

# The Missing Link: Monetary Policy and The Labor Share\*

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## Abstract

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

**JEL classification:** E23, E32, C52

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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.<sup>1</sup>

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 for a set of five economies<sup>2</sup> we present a new and robust set of facts. 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.<sup>3</sup>

The main 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.<sup>4</sup> These facts are robust across time periods, different countries, different measures of the labor share, different identification methods, and different information sets. 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,

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<sup>1</sup>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).

<sup>2</sup>The US, the Euro Area, UK, Australia, and Canada.

<sup>3</sup>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.

<sup>4</sup>We address later the concerns regarding the cyclical composition bias in the measurement of real wages and productivity discussed, among others, by Basu and House (2016).

once these key parameters are identified, we estimate them by matching the models' impulse responses to those of the VAR.

To advance some intuition, it is well known that, in the simplest version of the New-Keynesian (NK) model (see Galí 2015), the labor share is equal to the inverse of the price markup (the marginal cost). This makes the labor share pro-cyclical (the price markup is counter-cyclical) conditional on a MP shock, which is at odds with the empirical evidence we find here. However, this direct correspondence between the price markup and the labor share does not necessarily hold in other versions of the model such as those that 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 is that there is a 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 the combination of labor market frictions, in the form of wage bargaining, and high nominal wage inertia is able to reproduce the response of the labor share to an unexpected MP shock. 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.<sup>5</sup> The discussion in this section shows that 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 below focus on the dynamics of markups. Whilst markups are not directly observable and require the use of models to derive measures, the labor share is directly observable. Thus, 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.<sup>6</sup>

Empirically, Christiano, Eichenbaum, and Evans (2005) showed, only for the US and in a broader context, how wages and labor productivity respond pro-cyclically to an MP shock. However, they did not provide direct evidence on the labor share, and their focus was on the persistence of output and inflation inertia. 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 composition of

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<sup>5</sup>There is a literature on the cyclical behavior of the labor share conditional on technology shocks such as Hansen and Prescott (2005), Choi and Ríos-Rull (2009), Ríos-Rull and Santaella-Llopis (2010) and León-Ledesma and Satchi (forthcoming). However, our focus here is on the effects of MP innovations.

<sup>6</sup>King and Watson (2012) study the relationship between unit labor costs and inflation, unveiling a puzzling disconnect between them that contrasts with the close link implied by DSGE models. Although our focus here is not on the relationship between inflation and the labor share, our findings could be important to understand their puzzle.

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.<sup>7</sup> 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 2.4).

The relationship between the markup, the labor share, and their cyclical behavior 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-cyclical behavior of markups accounted for a substantial fraction of cyclical output movements. Galí, Gertler, and López-Salido (2007) expand on the resulting literature on business cycle and counter-cyclical markups and present a theory based measure of the variation in aggregate economic efficiency by focusing on the gap between the marginal product of labor and the household consumption and leisure trade off, the ‘labor wedge’. They show how this indicator corresponds to the reciprocal of the markup of prices over ‘social’ marginal costs. The inefficiency gap exhibits large pro-cyclical swings and, under the assumption that wages are allocational, most of its variation is associated with counter-cyclical movements in the wage markup hence pointing towards a greater importance of wage rigidities. The price markup shows, at best, a weak contemporaneous correlation. Under some alternatives to their baseline case, the price markup does move counter-cyclically but movements in wage markups still dominate the overall fluctuations of the inefficiency gap. More recently, Barattieri, Basu, and Gottschalk (2014), also find evidence of a greater importance of wage rigidities while Basu and House (2016), instead, provide evidence against this argument.

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 for the aggregate US economy and disaggregate manufacturing industries. They also show a pro-cyclical response of the markup conditional on demand shocks. Hence 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 measured labor share from national accounts and then use NK models from which we derive the behavior of the labor share, real wages, and labor productivity, and analyze the coherence between their response to an MP shock and that obtained in the VARs. For that, we make use of a wide variety of NK models introducing several types of nominal and real frictions. In several of these versions, the relationship between the labor share and the price markup breaks down. Our evidence also covers a wider range of countries and different identification schemes, as well as wider information sets. 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.<sup>8</sup>

Finally, Bils, Klenow, and Malin (2018) revive the role of counter-cyclical markups and sticky prices. They note that criticisms of the counter-cyclical behavior of the markup are based on the observation that the gap between average hourly earnings and labor productivity

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<sup>7</sup>The labor share is defined as  $S^h = W/Y/H = WH/Y$ , where W are real wages, Y is output, and H is hours worked.

<sup>8</sup>Hall (2012) also shows that cyclical movements in profit margins can be disconnected from cyclical movements in the labor share in the presence of other product-market wedges. Increasing profit margins should increase advertising spending by a large amount but Hall (2012) shows that this is not the case, refuting the hypothesis that profit margins rise in recessions.

is a-cyclical, suggesting that price markup movements are not cyclical. They argue that average hourly earnings may not reflect the true marginal cost of labor to the firm. Hence they seek evidence on cyclical distortions in the product market that does not rely on wage data for workers. For this, 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 distortions are at least as important as labor market distortions in recent recessions. The cyclical product market wedge they estimate is compatible with firm sales being constrained in recessions by a (too high) sticky price.

The counter-factual requirement of NK models that, in order to have a counter-cyclical markup, a pro-cyclical labor share is necessary, is also discussed by Karabarbounis (2014). He studies the fluctuations in the labor wedge by decomposing it in two parts: a gap coming from the difference between the marginal product of labor and the real wage (firm's wedge) and a gap coming from the marginal rate of substitution between consumption and leisure and the real wage (household wedge). Starting from the assumption that, under Cobb-Douglas, the gap between the real wage and the marginal product of labor 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 in order to make this condition hold in the data. Our findings also cast doubts on this counter-factual requirement of NK models.

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 in the form of overhead labor would imply that the labor share differs from the 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 workers in advance of production, then changes in interest rates would affect wage costs leading to a cost channel of MP.<sup>9</sup> 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 the existence of 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 this set up is able to reproduce the observed response of the labor share to a monetary policy shock but only when combined 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 some positive workers' bargaining power, 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.

The rest of the paper is organised as follows. Section 2 presents the data, stylised facts, and key results from the VAR analysis. An extended set of results and robustness is provided in section D of the Online Appendix accompanying the paper. Section 3 presents the quantitative analysis on medium scale DSGE models using a three step approach. Finally, Section 4 concludes.

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<sup>9</sup>Recently, Phaneuf, Sims, and Victor (2015) show that a model with firms networking and working capital channel can generate a procyclical markup conditional on an MP shock.

## 2 THE LABOR SHARE IN THE DATA

### 2.1 DATA: CONSTRUCTION AND SOURCES

Our data set consists of measures of the labor share, real wages, and labor productivity as well as a set of other variables that will enter our VAR analysis. Here we focus mostly on the former three measures and leave most of the detail in Appendices A to C as the other variables follow standard practice in the literature.

Measuring the share of labor in total income is complicated by problems associated with how to impute certain categories of income to labor and capital owners. 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. These have been discussed at length in Gollin (2002), Gomme and Rupert (2004) and Muck, McAdam, and Growiec (2015). In constructing the labor share data for the US, where data on income sources is richest, we use 7 different measures. The first and the last are directly taken from the Bureau of Labor Statistics and measure the labor share in the non-farm business and in the non-financial corporation sectors, the second to the fourth are based on Gomme and Rupert (2004), the fifth based on the approach of Cooley and Prescott (1995), and the sixth is taken from Fernald (2014).<sup>10</sup>

For other countries, where available, we will use similar measures. However, data availability limits the extent to which we can obtain corrected labor share measures and, in many cases, we work with rough estimates of labor shares. We work with only one measure of the labor share for the Euro Area and the United Kingdom (compensation of employees over nominal Gross Value Added at factor costs) while we will use five different measures for Australia and two for Canada (see figures A2-A3).<sup>11</sup> For each country with more than a proxy for the labor share we use a baseline measure for the empirical analysis below and present the results for the rest of the proxies in the supplementary Appendix.<sup>12</sup>

For real wages in the US, we used nominal compensation of employees deflated by CPI over hours worked from the database produced by Valery Ramey and updated from the BLS.<sup>13</sup> For the Euro Area, we use hours data from the AWM database. For the rest of the countries we use hours from the dataset constructed by Ohanian and Raffo (2012). Labor productivity is calculated as real GDP, using the GDP deflator, over hours worked from the same databases.<sup>14</sup>

For the rest of the variables in the VAR analysis, as explained below, we use data on Real GDP, the GDP deflator, an index of commodity prices, CPI, short term interest rates, and M2 growth. We construct these information sets for the 5 countries under analysis. Since these are standard, data sources and details are available in supplementary Appendix C.

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<sup>10</sup>All the proxies for the US are plotted in the supplementary Appendix in figure A1 for the post WWII period. Generally, these measures are highly correlated in levels. In first differences, the correlation between them always exceeds 0.5. Details in Appendix B.

<sup>11</sup>Again, the measures are highly correlated in all cases. Details in Appendix B.

<sup>12</sup>Where possible we follow Gomme and Rupert (2004) in using as a baseline measure labor share in the non-financial corporate sector. Neither proprietors' income nor rental income are included in this sector accounts, thus avoiding the issues of properly apportioning proprietors' income to labor and capital or accounting for labor income in the housing sector. For the US our baseline measure is LS2, labor share in the domestic corporate non-financial business sector, for Australia we choose the measure LS4, labor share in the domestic corporate sector and for Canada we choose LS2 in which we imputed mixed income in the same proportion as unambiguous labor and capital income. These measures are used in the baseline results with the alternative measures presented in the appendix.

<sup>13</sup>See <http://econweb.ucsd.edu/~vramey/research.html>.

<sup>14</sup>The use of different deflators in the construction of the two components of the labor share is discussed at length in section 2.4.

Country	Sample	LS	W	LP
US	1955Q1-2015Q3	[-0.29 , 0.04]	[0.13 , 0.47]	[0.14 , 0.50]
EA	1999Q1-2014Q4	[-0.91 , -0.37]	[-0.34 , 0.46]	[0.84 , 0.95]
UK	1971Q1-2016Q1	[-0.41 , 0.11]	[-0.26 0.19]	[0.19 0.64]
AUS	1959Q3-2013Q4	[-0.23 , 0.12]	[ [-0.35 , -0.01]	[0.13 , 0.43]
CAN	1981Q2-2013Q4	[-0.56 , -0.07]	[-0.49 , -0.04]	[0.16 , 0.47]

**Table 1:** Correlation with HP filtered Output. GMM 95 % Confidence Intervals. Wages and Labor productivity are HP filtered

Country	Sample	LS	W	LP
US	1955Q1-2015Q3	[0.28 , 0.60]	[-0.51 , -0.12]	[-0.55 , -0.19]
EA	1999Q1-2014Q4	[-0.76 , -0.28]	[-0.92 , -0.58]	[-0.85 , -0.18]
UK	1971Q1-2016Q1	[-0.52 , 0.08]	[-0.90 , -0.79]	[-0.94 , -0.82]
AUS	1959Q3-2013Q4	[0.49 , 0.70]	[-0.67 , -0.36]	[-0.68 , -0.38]
CAN	1981Q2-2013Q4	[0.45 , 0.72]	[-0.91 , -0.82]	[-0.92 , -0.85]

**Table 2:** Correlation with the policy rate. GMM 95 % Confidence Intervals. Wages and Labor productivity are HP filtered.

## 2.2 DESCRIPTIVE STATISTICS

Figure 1 plots the baseline quarterly labor share measures for all the countries under analysis over the available sample. From the figure, it is evident that it fluctuates systematically in the short run. Most of the countries display the well-known downward trend since the late 1970s.<sup>15</sup> Table 1 presents the 95% confidence intervals for the correlation of the raw labor share and HP filtered real wages and labor productivity with HP filtered output. Table 2 presents the same correlations but with the short term interest rate. In both cases we use the full sample available.<sup>16</sup> Previous literature has usually found the labor share to be counter-cyclical, a fact that seems to hold on average in our data. However, that unconditional correlation is weak except for the Euro Area and Canada.<sup>17</sup> Labor productivity appears to be significantly pro-cyclical for all countries while real wages show a more mixed picture. Regarding the correlation with the short term interest rate, we find a positive and significant correlation of the labor share in three of the countries in the sample (US, Australia and Canada) while we observe a strong and significantly negative correlation in the Euro Area. For real wages and labor productivity we find a significantly negative correlation with interest rates in all countries.

Note, however, that these correlations are unconditional and hence reflect the cyclical effect of any shock hitting the economy. The aim of the next sections is thus to uncover the cyclicity of these variables *conditional* on a MP shock.

<sup>15</sup> Young (2010) and Lawless and Whelan (2011), among others, have argued that nearly all fluctuations in the labor share are due to movements in shares within industries and not because of variations in the weights of different industries.

<sup>16</sup>The sample for Australia and Canada stops in 2013Q4 because of the availability of the data on total hours from Ohanian and Raffo (2012).

<sup>17</sup>This result is robust across labor share proxies, see appendix B, and different filtering techniques.

## 2.3 MONETARY POLICY AND LABOR SHARE: VAR RESULTS

### 2.3.1 Specification of the VAR

As baseline specification, we consider a 7 variables VAR merging part of the information sets in Olivei and Tenreyro (2007) (OT) and Christiano, Eichenbaum, and Evans (2005) (CEE). The variables in the information set are: the log of real GDP, the log of the GDP deflator, the log of an index of commodity prices as in OT, log of the CPI, the log of the labor share, short term interest rates, and M2 growth.<sup>18</sup>

Both OT and CEE included the real wage (and hours worked in the case of OT) in their information sets. We instead use the labor share for two reasons. First, and quite obvious, because we are interested in dynamics of factor shares and the real wage is one of the components of the labor share. Second, aggregate wage changes may reflect changes in the composition of the labor force over the business cycle.<sup>19</sup> Hence, as discussed at length by Basu and House (2016), data on aggregate wages and labor productivity suffer from a composition bias that makes them appear to be less pro-cyclical than the wages of individual workers. As argued by Basu and House (2016), the labor share does not suffer from this *composition bias*. We use the labor share in the baseline specification of the VAR for these reasons. However, when we are interested in the components of the labor share, in section 2.4, we use real wages and labor productivity separately. This would re-introduce the composition bias in the VAR. Nevertheless, we can show that, given our results, the *sign* of the response of these two variables is not affected by the composition bias. In fact, as we show below, this bias would reinforce our results. Beyond the sign of these responses, however, we cannot make assertions about their magnitude.

### 2.3.2 Baseline VAR Identification scheme: Cholesky

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

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

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

$$e_t = \Omega \nu_t,$$

where  $\Omega \Omega' = \Sigma$  and  $E(\nu_t \nu_t') = I_n$ . We use several strategies to retrieve the MP shock from the rotation matrix,  $\Omega$ .

We first identify MP shock using a Cholesky recursive ordering.<sup>20</sup> The Cholesky ordering follows the identification assumption 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

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<sup>18</sup>Results using a 9 variables VAR with consumption and investment are qualitatively similar but present a more pronounced price puzzle, hence the decision to drop them from the information set. See figure D4. Regarding corporate profits, in earlier versions of this paper we used both the level of corporate profits as in Christiano, Eichenbaum, and Evans (2005) and the corporate profit share in the SVAR. Results were very robust to the inclusion of these variables.

<sup>19</sup>Stockman (1983) and Solon, Barsky, and Parker (1994) have shown that low-paid workers account for a larger share of labor payments in booms than in recessions.

<sup>20</sup>The order is the following: the log of Real GDP, the log of GDP deflator, the log of an index for price of commodities, log of CPI, log of labor share, short term interest rates and M2 growth.



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.<sup>21</sup>

The sample spans used for each country VAR are summarized in table 3. Lag selection is guided by the BIC criterion.<sup>22</sup> All the VARs presented in the paper were estimated using Bayesian methods with Jeffrey priors.

Country	Sample	
US	1984:Q1	2007:Q4
EA	1999:Q4	2011:Q3
AUS	1985:Q1	2009:Q4
CAN	1985:Q1	2011:Q1
UK	1986:Q1	2008:Q1

**Table 3:** Sample periods used in the VAR analysis

Figure 2 reports the responses of all the variables in the information set to a monetary policy shock (tightening) normalized to a 1% increase in the short term interest rate.<sup>23</sup> We report the median response from the posterior distribution as well as the 68% confidence set. First, we notice how the shock resembles a monetary policy shock for all the countries. The price puzzle does not disappear completely in all the countries, with the exception of the EA. However, it is quantitatively small and non significant for the US. It is more pronounced and significant in the UK, and Australia. The response of the labor share in every country is positive and statistically significant. It also appears to be persistent 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 observed one 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 share 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.

### 2.3.3 Robustness: Information set and sample

We carried out several robustness checks on the baseline empirical results presented above which we summarize here.

First of all, in figures D1-D3 of the appendix, we present the results of the baseline specification using all the different labor share proxies constructed for the US, Australia and Canada. Second, we check if the results are robust to modifying the information sets and samples used. We check if the responses of the labor share carry over if we use the same information sets as in Olivei and Tenreyro (2007) and in Christiano, Eichenbaum, and Evans (2005)<sup>24</sup> separately.

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<sup>21</sup>We checked whether ordering the labor share after the short term interest rate changes the results. It does not.

<sup>22</sup>In particular, we assume 3 lags for Australia, 2 lags for US, UK and Canada, and one lag for the EA.

<sup>23</sup>All responses are in % deviations.

<sup>24</sup>Excluding corporate profits because available measures of profits also contain capital payments and are highly negatively correlated with the labor share. If we do include either the level or the share of corporate profits for all the countries under study we obtain IRFs that are the mirror images of the labor share ones.

Furthermore, Basu and House (2016) and Ramey (2016) show that using updated samples with more recent data to estimate SVARs as in Christiano, Eichenbaum, and Evans (2005), the impulse response functions change substantially and the price puzzle becomes more pronounced. Ramey (2016) concludes that the most likely reason for the breakdown in the later sample is simply that we can no longer identify monetary policy shocks well. The original sample in CEE was 1965:Q1-1995Q3.<sup>25</sup> Thus, we estimate the VAR under the baseline information set for the original CEE sample and for a full sample ranging from 1965:Q1 until 2007:Q4 for the US. We do this also with the information sets in OT and CEE. For the other countries, due to data constraints, we cannot perform sub-sample robustness. We observe a positive and significant response of the labor share in almost all the cases.<sup>26</sup>

### 2.3.4 Alternative Identification scheme: Sign Restrictions

Here, we study the impact of MP surprises on the labor share using an alternative identification scheme based on sign restrictions (see Uhlig (2005)). We postulate that a monetary policy shock

- increases the short term nominal interest rate at  $t = 0, 1, 2$
- decreases prices, i.e. the GDP deflator and CPI at  $t = 0, 1, 2$
- induces a contraction in M2 at  $t = 0, 1, 2$

This identification scheme imposes a weaker set of 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. Another way to see it is that, we are verifying whether the (sign of the) correlation of the LS conditional on a MP shock is stable across a large set of models with different types of frictions (real, nominal, labor market, etc.). We generate candidate draws for the rotation matrix satisfying these restrictions using the algorithm developed in Rubio-Ramrez, Waggoner, and Zha (2010). Figure 3 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.<sup>27</sup> 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.

### 2.3.5 Alternative Identification scheme: External Instrument

We also explore the dynamic transmission of monetary policy shocks to the labor share using the external/instrumental variable approach as proposed 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 allows to recover the the first column of the rotation matrix  $\Omega$ , and thus to recover impulse responses and transmission mechanism.

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<sup>25</sup>As noted in Olivei and Tenreyro (2007) only after 1965 did the federal funds rate exceed the discount rate and hence acted as the primary instrument of monetary policy.

<sup>26</sup>Table D1 in appendix D.1.2 summarizes the results.

<sup>27</sup>The same conclusion applies using different proxies for the labor share. See appendix D.2.

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:

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

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  $\Phi$  and  $\Sigma$ , 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 5 different proxy or instruments for monetary policy surprises. The first instrument we use is the Romer and Romer (2004) narrative measure of monetary policy.<sup>28</sup> The second instrument is the estimated monetary policy innovations in the Smets and Wouters (2007) model and spans the period 1959q1-2004q4.<sup>29</sup> 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).<sup>30</sup> 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)).<sup>31</sup>

Figure 4 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 (see Appendix D.3).

<sup>28</sup>Romer and Romer (2004) updated series are taken from Miranda-Agrippino and Rey (2015).

<sup>29</sup>This series is taken from the database of Stock and Watson (2012).

<sup>30</sup>Again taken from the database of Stock and Watson (2012).

<sup>31</sup>For this identification scheme we only focus on the US because we lack good instruments for other countries. For the Euro Area Jarret 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) obtain high frequency ones. Although we experimented with these two measures for the UK, we were unable to identify a shock 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 here.

### 2.3.6 Sectoral evidence

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 E. The results confirm a similar pattern to that obtained with aggregate data. I.e., at the sectoral level, the labor share increases after a contractionary MP shock.

## 2.4 LABOR SHARE COMPONENTS

In this section, we dig deeper into the transmission mechanism of MP on the labor share by looking into its different components. A counter-cyclical response of the labor share conditional on MP shocks can occur either because real wages are more counter-cyclical than labor productivity or because labor productivity is more pro-cyclical than real wages. The two scenarios have very different implications for the transmission mechanism of MP 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 data. Furthermore, we look at output and hours separately to understand the determinants of the behavior of labor productivity.

A crucial aspect here relates to the use of deflators. In the data, real wages are usually deflated using a different price index (typically CPI) from the one of income or GDP (see Pessoa and Van Reenen (2013)). To see this, we can look at the definition of labor share ( $S^h$ ) as the ratio between real hourly compensation ( $W^r$ ), usually deflated using CPI, and labor productivity ( $LP$ ) which is the ratio between real GDP deflated using the GDP deflator and a measure of hours:

$$S^h = \frac{W^r}{LP} = \frac{W^n}{P^{CPI}} \frac{HP}{Y^n} \frac{P^{CPI}}{P}, \quad (1)$$

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.<sup>32</sup>

We use the same Cholesky identification assumption as before and we run a VAR under two different information sets. The first is a 8 variable set that augments the baseline 7 variable VAR by substituting the labor share with (the log of) real wages and labor productivity.<sup>33</sup> In the second specification, we substitute labor productivity with hours. For the US we now use data for the non-financial corporate sector only for GDP, GDP deflator, CPI, and Labor Productivity. This is because, as discussed by Gomme and Rupert (2004), in this sector there are no problems arising from the measurement of proprietors and rental income. Hence, we can decompose the measure of the labor share in this sector exactly as in equation (1) and we have access to data for each of its components.<sup>34</sup> For the rest of the

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<sup>32</sup>In two-sector models and open economy models, typically, the GDP deflator and the consumption price deflator differ. Thus, the dynamics of the real wage may also differ if they are measured using the consumption or the GDP deflators. Nevertheless, in these models there is a straightforward mapping between model and data quantities.

<sup>33</sup>The ordering is then: Real GDP, GDP deflator, price of commodities, CPI, real wages, labor productivity, 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.

<sup>34</sup>Details on data sources are available in Appendix C.1.1. The results using data for the aggregate economy show the same picture.

countries, however, we do not have access to these variables and hence we use the same data as before for the whole economy.

Figure 5 plots the individual impulse responses to a monetary tightening for each of the labor share components in the countries under analysis.<sup>35</sup> 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 hence 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 above 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 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 ( $W_t^r, LP_t$ ). Now assume we can classify workers in a discreet grid of  $N$  levels of “human capital” or skills from lowest to highest,  $j = 1, \dots, N$ . 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:

$$x_t = \sum_j x_{j,t} \alpha_{j,t} = \bar{x}_t + \sum_j (x_{j,t} - \bar{x}_t) (\alpha_{j,t} - \bar{\alpha}_t) = \mu_t + \theta_t,$$

where  $\bar{x}_t$  and  $\bar{\alpha}_t$  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 ( $\mu_t$ ), and the covariance between wages/productivity and the share of workers by level of human capital ( $\theta_t$ ). 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

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<sup>35</sup>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.

booms the share of high productivity workers decreases, then the covariance would fall.

Our interest is in the cyclical evolution of  $\mu_t$  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  $f(\cdot, t)_{MP}$  the impulse response function (IRF) over  $t = 1, \dots, T$  of any variable to a MP tightening. Since the IRF of two additive variables is also additive, we have that:  $f(x_t, t)_{MP} = f(\mu_t, t)_{MP} + f(\theta_t, t)_{MP} \forall t$ . 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:  $f(\mu_t, t)_{MP} = -f(\theta_t, t)_{MP}$ . 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.<sup>36</sup>

As a second cross-check of this argument, we use data on composition bias corrected 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.<sup>37</sup>

### 3 THEORY

We 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 known 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)). This can be seen by rearranging the linear version of the New Keynesian Phillips curve as in Galí (2015),

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

where  $\theta_t$  represents real marginal costs (inverse of the price markup),  $\pi_t$  is inflation, and  $\lambda$  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 of factor adjustment costs and nominal wage rigidities 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

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<sup>36</sup>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.

<sup>37</sup>Details available in section F of the Appendix.

a wedge between these two variables that depends on labor productivity and the elasticity of capital-labor substitution. The cost channel of monetary policy (Ravenna and Walsh (2006), Christiano, Trabandt, and Walentin (2010)) 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 only proportionally to the markup and labor productivity anymore.<sup>38</sup>

Each of the channels described above could, in principle, help a New-Keynesian model to match the impulse responses of interest. State of the art medium scale DSGE models widely 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.<sup>39</sup> We label this model NK. The second model extends NK by generalizing the production function to a CES as in Cantore et al. (2015). We label this model 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 (2015) which we label NK\_WKN.<sup>40</sup> Finally, we consider a medium scale DSGE model with labor market frictions and alternate offer bargaining developed by Christiano, Eichenbaum, and Trabandt (2016) (labeled 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 NK\_SM also abstracts from sticky wages and endogenously generates wage inertia.<sup>41</sup>

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

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

where  $r_t$  is the interest rate set by the monetary authority,  $y_t$  is real output,  $\varepsilon^r$  is the monetary policy shock and variables are defined in deviations from their steady state values.

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<sup>38</sup>Supplementary Appendix G provides a detailed discussion of each of these theoretical channels that can separate the labor share from the inverse of the markup.

<sup>39</sup>This model is essentially equivalent to the Smets and Wouters (2007) model abstracting from growth.

<sup>40</sup>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.

<sup>41</sup>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.

$\rho^r$  is the degree of interest rate smoothness while  $\rho^\pi$  and  $\rho^y$  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: A THREE STEP APPROACH

Our objective here is to assess quantitatively the ability of the models discussed above to replicate the identified MP shock responses of the labor share and its components from the SVAR. This is done following a three step approach. We first ask whether there are combinations of model parameters that can, at least a priori, replicate the response of the variables of interest. Second, we want to identify which parameters, if any, are important to generate those responses. Finally, we estimate the parameters of interest by minimizing the distance between the SVAR and DSGE impulse response functions.

In step one, we use Prior Sensitivity Analysis (PSA) (Canova (1995), Lancaster (2004) and Geweke (2005)) to quantify the likelihood that the model generates a set of signs patterns that are consistent with those observed in the data. This step will tell us what percentage of the parameter space of each model is able to generate a positive response of the labor share (and a negative response of real wages and labor productivity) following a monetary policy tightening. Step two will make use of Monte Carlo Filtering methods (MCF) (Ratto (2008)) to determine which parameters are responsible for driving those responses. Step three, instead, will use Bayesian IRF matching (as in Christiano, Trabandt, and Walentin (2010) and Christiano, Eichenbaum, and Trabandt (2016)). This will offer us an assessment of the ability of these models to replicate the joint responses of a set of macroeconomic variables and the labor share obtained from the SVAR. In particular, which conditional moments can (or cannot) each model replicate.

### 3.2 STEP 1: PRIOR SENSITIVITY ANALYSIS

Only in very particular situations can we 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 predictive analysis 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.<sup>42</sup> In other

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<sup>42</sup>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 Fève and Sahuc (2014).



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 4 shows the calibration of parameters held fixed while table 5 shows the bounds of the uniform distributions we attach to all the other parameters.<sup>43</sup> Basically, we allow for any economically meaningful value of the parameters, even for extreme values such as full price flexibility.<sup>44</sup> 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 6 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 productivity. We repeat the exercise by imposing the same restrictions from quarters five to eight.<sup>45</sup>

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. 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 and, moreover, that this percentage is increasing over the IRF horizon.

### 3.3 STEP 2: MONTE CARLO FILTERING

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)

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<sup>43</sup>For NK\_SM model all the parameters not shown in table 4 are calibrated as in Christiano, Eichenbaum, and Trabandt (2016).

<sup>44</sup>The only exception to this is the share of intermediate goods in production in model NK\_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.

<sup>45</sup>Note that these restrictions are quite favourable 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.

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 Smirnov test offers, implicitly, a statistical ranking of parameters from the most to the least influential. Finally, it unveils important relationships among parameters.<sup>46</sup>

Table 7 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 6.<sup>47</sup> 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 Calvo price and wage parameters are identified as crucial in all models except in `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 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 the share of labor income relative to total income. Hence, the labor share goes up but for the ‘wrong’ reasons.

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 `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 `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 `NK_SM`

<sup>46</sup>Details in supplementary Appendix H.

<sup>47</sup>Detailed results by model are presented in supplementary Appendix H.

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.

### 3.4 STEP 3: BAYESIAN IMPULSE RESPONSES MATCHING

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 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.<sup>48</sup> 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). Third, because not all the models have labor market frictions, we abstract from certain labor market variables included in Christiano, Eichenbaum, and Trabandt (2016).<sup>49</sup> 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 the analysis to the US economy for the sample period 1959Q2 to 2008Q4.<sup>50</sup> 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

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<sup>48</sup>Hence, the information set of the SVAR estimated for IRF matching is the following:  $\Delta \log$  of the relative price of investment,  $\Delta \log$  of Real GDP,  $\Delta \log$  of GDP deflator,  $\Delta \log$  of price of commodities,  $\Delta \log$  of CPI, capacity utilization,  $\Delta \log$  of consumption,  $\Delta \log$  of investment,  $\log$  of the labor share, Federal Funds Rate,  $\Delta M2$ . Data on capacity utilization and relative price of investment come from Altig et al. (2011). For the Labor Share we use our baseline proxy LS2.

<sup>49</sup>In the SVAR, results for the labor share are robust to the inclusion of labor market variables and are available upon request.

<sup>50</sup>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.

Rate is ordered just before money growth.<sup>51</sup>

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 exercise are the same as in table 4.<sup>52</sup> Table 8 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.<sup>53</sup> All priors are centred around values chosen in line with the literature on Bayesian estimation of DSGE models.

In Table 9 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<sup>54</sup> 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 `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 `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.<sup>55</sup> Only `NK_CES` and `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 one estimated in the SVAR.

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<sup>51</sup>For details see Appendix I.

<sup>52</sup>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.

<sup>53</sup>Note that the MP shock standard deviation prior is centred around the estimated standard deviation value in the SVAR.

<sup>54</sup>Which determines the proportion of fixed costs in production.

<sup>55</sup>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 2.4.

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 NK, are able to separate 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.<sup>56</sup> This fact sheds doubts on the transmission mechanism of MP in these models. Furthermore, in estimated DSGE models for policy analysis, it is common practice to proxy marginal costs with the labor share as an observable (see, for instance, Del Negro et al. (2013)). However, if we take the 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.

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<sup>56</sup>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.

We show that, in the models considered, there is a 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 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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TABLES AND FIGURES

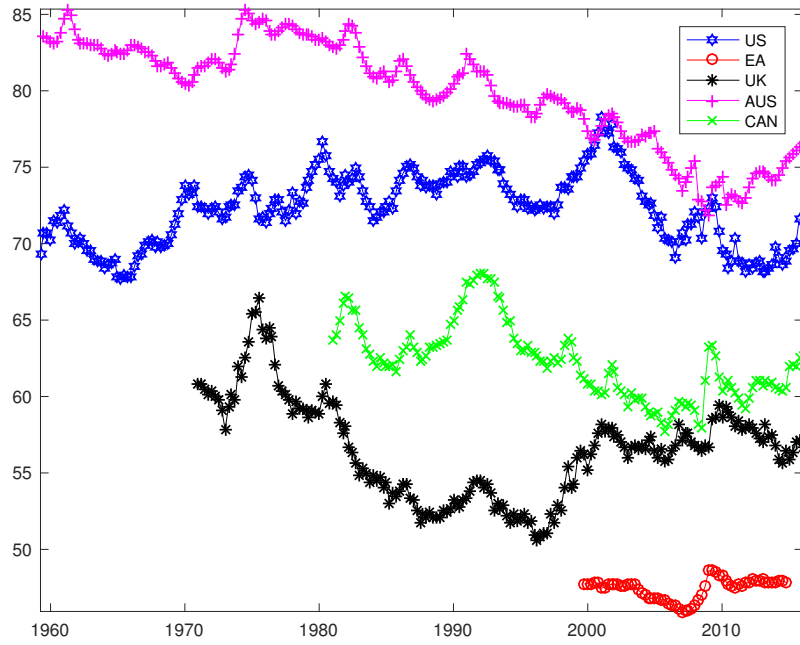


Figure 1: Cross Country Labor Share

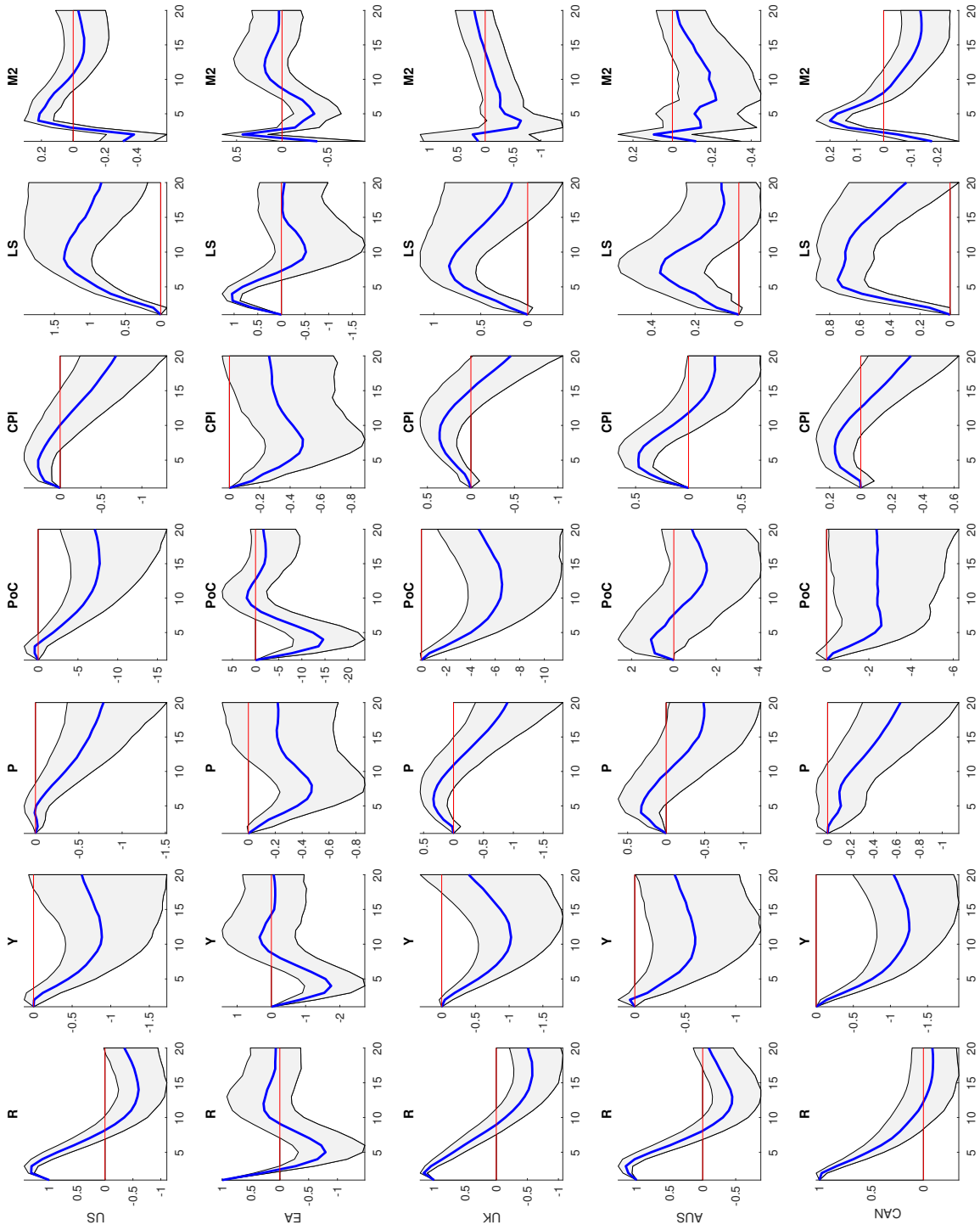


Figure 2: Impulse Response Function normalized to a 1% increase in the short term interest rate using recursive Cholesky.

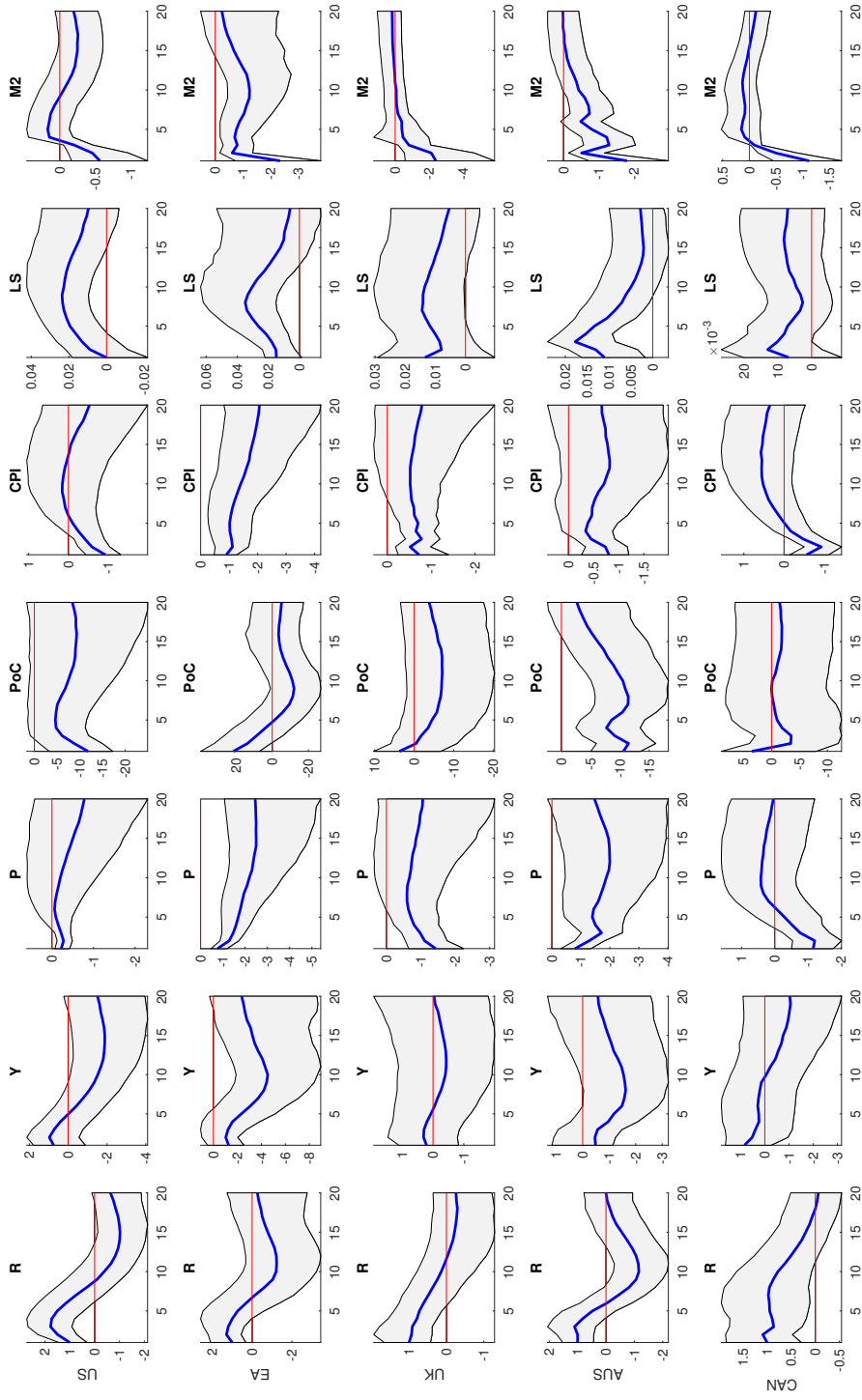


Figure 3: Impulse Response Functions normalized to a one percent increase in the short term nominal interest rate using an identification scheme based on **sign restrictions**.

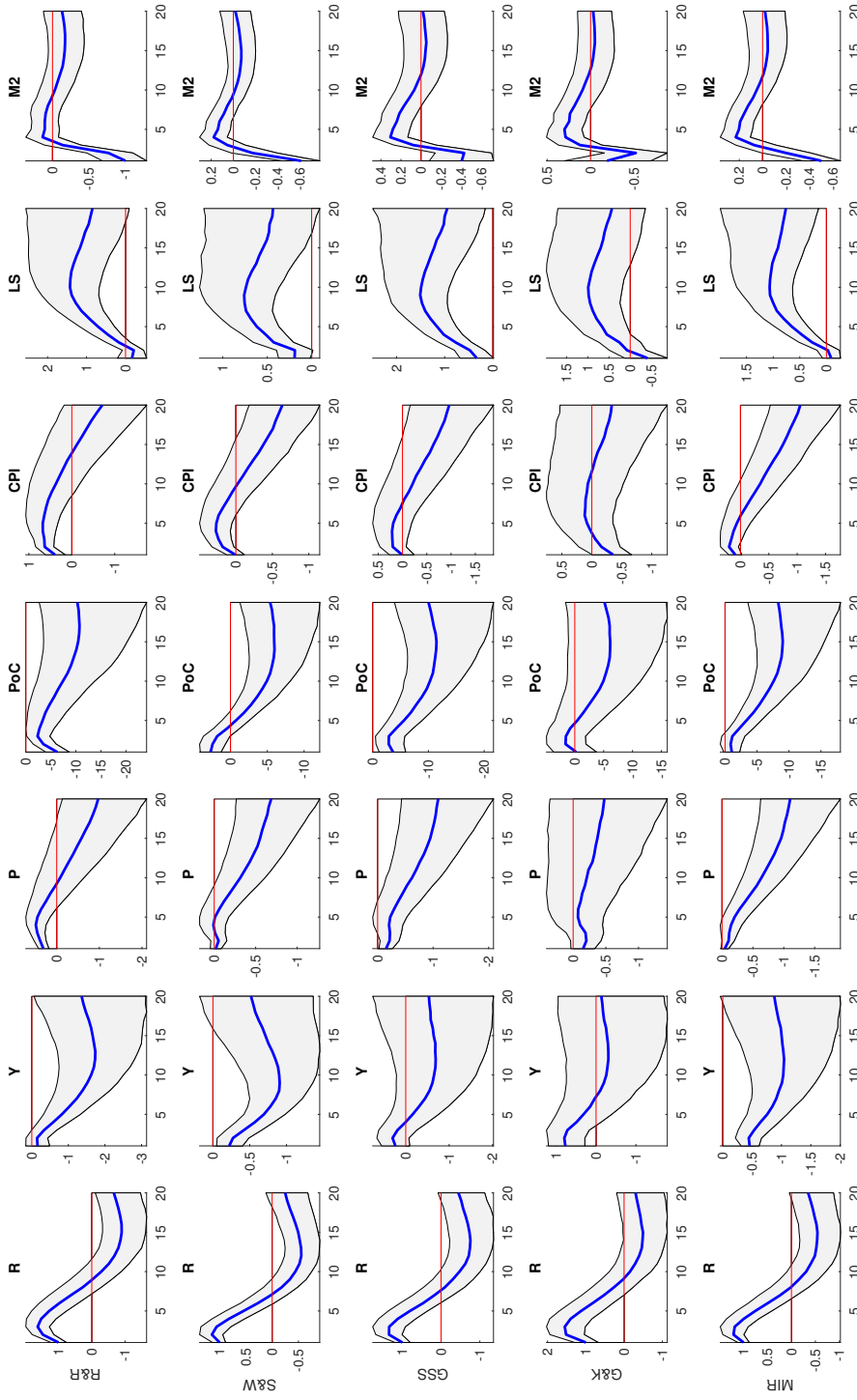


Figure 4: Impulse Response Functions normalized to a one percent increase in the short term nominal interest rate using an identification scheme based on the **Instrumental Variable VAR**. [*R&R*]: Romer and Romer; [*S&W*]: Smets and Wouters; [*GSS*]: Gürkaynak et al.; [*G&K*]: Gertler and Karadi; [*MIR*]: Miranda-Agrippino.

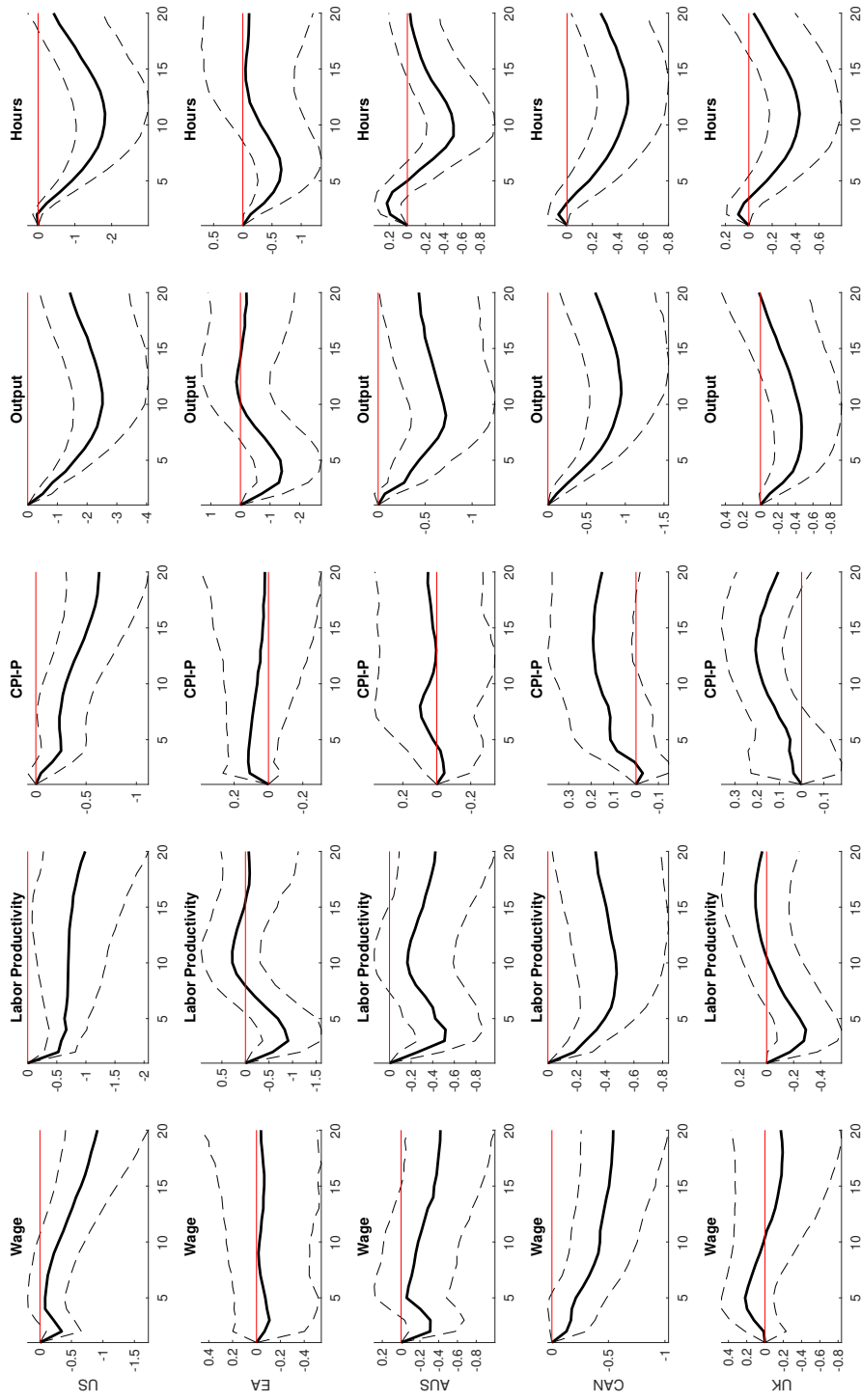


Figure 5: Impulse Responses of labor share components normalized to a 1% increase in the short term interest rate using recursive Cholesky.

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 4:** 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 5:** Uniform Distribution bounds for PSA and MCF.



Model	Restrictions			
	2:5 quarters		5:8 quarters	
	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 6:** 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	<u>✓</u>	✓	✓	✓
Habits in Consumption		✓	✓	
Variable Capital Utilization				
Calvo price stickiness	<u>✓</u>	<u>✓</u>	<u>✓</u>	
Calvo wage stickiness	✓	<u>✓</u>	<u>✓</u>	
price markup	<u>✓</u>		<u>✓</u>	<u>✓</u>
wage markup				<u>✓</u>
Interest rate smoothing	✓	✓	<u>✓</u>	
Taylor rule response to inflation				
Taylor rule response to output				
Price Indexation				
Wage Indexation				
K/L elasticity of substitution		✓		
working capital fraction (labor)			✓	<u>✓</u>
Intermediate inputs share in production			<u>✓</u>	
working capital fraction (capital)				
working capital fraction (intermediate inputs)				
technology diffusion				
prob. of barg. session determination				
replacement ratio				<u>✓</u>
hiring fixed cost relative to output %				
search cost relative to output %				
matching function share of unemployment				<u>✓</u>
job survival rate				<u>✓</u>
vacancy filling rate				

**Table 7:** Parameters responsible for matching prior restrictions over quarters 2:5 (black checkmark), 5:8 (red checkmark) and 2:8 (red underlined checkmark).

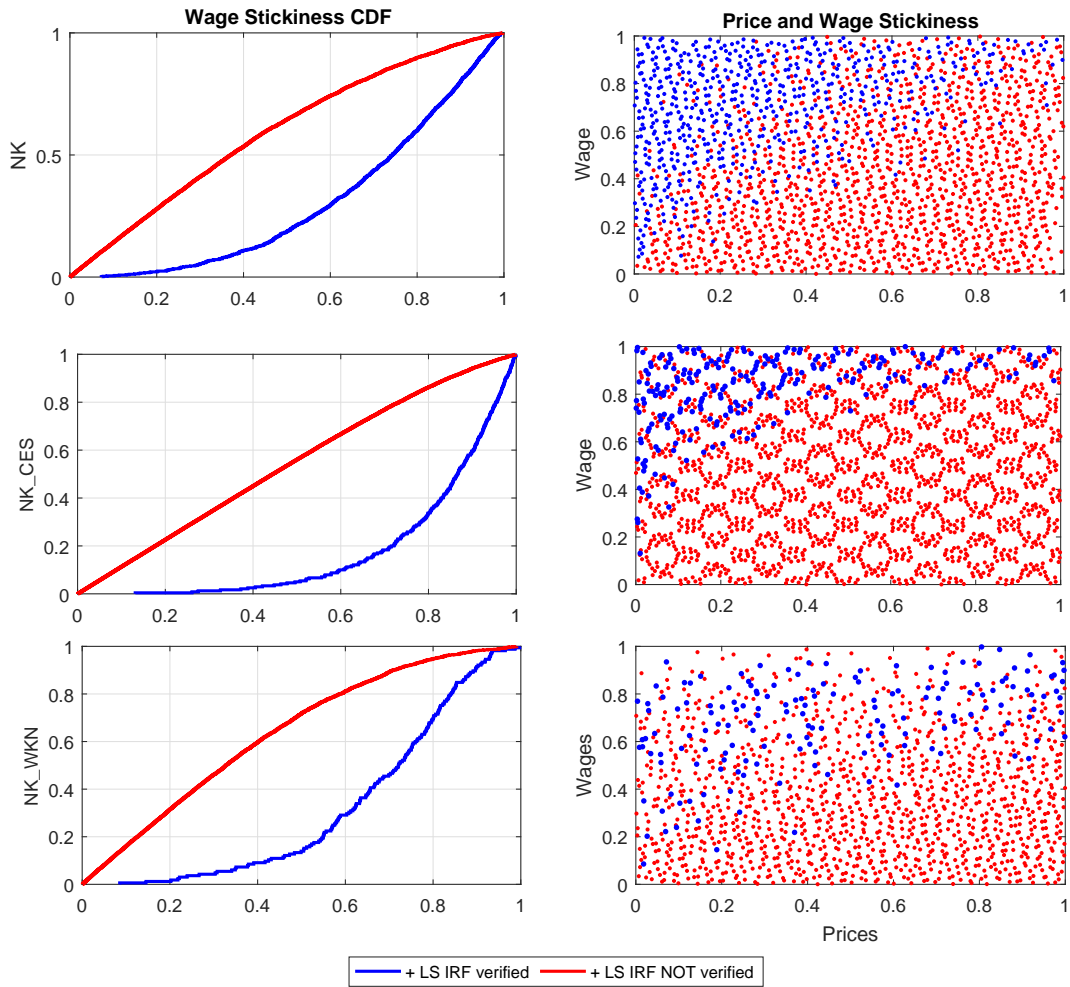


Figure 6: The wage stickiness Cumulative Density Function (CDF) on the left panels; in blue (red) the CDF that does (not) generate a positive response of the labor share. On the right panels, the combination of random draws from price and wage stickiness that do (not) verify the labor share IRF in blue (red). From top to bottom, the NK model, the NK\_CES model, and the NK\_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 8:** Priors for Bayesian IRF Matching. Distributions:  $\Gamma$  *Gamma*,  $B$  *Beta*,  $N$  *Normal*.

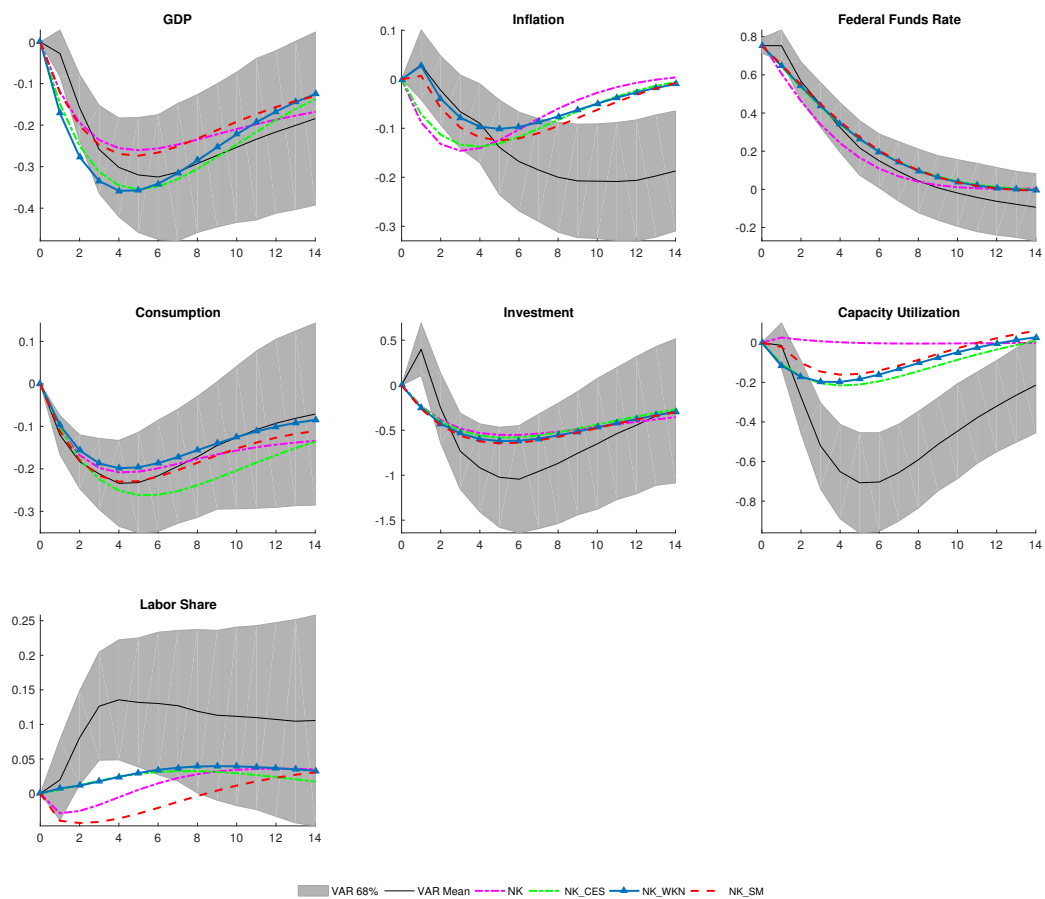


Figure 7: Bayesian Impulse Responses Matching - SVAR vs DSGE models

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