1965Q3-1995Q3

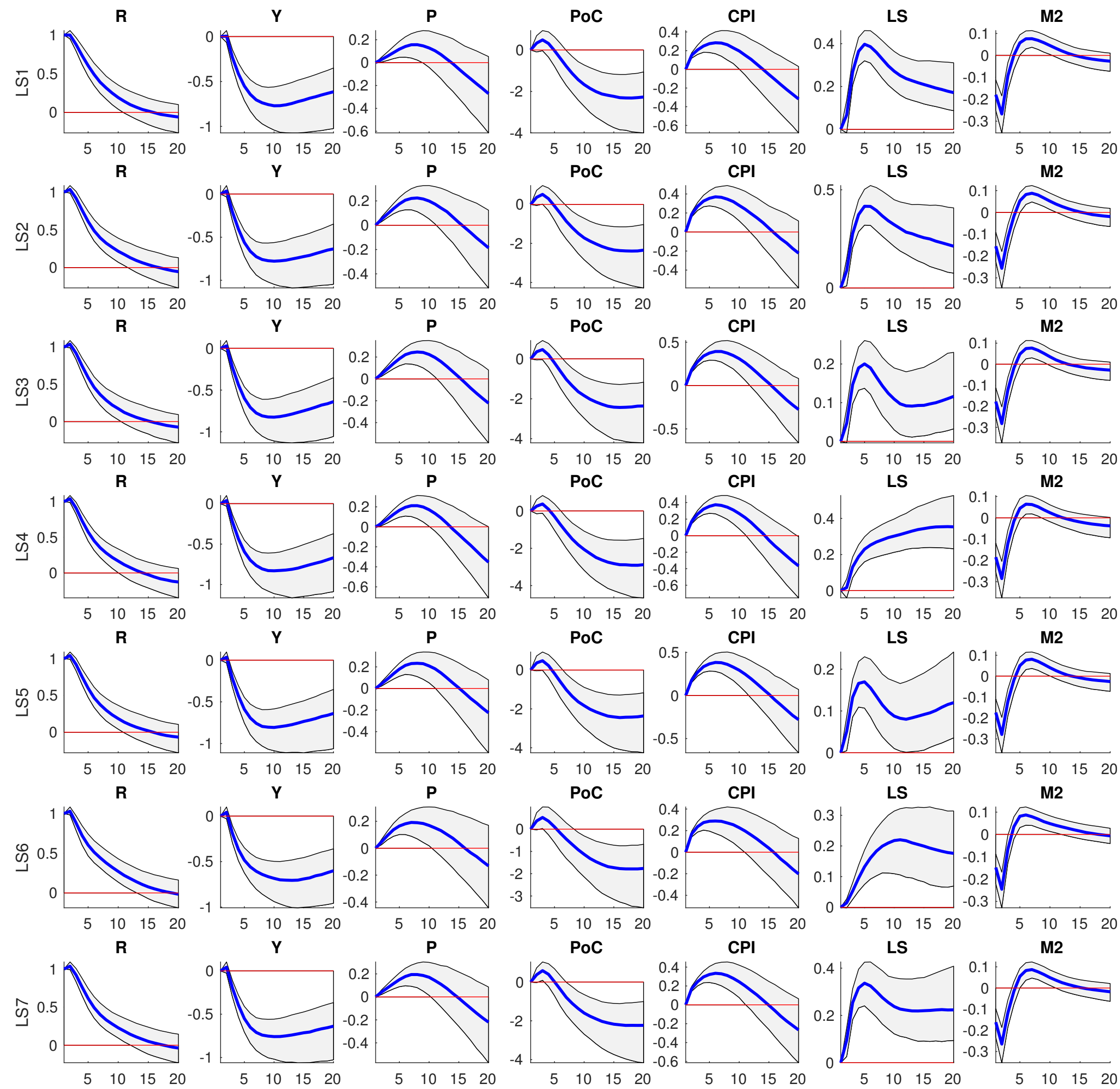


Figure D4: Impulse Response Function normalized to a 1% increase in the short term interest rate using recursive Cholesky. Baseline information set. All Labor Share proxies US. 1965Q3-2007Q4

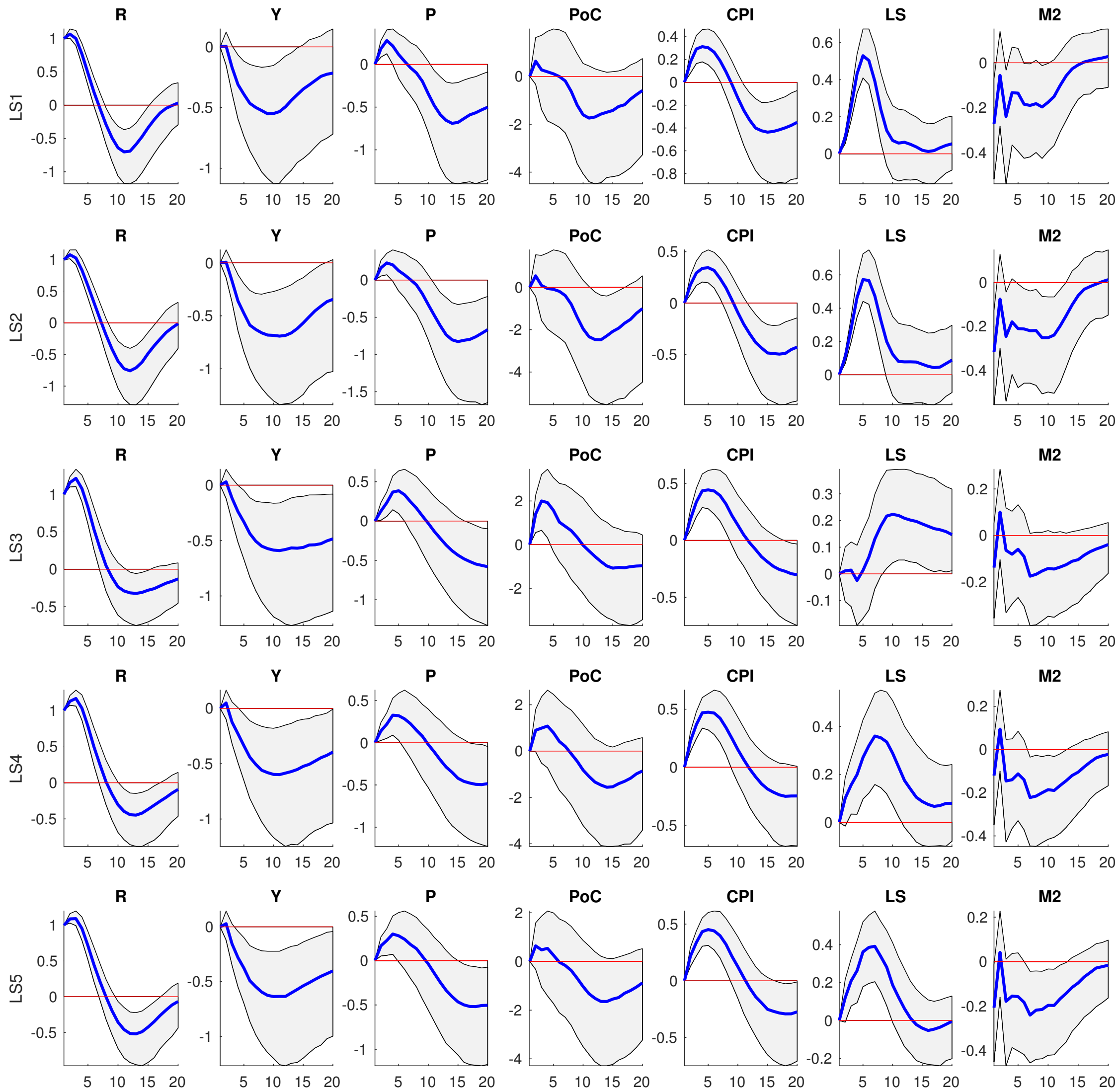


Figure D5: Impulse Response Function normalized to a 1% increase in the short term interest rate using recursive Cholesky. All Labor Share proxies Australia.

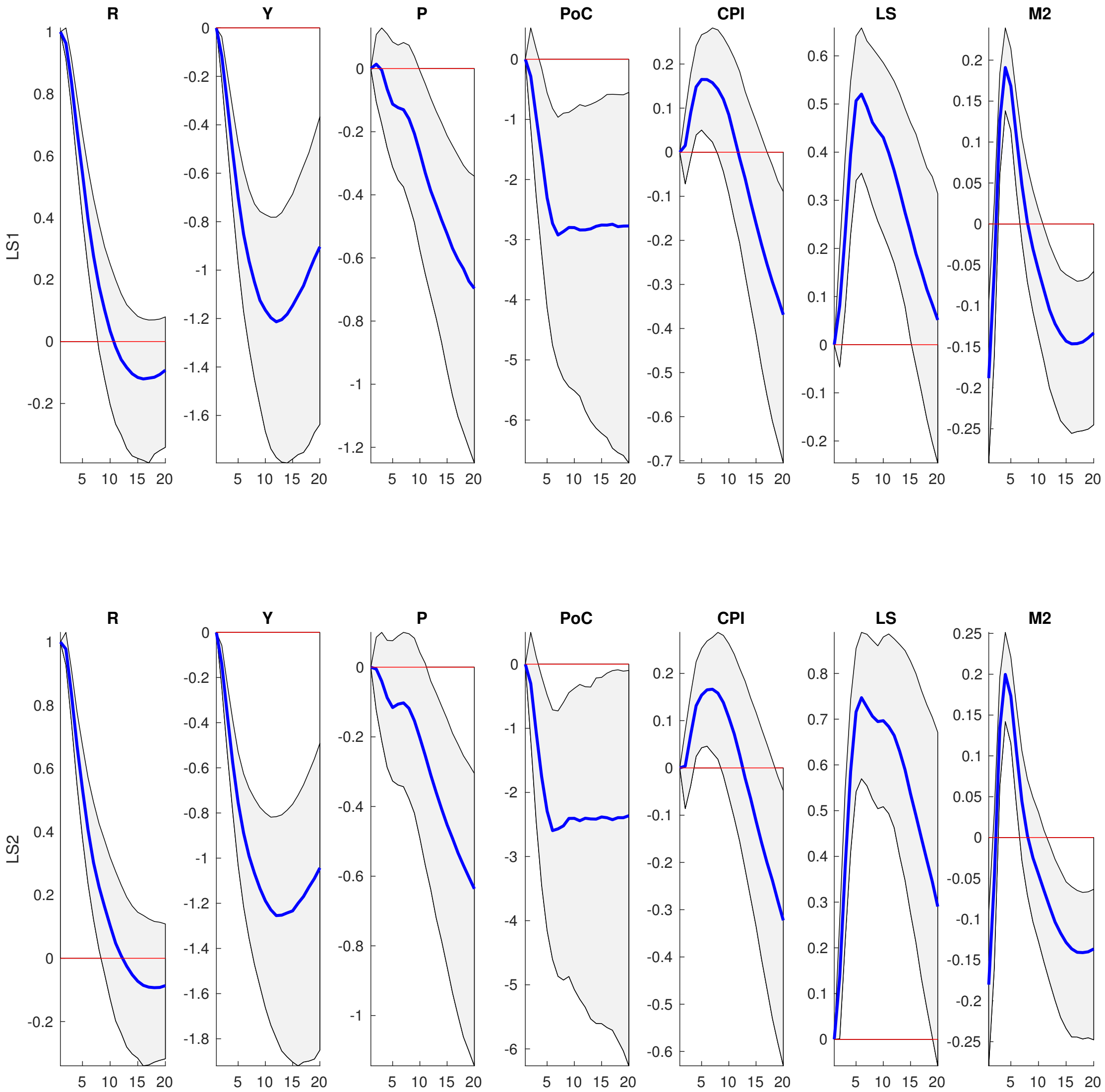


Figure D6: Impulse Response Function normalized to a 1% increase in the short term interest rate using recursive Cholesky. All Labor Share proxies Canada.

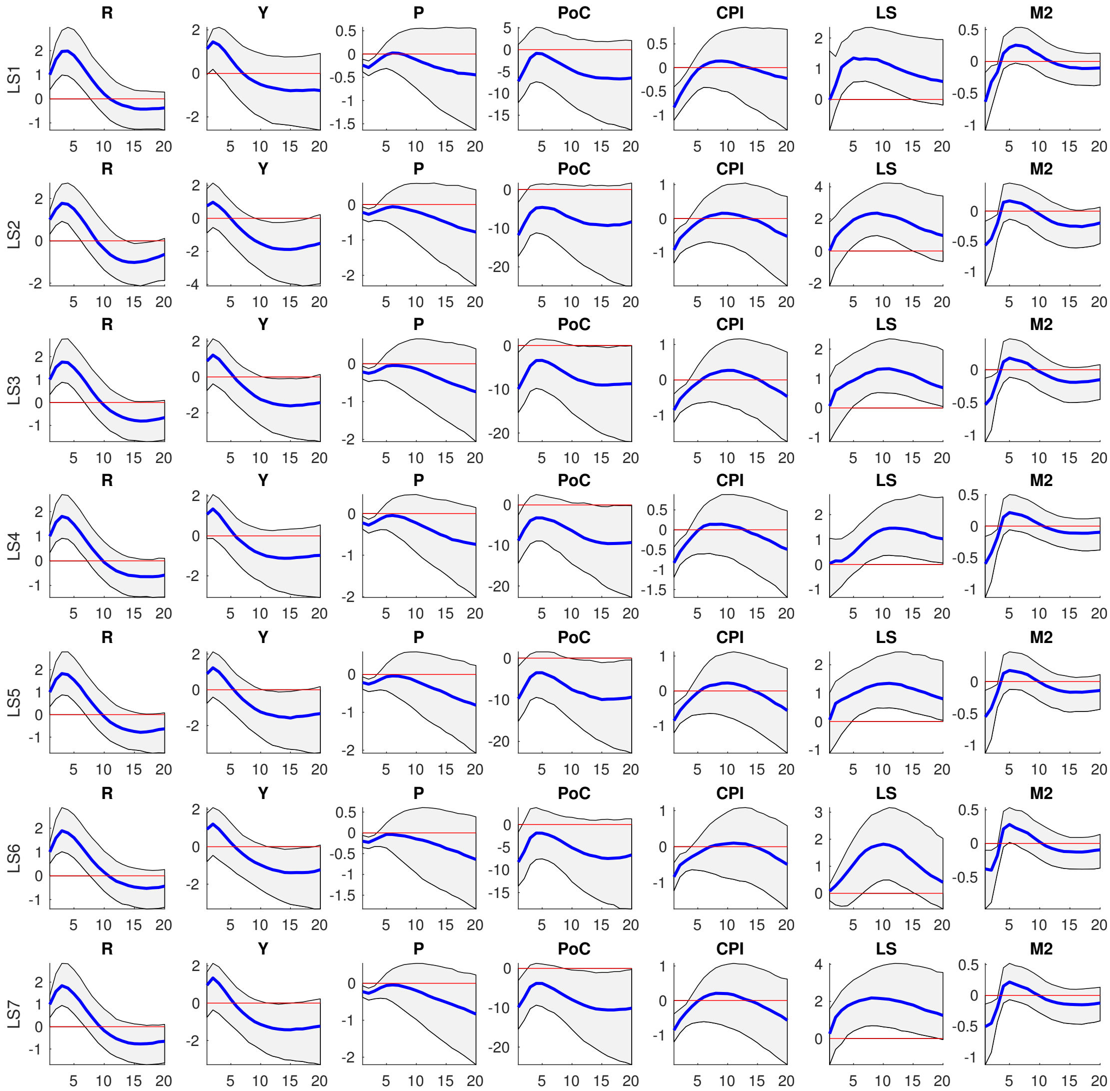


Figure D7: Impulse Response Functions normalized to a one percent increase in the short term nominal interest rate using an identification scheme based on sign restrictions. All Labor Share proxies US.

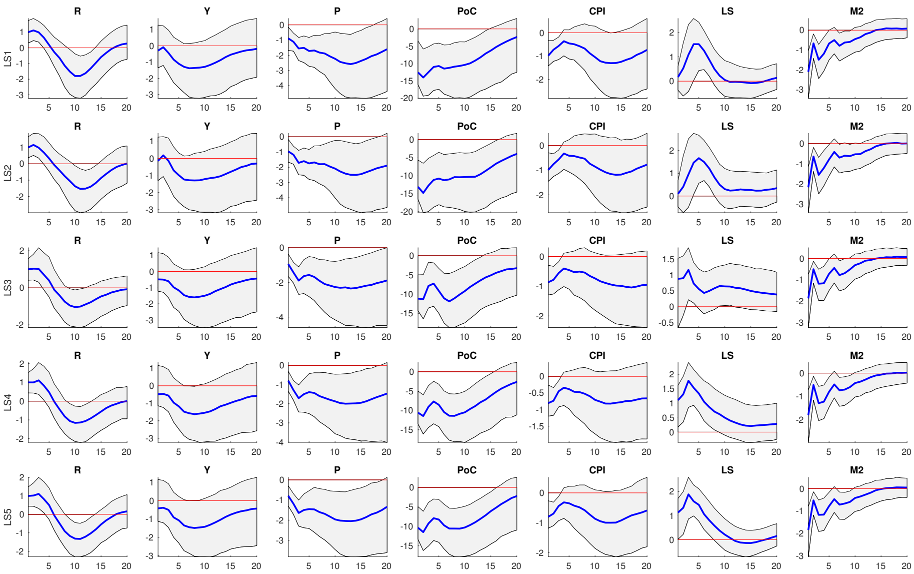


Figure D8: Impulse Response Functions normalized to a one percent increase in the short term nominal interest rate using an identification scheme based on sign restrictions. All Labor Share proxies Australia.

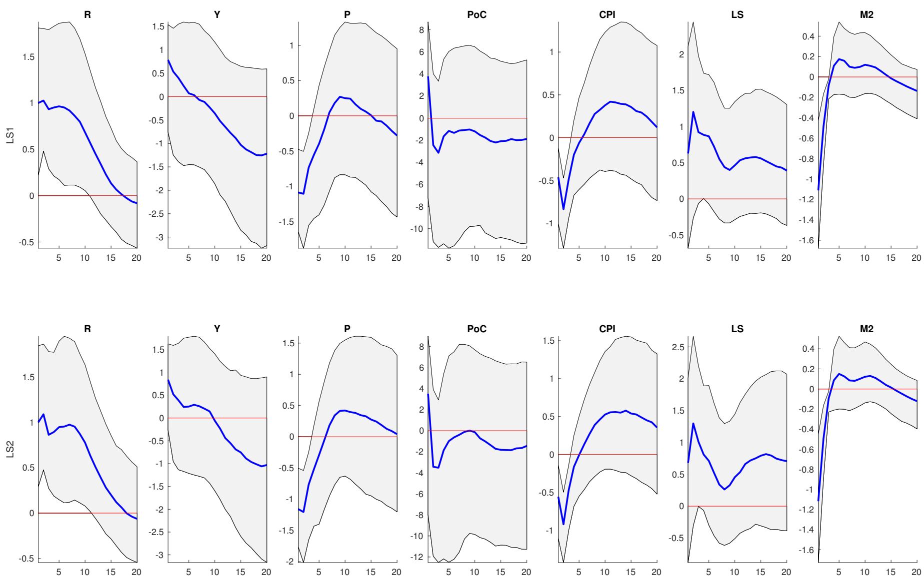


Figure D9: Impulse Response Functions normalized to a one percent increase in the short term nominal interest rate using an identification scheme based on sign restrictions. All Labor Share proxies Canada.

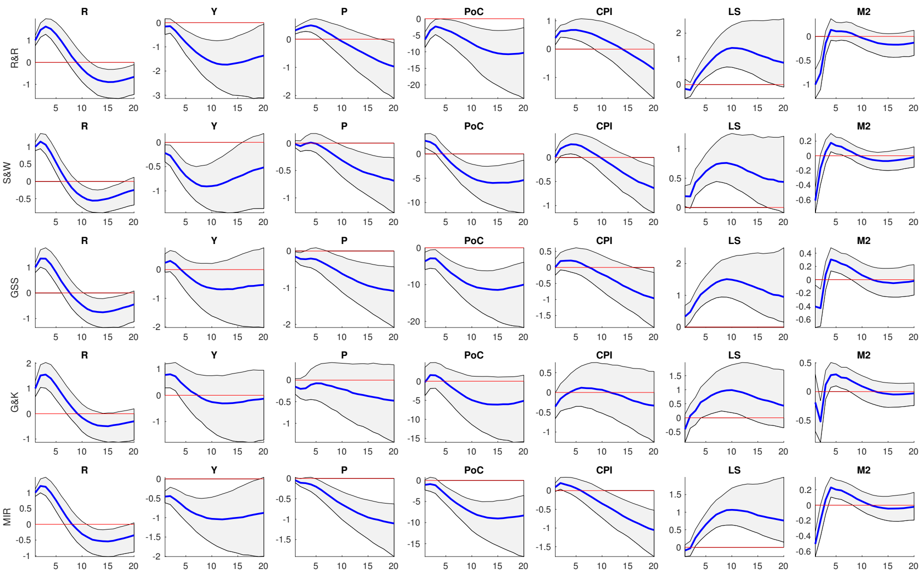


Figure D10: Impulse Response Functions normalized to a one percent increase in the short term nominal interest rate using an identification scheme based on the Instrumental Variable VAR. Labor Share proxy LS1.

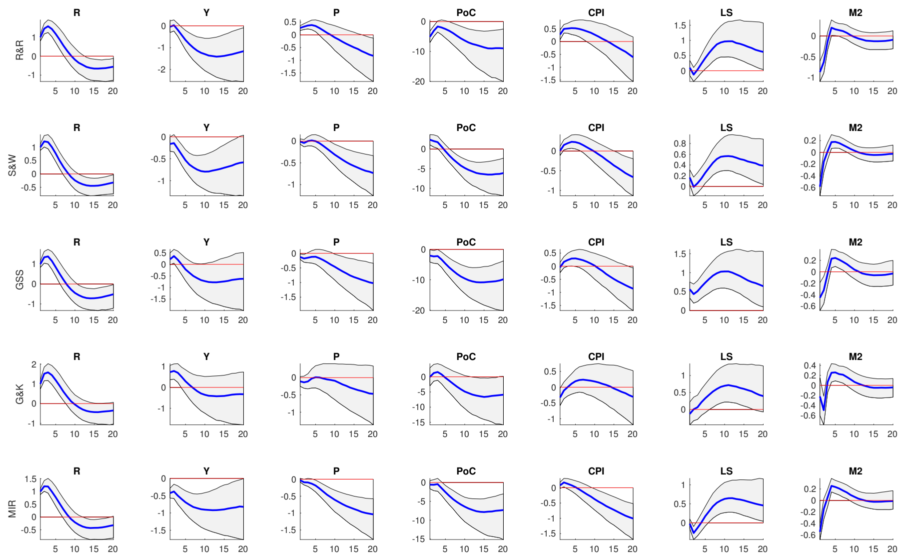


Figure D11: Impulse Response Functions normalized to a one percent increase in the short term nominal interest rate using an identification scheme based on the Instrumental Variable VAR. Labor Share proxy LS3.

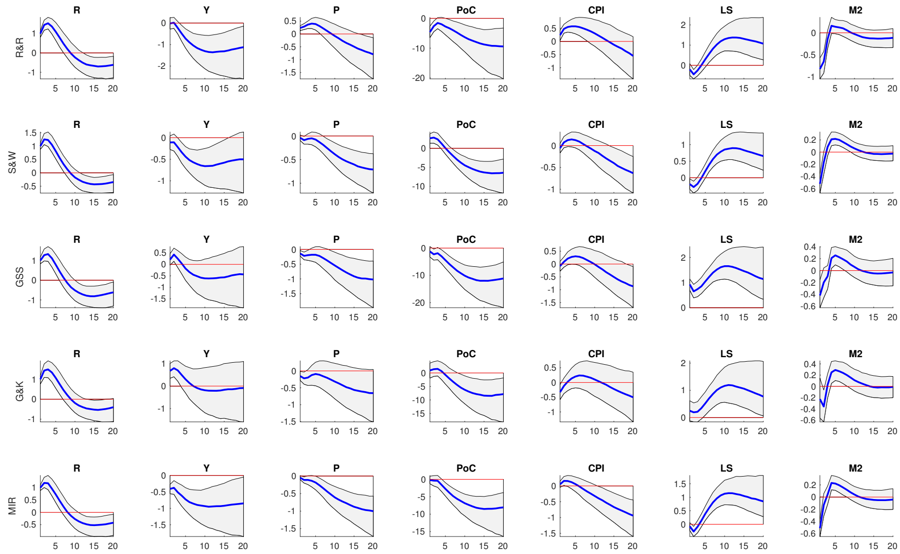


Figure D12: Impulse Response Functions normalized to a one percent increase in the short term nominal interest rate using an identification scheme based on the Instrumental Variable VAR. Labor Share proxy LS4.

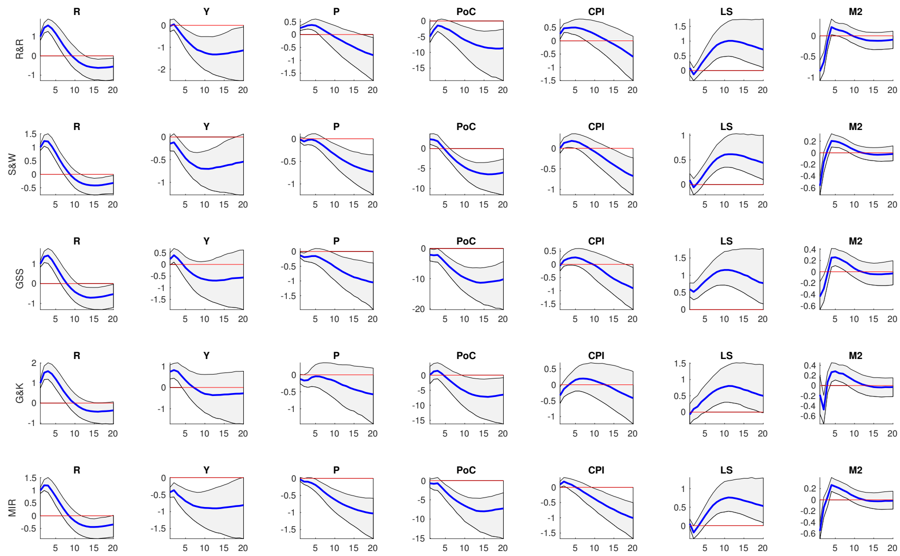


Figure D13: Impulse Response Functions normalized to a one percent increase in the short term nominal interest rate using an identification scheme based on the Instrumental Variable VAR. Labor Share proxy LS5.

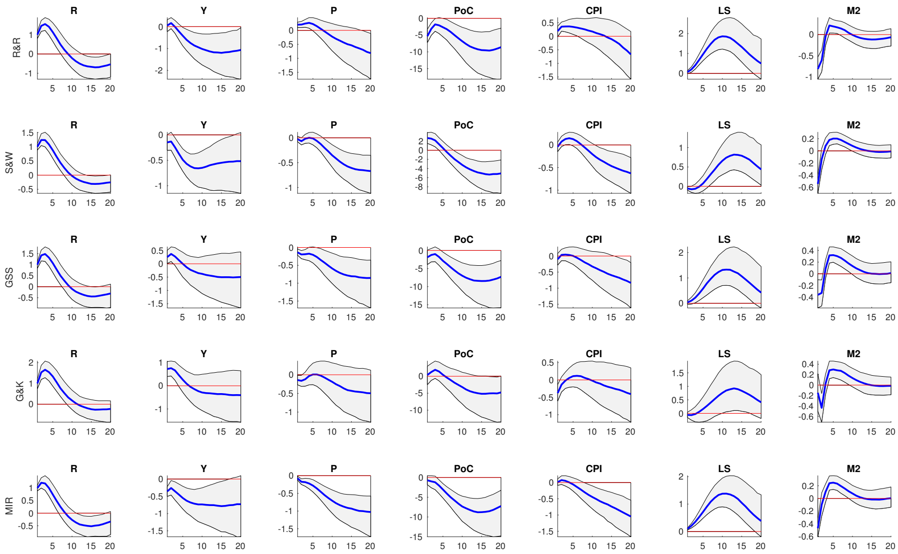


Figure D14: Impulse Response Functions normalized to a one percent increase in the short term nominal interest rate using an identification scheme based on the Instrumental Variable VAR. Labor Share proxy LS6.

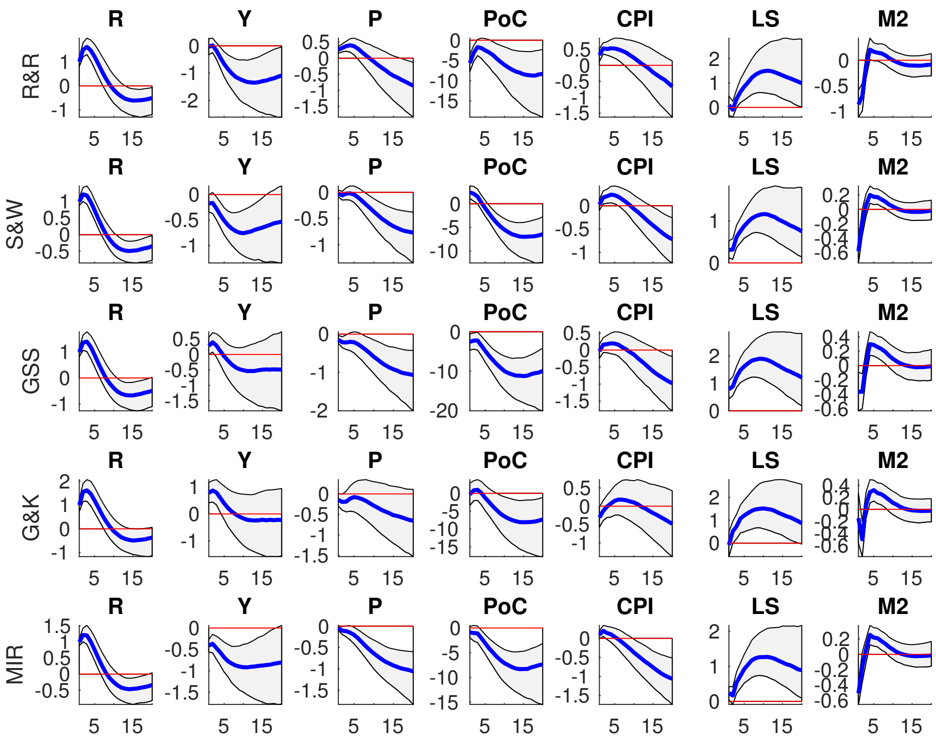


Figure D15: Impulse Response Functions normalized to a one percent increase in the short term nominal interest rate using an identification scheme based on the Instrumental Variable VAR. Labor Share proxy LS7.

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 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 E1. Between 1985 and 2007, the labor share falls in the manufacturing sector by 10 percentage points.

[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.

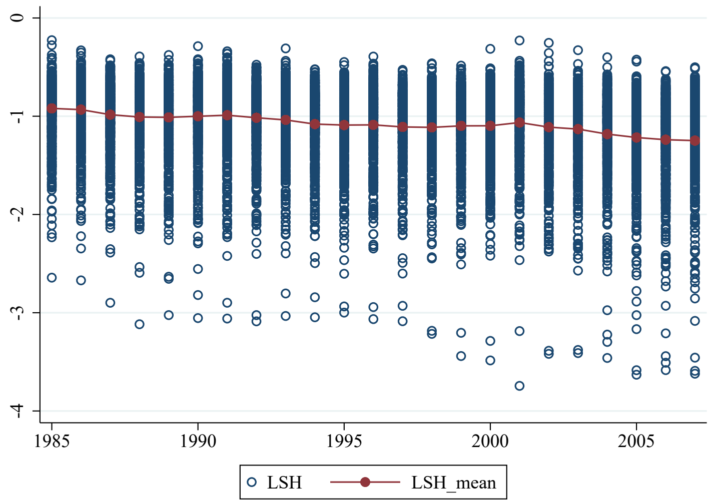


Figure E1: Average and dispersion of (log) labor shares in the NBER productivity database, 1985-2007.

C.2 Results

The results from the estimated θ_h for horizons $h = 1, ..., 5$ for the NBER database are reported in figure E2, 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 E3 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 E4 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.

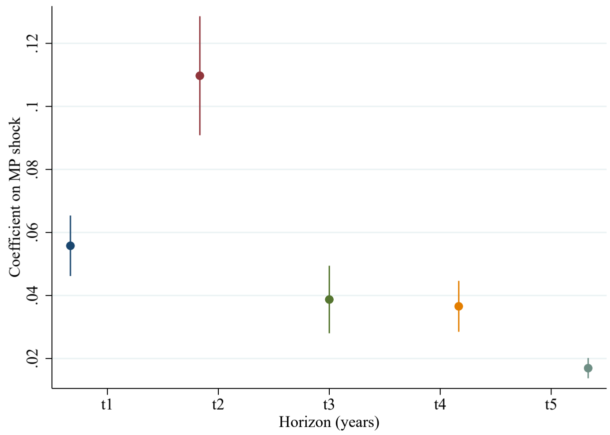


Figure E2: Coefficient on monetary policy shock variable (Cholesky VAR) using the NBER manufacturing database (464 manufacturing sectors). Period is 1985-2007. The plot shows the coefficient on the year of impact (t_1) and four years after.

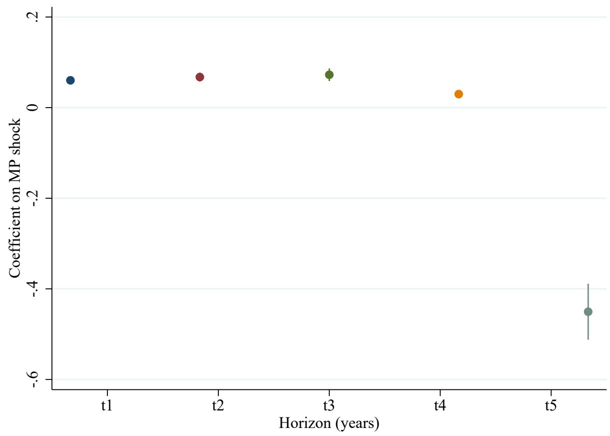


Figure E3: Coefficient on monetary policy shock variable (Romer and Romer) using the NBER manufacturing database (464 manufacturing sectors). Period is 1985-2007. The plot shows the coefficient on the year of impact (t_1) and four years after.

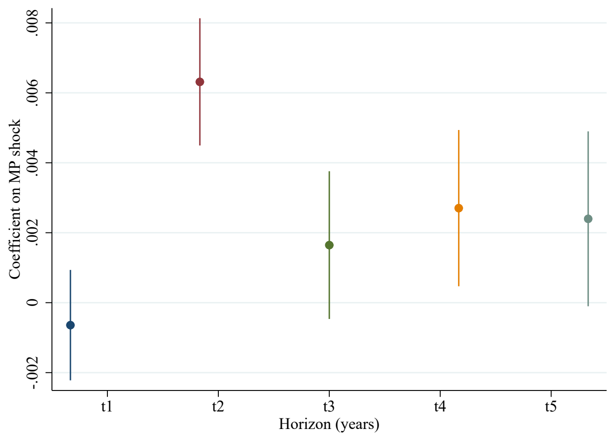


Figure E4: Coefficient on monetary policy shock variable (Cholesky VAR) using the Klems database (30 sectors). Period is 1987-2007. The plot shows the coefficient on the year of impact (t_1) and four years after.

D Composition Bias corrected measures for the US.

Here we present results using the same baseline cholesky specification used in the paper substituting the labor share in turn with data on aggregate wages in the US and composition bias corrected measures of wage as constructed by Haefke, Sonntag, and Van-Rens (2013). The sample is 1984-2006 as their datasets stops in 2006.[1] For details about data construction we refer the reader to the original paper of Haefke, Sonntag, and Van-Rens (2013).

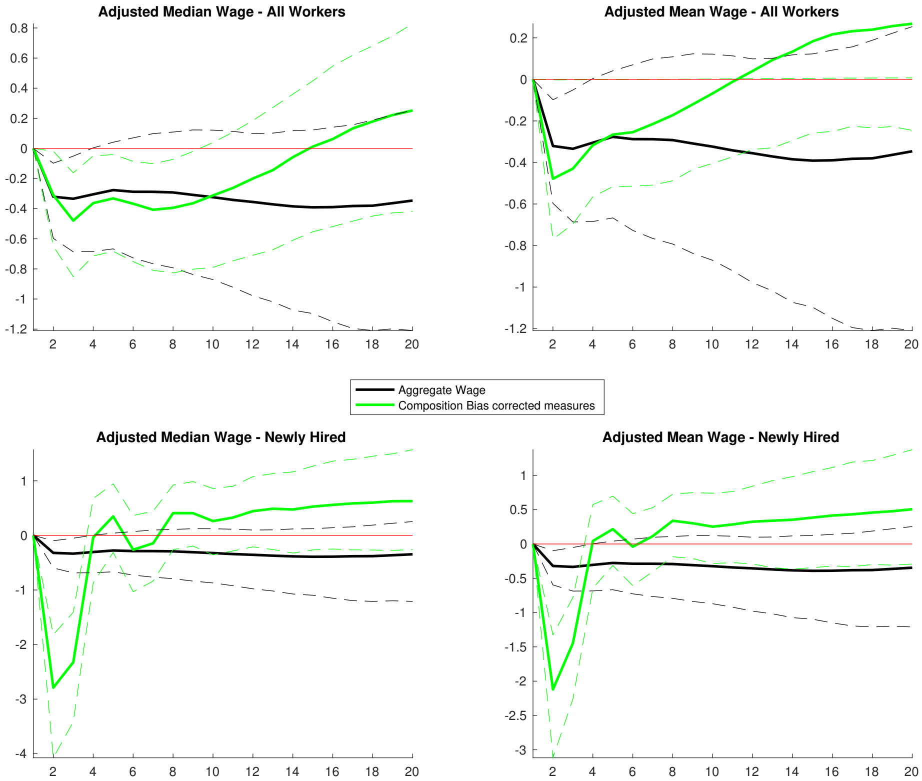


Figure F1: Impulse Response Functions comparing the response of Aggregate Wages in the US and composition bias corrected measures for all and newly hired workers.

[1]In their original dataset there are 4 missing observations in the sample. We interpolate the data but our results are robust to this interpolation.

E Theory

E.1 The labor share in NK theory

Galí, Gertler, and López-Salido (2007) and Nekarda and Ramey (2013), amongst others, have discussed extensively the inverse relationship between the labor share and the price markup in this set up. We review the intuition of this result starting from the simplest possible NK model here.

We can define the labor share in log-linear deviation from the steady state as

$$s_t^h = w_t + h_t - y_t, \tag{1}$$

where w_t is the real wage, h_t is hours worked and y_t is output. We start by assuming perfect competition in the labor market and hence labor is paid its marginal product. Hence:

$$w_t = \theta_t + y_t - h_t, \tag{2}$$

where θ_t are real marginal costs coming from the assumption of monopolistic competition in the product market and are not constant given the standard Calvo price staggering setup.

Combining (1) and (2) we get that

$$s_t^h = \theta_t. \tag{3}$$

The behaviour of the marginal cost is described by the NK Phillips Curve (PC):

$$\theta_t = \frac{\pi_t - \beta \mathbb{E}_t \pi_{t+1}}{\lambda}, \tag{4}$$

where λ is the slope of the PC and π_t is inflation. A temporary decline in inflation (tighter MP) will see marginal costs (labor share) decline and markups increase.

This result is quite general and does not depend on nominal wage rigidities, factor adjustment costs,[1] and financial frictions.[2] As it is well known, after a MP tightening households will reduce current consumption given the increase in the real interest rate and, because prices are not flexible, marginal costs have to decline to ensure that supply follows demand. As marginal costs will decline more than prices the price markup will increase and hence the labor share will always be procyclical no matter the assumption on wage rigidity.[3]

Given that the introduction of nominal wage rigidities alone does not help to get the right response of the labor share in the NK model, we proceed by looking at two extensions that can break the equality in equation (3) and at the same time go in the direction of producing a more pro-cyclical response of labor productivity compared to the one of real wages, consistent with the empirical results in section 2.1.

[1] For example labor adjustment costs would introduce a wedge, cl_t between the labor share and marginal costs $s_t^h = \theta_t - cl_t$. With convex adjustment costs it is easy to show that this wedge will move procyclically on impact of a MP shock and then counter-cyclically in subsequent periods. It follows from previous equation then that this could only lead to a procyclical labor share on impact but not in subsequent periods. Derivation details available upon request.

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

[3] Broer et al. (forthcoming) have shown that, in this model, the presence of wage rigidities is crucial in order to get a transmission mechanism of monetary policy consistent with the data. Their focus is, however, on the response of the *level* of profits which can be shown to switch sign when sticky wages are particularly strong. Here, instead, the focus is on the *shares* and, in this set up, abstracting from capital, the profit share is exactly the opposite of the labor share and moves always counter-cyclically given the counter-cyclicality of the markup. Equation (3) shows that this result is independent of the assumption of wage stickiness.

E.2 The labor share and CES production

It is worth noting that the result above is true in an economy with or without capital accumulation provided that the production function is either Cobb-Douglas or linear in labor. However, as Galí, Gertler, and López-Salido (2007) and Nekarda and Ramey (2013) show, a CES production function provides a simple way of introducing a wedge between the labor share and the marginal costs:

$$s_t^{CES} = \theta_t + \frac{1-\sigma}{\sigma}(y_t - h_t), \tag{5}$$

where σ is the elasticity of substitution between capital and labor. We consider this specification in the $\mathbb{NK\_CES}$ model of Cantore et al. (2015).

In what follows, for ease of exposition, we will assume that the production function is linear in labor.[4] Given a linear production function with labor as the only variable input ($y_t = h_t$) now the real wage is also equal to the labor share and real marginal costs:

$$w_t = s_t^h = \theta_t. \tag{6}$$

E.3 The labor share and fixed costs in production

Nekarda and Ramey (2013) also discuss two further production function generalizations that are able to break down (3): overhead and overtime labor. Both 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 showed that 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 again a NK economy with a simple linear production in labor with the presence of fixed costs F: $Y_t = H_t - F$. In log deviations from the steady state the labor share is now:

$$s_t^h = \theta_t - h_t \frac{F}{Y}. \tag{7}$$

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.[5] Numerical results show that this might work only on impact and for implausibly high values of $\frac{F}{Y}$.

E.4 The cost-push channel of Monetary Policy

The cost-push channel introduces a direct effect of the nominal interest rate (rn_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 (2013).

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 need for credit from financial intermediaries.

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

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

[5] 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)).

$$w_t = \theta_t + y_t - h_t - rn_t.^6 \tag{8}$$

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

$$w_t = s_t^h = \theta_t - rn_t. \tag{9}$$

This channel is thus able to break up 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 (2013). However, as the nominal interest rate moves counter-cyclically by definition, the direct effect of rn_t in (9) reinforces the pro-cyclicality of the labour share. Hence we need to rely on numerical simulations to check which of the two competing effects dominates.

E.5 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 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 equation 2 is no longer true and $w_t \neq \theta_t + lp_t$. It follows then that $s_t^h \neq \theta_t$. 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:

$$s_t^h = w_t \neq \theta_t. \tag{10}$$

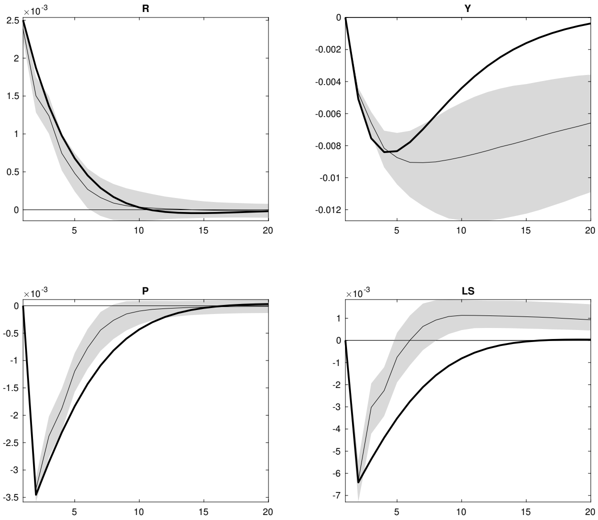
Hence to generate an increase in the labor share the only possibility is to have a counter-factual response of wages to a monetary policy shock. Without wage rigidities, it would be difficult for wages to display a positive response given that the bargaining power of workers is bounded by one. The combination 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.

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

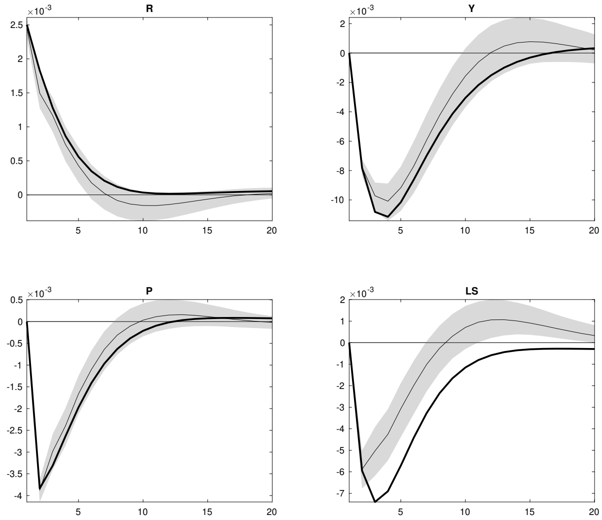
F SVAR with model simulated data

Here we check the ability of the recursive SVAR to reproduce the model impulse responses to a MP shock. To do so, following Erceg, Guerrieri, and Gust (2005), we first simulate interest rate, output, price, and labor share data from the model using a parameterization that produces a significant and persistent procyclical response of the labor share to a MP shock.[7] We then estimate the SVAR model using a sample of 150 observations of this synthetic data and, finally, compare the IRFs arising from the SVAR to those arising directly from the DSGE model. We do so for the four models considered in the main text. To make models comparable, and to allow for the invertibility of the VAR, we simulate all models with 4 shocks. 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 G1, where the thick black line is the model IRF and SVAR IRF is presented with 68% confidence sets.

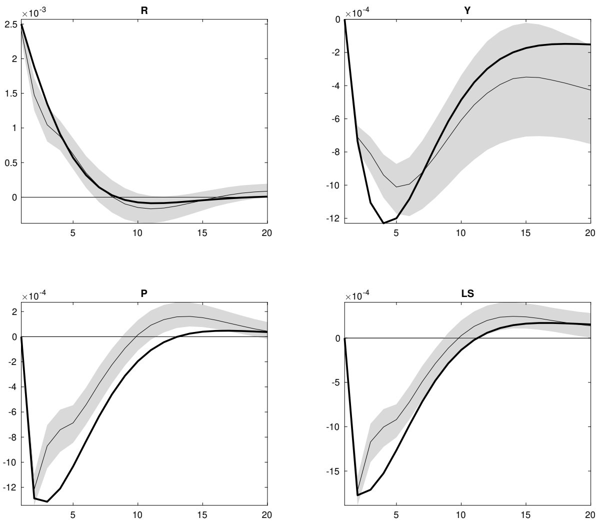
[7]This is obtained by assuming a degree of price stickiness substantially larger than wage stickiness (0.75 vs 0.5 respectively) in each model. All other parameters are standard.



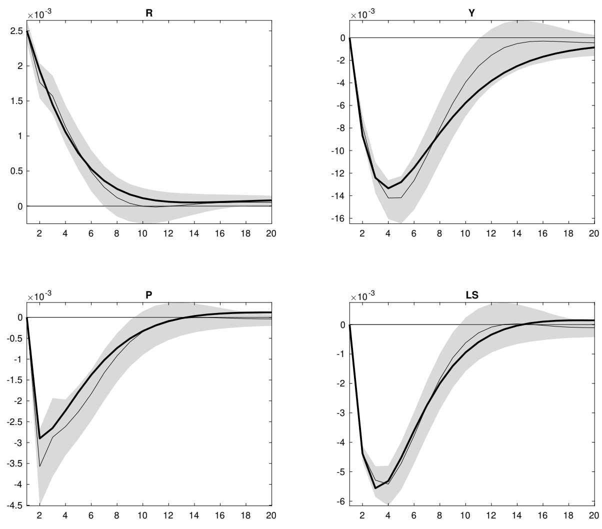
(a) NK



(b) NK_CES



(c) NK_SM



(d) NK_WKN

Figure G1: Thicker black line is the true IRF.

G Monte Carlo Filtering

As in the prior predictive analysis, a random sample of the prior[8] 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.

	2:5 quarters	
Parameter	D-Stat	P-value
price markup	0.529	0.000
Calvo price stickiness	0.494	0.000
Calvo wage stickiness	0.420	0.000
Investment adjustment costs	0.333	0.001
	5:8 quarters	
price markup	0.187	0.000
Calvo price stickiness	0.187	0.000
Investment adjustment costs	0.170	0.000
Interest rate smoothing	0.163	0.000

Table H1: Smirnov statistics in driving prior restrictions $\mathbb{NK}$

[8]Same priors as above are used, see table 3.

	2:5 quarters	
Parameter	D-Stat	P-value
Calvo wage stickiness	0.842	0.000
Calvo price stickiness	0.632	0.000
K/L elasticity of substitution	0.519	0.001
	5:8 quarters	
Investment adjustment costs	0.343	0.000
Interest rate smoothing	0.249	0.000
Calvo wage stickiness	0.238	0.000
Habits in Consumption	0.217	0.000
Calvo price stickiness	0.209	0.001

Table H2: Smirnov statistics in driving prior restrictions $\mathbb{NK}$_$\mathbb{CES}$

	2:5 quarters	
Parameter	D-Stat	P-value
Intermediate inputs share in production	0.335	0.000
price markup	0.333	0.000
Calvo wage stickiness	0.296	0.000
Calvo price stickiness	0.240	0.000
working capital fraction (labor)	0.227	0.000
habits in consumption	0.166	0.001
Interest rate smoothing	0.165	0.001
	5:8 quarters	
Intermediate inputs share in production	0.327	0.000
price markup	0.309	0.000
Calvo price stickiness	0.215	0.000
Calvo wage stickiness	0.213	0.000
Interest rate smoothing	0.202	0.001
Investment adjustment costs	0.189	0.000

Table H3: Smirnov statistics in driving prior restrictions $\mathbb{NK}$_$\mathbb{WKN}$

	2:5 quarters	
Parameter	D-Stat	P-value
working capital fraction (labor)	0.442	0.000
job survival rate	0.429	0.000
price markup	0.419	0.000
matching function share of unemployment	0.408	0.000
replacement ratio	0.271	0.001
	5:8 quarters	
price markup	0.281	0.000
working capital fraction (labor)	0.257	0.000
Investment adjustment costs	0.235	0.000
matching function share of unemployment	0.232	0.000
replacement ratio	0.199	0.000

Table H4: Smirnov statistics in driving prior restrictions $\mathbb{NK}$_$\mathbb{SM}$

H Bayesian Impulse Responses

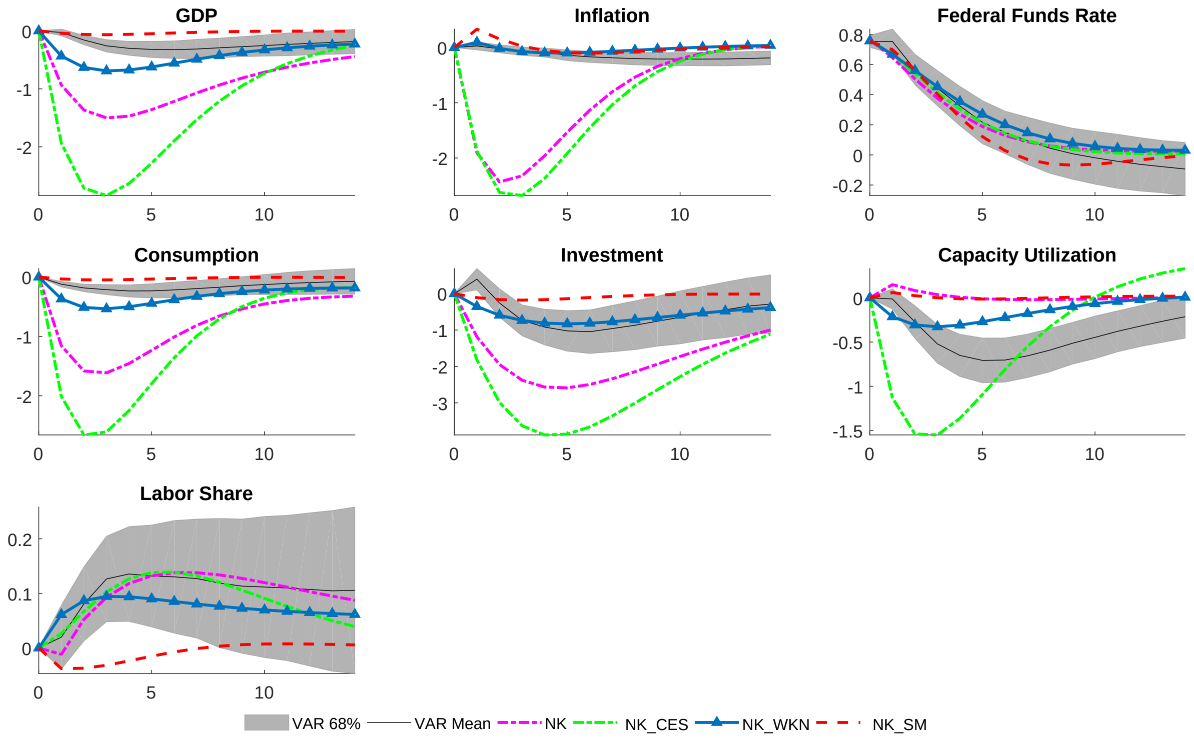


Figure I1: Bayesian Impulse Responses Matching - Matching only Federal Funds Rates and the Labor share.

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