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# 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 during the Great Moderation period in the US, the Euro Area, the UK, Australia, and Canada. We show that this is inconsistent not only with the basic NK model, but with medium scale NK models commonly used for monetary policy analysis and where it is possible to break the direct link between the labor share and the inverse markup. Our results imply that either NK models are unable to separate the dynamics of the labor share from the markup, or that markups do not respond in the way NK models predict.

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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

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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, we present a new and robust set of facts for the US, the Euro Area, UK, Australia, and Canada. Furthermore, we look at the reaction of real wages as one of the key drivers of the labor share. This is needed to identify the channels through which the labor share response operates. Once we establish the empirical facts, we address our second objective. We ask the question: are current models of economic fluctuations widely used for monetary policy analysis able to jointly match the response of the labor share and real wages? This is an important question given the above mentioned reliance of models on specific MP transmission channels.<sup>2</sup>

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

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

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

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

To analyze whether theories are consistent with these robust stylized facts, we study the properties of NK models commonly used in macroeconomics for the analysis of monetary policy. We first study a simple NK model with both price and wage rigidity where we can obtain analytical results relating MP shocks and the response of the labor share and real wages. We then look at the quantitative properties of a larger model incorporating a combination of different rigidities that allow the model to separate the dynamics of the labor share from that of the markup.<sup>4</sup> We derive measures of the labor share from the model and look at their response to a MP shock. This is carried out using a three step approach. We first look at the likelihood that the model can generate the observed responses obtained in the VAR by using a Prior Sensitivity Analysis (PSA) approach. Secondly, we identify the key model parameters driving the response of the labor share and real wages using Monte Carlo Filtering (MCF) techniques. Third, once these key parameters are identified, we estimate them by matching the model's impulse responses to those of the VAR.

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

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

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4. We focus here on the model by Christiano et al. (2016), but we also provide a comprehensive analysis of other types of models in Appendix H and in a previous version of this paper (Cantore et al., 2019).

separate the dynamics of the labor share from the markup, or that markups do not respond in the way NK models predict.

*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 relationship between the markup, the labor share, and their cyclical behavior is the focus of, amongst many others, Barattieri et al. (2014), Bilts (1987), Bilts et al. (2018), Galí et al. (2007), Hall (2012), Karabarbounis (2014), and Rotemberg and Woodford (1999). These papers are closely related to the cyclical behavior of the so-called ‘labor-wedge’. Whereas papers such as Galí et al. (2007) conclude in favor of a larger role of wage rigidities to explain the cyclical behavior of the labor wedge, Bilts et al. (2018) revive the role of price stickiness as they find a counter-cyclical price markup. The conditional correlation of the labor share to demand shocks is still empirically and theoretically an open question.<sup>6</sup> However, most of these related studies focus on the dynamics of markups. Whilst markups are not directly observable and require the use of models to derive data counterparts, the labor share is directly observable. Our approach differs from these as we provide an analysis of the conditional correlations of measured labor shares in the data and their implied behavior in NK models. We start off analyzing national accounts based measures and then contrast them with consistent model-implied measures. Furthermore, our contributions relative to the extant literature are twofold: on the empirical side, we provide systematic, robust, as well as cross-country evidence and, on the theory side, we focus on the role of a wide set of real and nominal frictions and not only on price/wage stickiness.

Perhaps most closely related to our paper is Nekarda and Ramey (2019). They discuss generalizations of the production function used in NK models that decouple the price markup from the measured labor share in the data. Using these theory generalizations as empirical proxies for the markup, they show that the markup is pro-cyclical or a-cyclical in the US. Like us, they also show a counter-cyclical response of the labor share conditional on a MP shock. Their conclusions, like ours, cast doubts on the standard transmission mechanism of NK models. Our approach differs from theirs because, as mentioned above, we first obtain evidence from directly measurable labor shares and then use NK models from which we derive the behavior of the labor share and real wages and analyze the coherence between their responses to a MP shock and

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

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

that obtained in the VARs. We also make use of a wider variety of potential frictions that can decouple the dynamics of the labor share from markups. Finally, our empirical evidence on the conditional response of the labor share spans several countries and is more systematic. Importantly, while Nekarda and Ramey (2019) conclude that refocusing models around wage rigidity may resolve their empirical inconsistency, we show that, even with strong wage and labor market rigidities, models are unable to reproduce the joint behavior of the labor share and real wages.

Recently, Broer et al. (2020) address the issue of MP transmission in a simple version of the heterogeneous agent NK model. In their model, distributional effects of MP shocks in a model with only price rigidity would imply no output response. Instead, with wage rigidity, the response of labor supply disconnects from workers' income leading to output effects. They show that, with wage rigidity, profits become pro-cyclical. However, the share of output accruing to profits (i.e. the markup) is still counter-cyclical as wage rigidity can only affect its magnitude and persistence but not its sign.<sup>7</sup> Thus, the problems faced by these types of models in reproducing the dynamics of the labor share also persist when we introduce distributional effects with heterogeneous agents.

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

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

## 2. The labor share and monetary policy: Empirics

The share of labor in total income can be measured directly from national accounts. Loosely speaking, it represents the fraction of total income that is attributable to labor earnings. Unlike markups, measuring it does not require any specification of the production side of the economy. Its precise measurement is, however, complicated by issues associated with how to impute certain categories of income to labor and/or to capital earnings. The existence of self-employment income, the treatment of the government sector, the role of indirect

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

taxes and subsidies, household income accruing from owner occupied housing, and the treatment of capital depreciation, are common problems highlighted in the literature, see e.g. Gollin (2002), Gomme and Rupert (2004) and Muck et al. (2015). As in Gomme and Rupert (2004) we consider the labor share in the non-financial corporate sector. Neither proprietors' income nor rental income are included in this sector accounts. We thus avoid the issues of properly apportioning proprietors' income to labor and capital or of accounting for labor income in the housing sector. Similarly, we consider the labor share in the domestic corporate sector in Australia and we imputed mixed income in the same proportion as unambiguous labor and capital income when computing the labor share in Canada. For the Euro Area and the United Kingdom we define the labor share as compensation of employees over nominal Gross Value Added at factor costs.<sup>8</sup>

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

TABLE 1. Correlation with HP filtered Output and Policy rate.

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

Notes: GMM 95 % Confidence Intervals and sample coverage.

In these five major economies the labor share fluctuates over the business cycles possibly in response to different types of shocks. The question is then, can an unexpected MP accommodation or tightening modify the share of labor

8. In the Appendix, we describe in more detail the data construction. In particular, we consider seven different proxies for the labor share in the US for the post WWII period. The Bureau of Labor Statistics provides measures of the labor share in the non-farm business and in the non-financial corporation sectors. Cooley and Prescott (1995), Gomme and Rupert (2004) and Fernald (2012) offer alternative measurements, which we considered in the empirical exercises in order to make our statements more robust. Being highly correlated, the different proxies do not matter for the results of the paper. For the other countries, where available, we used similar approaches and measurements.

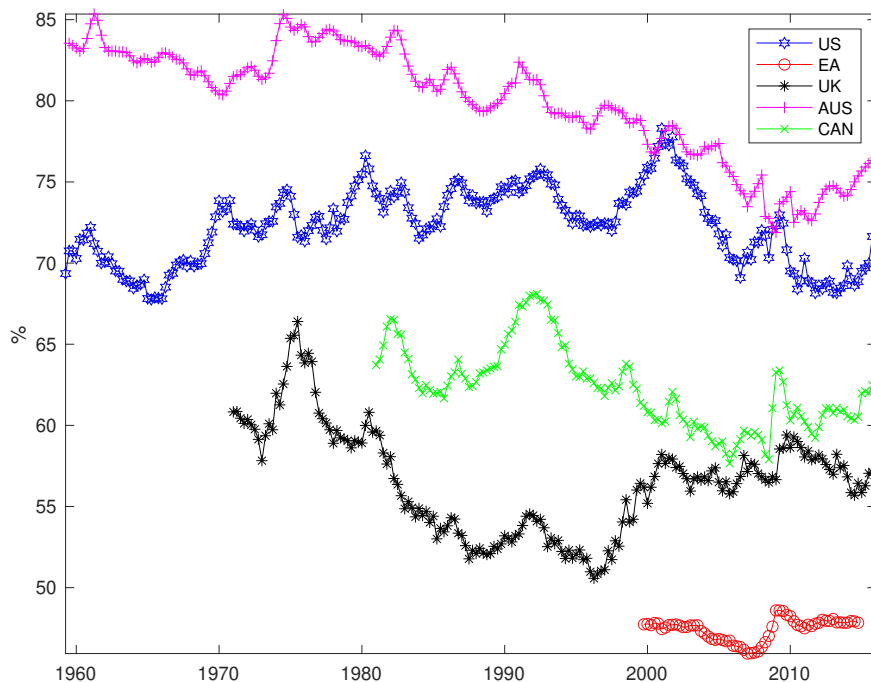


FIGURE 1. Cross Country Labor Share

income? By looking at the unconditional correlation between the labor share and the policy rate little can be inferred. As interest rates can vary for a variety of reasons, their co-movement could be the result of the systematic response of MP to other shocks hitting the economy, e.g. financial shocks. If we want to answer these questions, we need to impose more structure in order to isolate the changes in the labor share ascribed to an exogenous MP impulse. For this, we use the Vector Autoregressive (VAR) model which is a framework that has been extensively used to study the dynamic transmission of exogenous policy variations to macroeconomic aggregates. One of the advantages of VAR models is their extreme flexibility compared to theoretical business cycle models. This flexibility makes VAR-based analysis less likely to be distorted by incorrect specifications of the equilibrium conditions implied by the theoretical model. Also, under mild conditions, VARs can be regarded as unrestricted representations of micro-founded structural macroeconomic models. Thus, the dynamic transmission of monetary shocks in the structural model can be mapped into the VAR impulse responses with a minimal set of restrictions.

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

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



where  $\varepsilon_t$  is a vector of normal zero mean i.i.d. shocks with  $\Sigma = E(\varepsilon_t \varepsilon_t')$ .  $\Phi_0, \Phi_1, \dots, \Phi_p$  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  $E(\nu_t \nu_t') = I_n$ . To identify  $\Omega$ , we explored two popular approaches proposed in the literature.

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

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

The second strategy to retrieve the MP innovation from the rotation matrix,  $\Omega$ , is to assume a recursive timing restriction on the real variables of the VAR. The identification assumption is that a shock to the policy rate only has an instantaneous effect on the short term interest rate. This implies that all the other variables do not react contemporaneously to changes in the interest

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

10. We could not find any external instrument for MP surprises in Australia. Cloyne and Hürtgen (2016) developed a narrative measure of MP surprise for the UK, the results of which are discussed in footnote 13.

rate. It also implies that the policy rate does respond contemporaneously to all the macroeconomic shocks affecting prices and real variables. The specific ordering of the labor share (before or after the short term interest rate) is not crucial for the results. The virtue of this approach is that it does not require explicit measures of MP surprises, which allows us to conduct inference also for those countries where we lack proxy variables for these shocks, e.g. Australia. Moreover, as it will become apparent soon, these two approaches deliver very similar results.

Each country-specific VAR model consists of log of real GDP, the log of the GDP deflator, the log of an index of commodity prices, the log of the CPI, the log of real wages, the log of the labor share and short term interest rates.<sup>11</sup> The sample spans used for each country VAR cover the Great Moderation period. Since we are interested in the relationship between the labor share and MP, we restrict the samples to periods where monetary policy was not constrained by the effective lower bound.<sup>12</sup>

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

A bird eye view of Figure 2 suggests that the identified transmission reflects our priors about the dynamic propagation of monetary policy: in response to an interest rate hike output falls and prices decline slowly for all the countries considered. The persistence and the signs of the responses of our key macroeconomic variables are in line with what is found in other studies. What is new is the response of the labor share. In every country it is positive and statistically significant, at least using the 68% confidence sets. The increase in the labor share also appears to be persistent and does not vanish within a few quarters. The peak effect is located between five and ten quarters for the US, Canada and Australia and before five quarters for UK and EA. Furthermore, the response of the shares are also quantitatively relevant. Across all countries, we observe that the magnitude of the increase in the labor share in percentage points is at least half of the one observed for output and, in some cases, even bigger. For example, if we look at the US with the recursive identification, we

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11. VAR parameters and impulse response functions are estimated using the MATLAB toolbox discussed in Ferroni and Canova (2020).

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

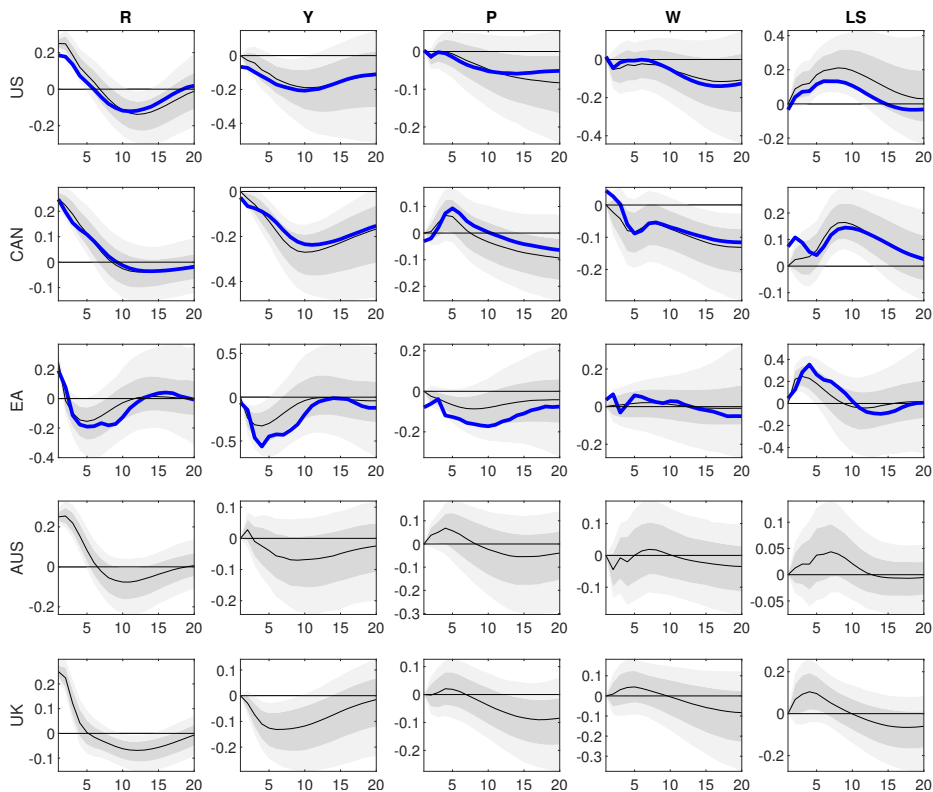


FIGURE 2. Impulse Response Function to a 25 bps increase in the short term interest rate using an identification scheme based on recursive ordering and proxy or instrumental variables (IV) for the shock of interest. The black solid line reports the median IRF using a recursive identification scheme and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

observe that the median response of output after 10 quarters is almost 20 basis points down while the increase in the labor share peaks at 20 basis points at about the same horizon. For the rest of the countries, instead, the labor share responses are about a half of the response of output.

The median impulse response functions identified via recursive ordering are very similar to those identified via proxy variables. For the US and Canada, these responses virtually overlap (first and second rows). Typically, we notice some differences on impact which occurs by construction as a result of the recursive identification. Otherwise, the responses with these two identification schemes are very similar. This is not entirely surprising when looking at the correlation between these instruments and the recursive identified innovations which are in the range of 0.2-0.5 (not shown here). Albeit less striking than

TABLE 2. Forecast Error Variance Decomposition of the Monetary Policy shock in the US.

Variable	next quarter	one year	two year	five
Real GDP	0	2	6	10
GDP deflator	1	0	1	11
CPI	0	0	0	10
PoC	0	0	2	5
Real Wage	0	1	1	3
Labor Share	2	6	11	7
Interest Rate	70	32	18	13

for the US and Canada cases, the responses with the two identification strategies are also very similar in the EA (third row). While real GDP and the GDP deflator tend to respond more with the IV identification, the median responses lie within the 68% confidence sets of the recursive identification. And, most importantly for our purposes, the labor share increases in the same qualitative and quantitative fashion. For both the UK and Australia, the recursive identification generates similar patterns which are in the ballpark of the estimates of other countries.<sup>13</sup>

The total contribution of monetary and non-monetary policy shocks to the variables in levels is small since most of the low frequency movements are explained by the deterministic component. The contribution of the MP shock to the variance of the forecast error at different horizons in the US is displayed in Table 2. These shocks explain less than 10% of the forecast error volatility of output at business cycles frequencies; these figures are in line with the findings of Ramey (2016). For the labor share, the orders of magnitude are similar to the ones of output; perhaps somewhat larger at shorter horizons. The relatively small numbers are to be expected, as a stabilizing MP should not increase the variance of macroeconomic variables. This, however, does not imply that we should not care: the importance of our evidence is about the transmission mechanism of MP shocks in models and data.

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

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

of experiments to check whether the empirical results are robust to alternative specifications which we describe next.

### **2.1. Robustness**

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

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

This identification scheme imposes a weaker restrictions relative to the recursive identification. Implicit is the idea that a MP tightening should at least raise interest rate, and depress the price level and monetary aggregates for at least three quarters. While one could impose more restrictions, these ones are uncontroversial and common to a wide variety of structural models with different types of frictions. We generate candidate draws for the rotation matrix satisfying these restrictions using the algorithm developed in Rubio-Ramírez et al. (2010). Figure [B2](#) in the Appendix plots the results for all the countries. While there are quantitative differences between this and the Cholesky identification restrictions, the qualitative results are unchanged. That is, after a MP contraction, the labor share increases for all countries (and for all labor share proxies). It is important to note that, for all the countries except the EA, we find that the impact response of

output is non-negative, which is the same result obtained by Uhlig (2005) for the US.

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

## 2.2. Discussion

Our results show that the labor share (robustly) responds positively to a MP contraction. Given that real wages fall or remain constant, this necessarily implies that labor productivity must fall more than real wages. This is because, loosely speaking, the labor share can be defined as the ratio between real wages and labor productivity:<sup>14</sup>

$$LS = \frac{WL}{Y} = \frac{W}{Y/L}.$$

Therefore, to compare the empirical results with theory models, we focus on the labor share and real wages since, in the models,<sup>15</sup> these two objects will automatically define the behavior of labor productivity.

It is also important to note that the results for real wages (and, thus, labor productivity) are not driven by composition biases in the labor force. This composition bias could arise as less productive (low wage) workers tend to exit the labor force during recessions and enter during expansions.<sup>16</sup> This bias would not affect the labor share as it is a ratio of two potentially biased responses (see Basu and House (2016)). In the case of real wages (or labor productivity) this

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

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

16. However, see Gertler et al. (2019) who argue that wages of existing workers are a better guide to the cyclicity of the marginal cost of labor due to the cyclicity of match quality.

bias may potentially affect our results. However, since we find that real wages fall or remain constant after a MP contraction, the bias can only reinforce our result: if low wage workers tend to exit during recessions, average real wages are likely to fall by more than aggregate real wages. In Appendix D we provide a detailed discussion of this problem together with estimates of the responses of wages of new hires which are less likely to be affected by composition changes. The response of wages of new hires to a contractionary MP shock is negative and stronger than for aggregate wages.

It is well known that, in standard NK models, the labor share is equivalent to the inverse of the price markup (Galí et al. (2007), Nekarda and Ramey (2019)). Rearranging the linear version of the New Keynesian Phillips curve (NKPC) as in Galí (2015), we have:

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

where  $mc_t$  represents real marginal costs (inverse of the price markup),  $\beta$  is the discount factor,  $\pi_t$  is inflation, and  $\kappa_p$  is the slope. From this expression, it is clear that a temporary decline in inflation (because of tighter monetary policy, for example) implies a decline in marginal costs (*labor share*) and an increase in the markup. This one to one relationship is independent of the presence factor adjustment costs, or financial frictions<sup>17</sup> and it is true in an economy with and without capital accumulation, provided that the production function is either Cobb-Douglas or linear in labor.

In models where the dynamics of inflation can be represented by a NKPC such as (1), the finding that the labor share increases after a MP contraction is at odds with the observed dynamics of prices and inflation. To illustrate this, we can look at a simple example. Using the basic NKPC, we can calculate the implied response of prices to a MP shock if the labor share responds as in the baseline VAR presented in the previous section, and compare it to the actual response of prices in the same VAR. In the NK model,  $\kappa_p = (1 - \theta_p)(1 - \theta_p \beta) \theta_p^{-1}$ , where  $(1 - \theta_p)$  is the proportion of firms that are allowed to reset prices. We calibrate these parameters to standard values for illustrative purposes ( $\theta_p = 0.6$ ,  $\beta = 0.99$ ).<sup>18</sup> Figure 3 shows, given the response of the labor share, the evolution of prices from the theoretical NKPC compared to the actual evolution of prices in the VAR. Prices would increase after the MP shock compared to a decrease in the data.<sup>19</sup> Hence, either the labor share is not a good proxy for marginal costs, or the NKPC is not a good representation

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17. In the form of a wedge between the real interest rate and return to capital.

18. Appendix E shows the details of this derivation.

19. It should be noted that there is a prize puzzle for Australia and Canada in the VAR. However, the implied theoretical response of prices from a NKPC given the response of the labor share would by far exceed the increase observed in the first few quarters in the data.

of inflation dynamics.<sup>20</sup> In the next section we discuss theoretical mechanisms that could separate the dynamics of the marginal cost and the labor share and hence potentially generate a positive response.

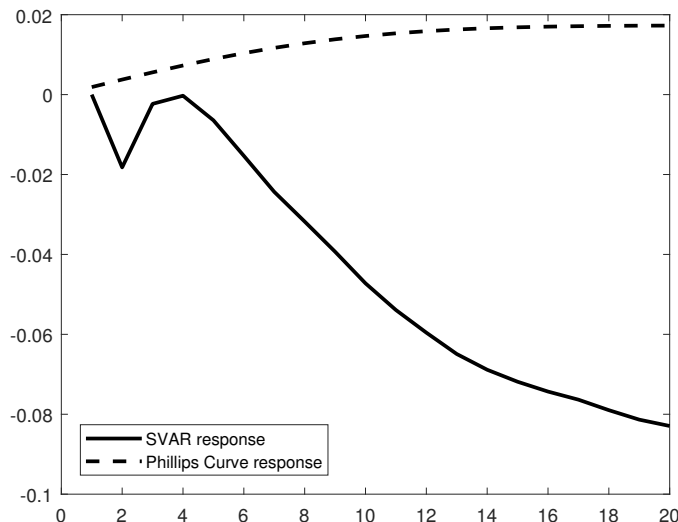


FIGURE 3. Median response of price level to a 1% MP shock in the VAR and response implied by a NK Phillips Curve given the response of the labor share. Baseline VAR using recursive identification.

### 3. The labor share and monetary policy: Theory

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

#### 3.1. Analytical results

We start with a simple model where we can obtain analytical expressions to illustrate the basic mechanisms. In log-deviation from the steady state, the labor share is defined as  $ls_t = w_t + h_t - y_t$ , where  $w_t$  is the real wage,  $h_t$  is hours, and  $y_t$  output. In a competitive labor market, labor is paid its marginal

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



product and hence  $w_t = mc_t + y_t - h_t$ , where  $mc_t$  is the real marginal cost (the inverse of the price markup). This then implies that  $mc_t = ls_t$ , a standard result in NK models. When production uses only labor and the production function displays constant returns to scale (CRS),  $y_t = h_t$ , then  $mc_t = ls_t = w_t$ . In principle, thus, the labor share could increase if nominal wages are more rigid than prices. After a MP contraction, prices fall more than nominal wages, potentially leading to an increase in real wages and the labor share. Thus, the response of the labor share should be a function of the relative degree of wage and price rigidity at least in a basic NK model. To show analytically this result, we use a simple NK model with price and wage rigidities as in Galí (2015). The set of equations describing the model are:

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

$$y_t = (1 - \alpha)h_t \quad (3)$$

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

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

$$ls_t \equiv w_t + h_t - y_t \quad (6)$$

The model is written in “gap” form. Equation (2) is the IS curve, (3) is the production function, (4) and (5) are the price and wage Phillips curves respectively, and (6) is the definition of the labor share. Here,  $y_t$  is the output gap (deviations from the flexible price/wage economy),  $w_t$  is the real wage gap,  $\pi_t$  and  $\pi_t^w$  are price and nominal wage inflation respectively,  $h_t$  is the employment gap, and  $i_t$  is the interest rate *in deviation from the natural real rate of interest* ( $r^n$ ).  $\beta$  is the discount factor,  $\alpha$  is the degree of decreasing returns in production, and  $\lambda_p$ ,  $\lambda_w$ ,  $\kappa_p$ , and  $\kappa_w$  are (positive) slope coefficients of the Phillips Curves that are a function of deep parameters of the model as follows:

$$\lambda_p = \frac{\alpha}{1 - \alpha} \kappa_p > 0 \quad (7)$$

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

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

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

where  $(1 - \theta_p)$  is the fraction of firms that readjust prices,  $(1 - \theta_w)$  the fraction of workers that readjust wages,  $\varepsilon_w$  is the elasticity of substitution of differentiated labor inputs, and  $\eta$  is the inverse Frisch elasticity. We have assumed throughout, without any loss of generality, that the degree of relative risk aversion is one.

In order to obtain an analytical solution for the responses of real wages and the labor share, we assume that the monetary authority is able to set the interest rate to track the natural real rate of interest (and hence make the gaps zero) in every period except for the initial period in which it deviates by an amount  $\varepsilon_t^{MP}$ , the MP shock.<sup>21</sup> Written in terms of deviations from  $r^n$ , this then implies:

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

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

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

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

Since coefficients  $\lambda_p$  and  $\lambda_w$  are decreasing functions of the degree of price and wage stickiness, it is clear that real wages could increase after a MP contraction given a sufficient degree of wage relative to price stickiness. In the CRS case ( $\alpha = 0$ ) the response of both variables would be equal. However, as long as  $0 < \alpha < 1$ , the response of the labor share will always be below the impact response of real wages. Thus, although nominal wage stickiness shapes the response of the labor share, this response is inconsistent with our empirical evidence. In the VAR, the labor share increases and is always above the response of real wages which generally fall after the MP contraction. Importantly, we can show that the response of the labor share *will always be negative* in this simple model. To see this, note that after a MP tightening ( $\varepsilon_t^{MP} > 0$ ) the labor share will go up only if (from equation (13)):

$$\left( \frac{\lambda_p - \lambda_w}{1 + \kappa_w + \kappa_p} - \frac{\alpha}{1 - \alpha} \right) > 0.$$

Given the definition of  $\lambda_p$  and  $\lambda_w$  above, this would imply

$$\kappa_w < -\frac{\alpha}{1 + \alpha} < 0,$$

which contradicts equation (10) above. Thus, whatever the degree of wage stickiness, the labor share and, by implication, marginal costs must decrease after a MP contraction. The intuition behind this result is that it must be the

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21. This is similar to the exposition of McKay et al. (2016).

case that a shock that reduces demand must be met by a decrease in supply in equilibrium. This can only happen if the demand for labor falls and, hence, so does its real unit cost. The labor share, which equals real marginal costs in a model with only labor in production, will then fall *regardless of the relative degree of wage and price rigidity*.

### **3.2. Medium scale models**

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

Several mechanisms commonly introduced in DSGE models can alter the relationship between the labor share and the inverse markup (marginal costs). The cost channel of monetary policy (see Ravenna and Walsh (2006) and Surico (2008)) introduces a direct effect of the interest rate on the marginal costs since firms need to borrow in order to pay in advance all or part of their labor input costs. In this setup, the markup can indeed become pro-cyclical and help generate a counter-cyclical response of the labor share. However, this cost channel also introduces a direct effect of the interest rate on the labor share which works in the opposite direction. Another way to introduce a wedge between the labor share and the markup is by relaxing the assumption of equality between the average and marginal wage (Bils (1987), Nekarda and Ramey (2019)). This is usually implemented through the introduction of fixed costs in production. Generalising the production function to the Constant Elasticity of Substitution (CES) family, as in Cantore et al. (2014), introduces a wedge between the labor share and marginal costs that depends on labor productivity and the elasticity of capital-labor substitution. Open economy models also offer a way to break the link between the labor share and marginal costs. In these models, the labor share equals the marginal cost times the terms of trade. If the elasticity of substitution between home and foreign varieties is low and/or the degree of home bias is high this could potentially increase the labor share even if marginal costs fall. Finally, relaxing the assumption of competitive labor markets and assuming search and matching (Galí (2010), Christiano et al. (2016)) implies that the real wage is related to

the bargaining power of workers. In this setting, wages do not move anymore only proportionally to the markup and labor productivity.<sup>22</sup>

Since there is a wide array of possible models, here we focus on one of the benchmark medium scale NK-DSGE models in the literature, namely, the *Calvo-sticky-wage* DSGE model presented in Christiano et al. (2016). It is a NK model containing several of these channels including fixed costs, a cost channel of monetary policy through working capital, price, and wage rigidities. Wage rigidity is introduced via the standard sticky wages Calvo set up which makes it very similar to the model in Christiano et al. (2005) and Smets and Wouters (2007). Nevertheless, Christiano et al. (2016) show that this model, conditional on a MP shock, is observationally equivalent to a model where labor market and wage rigidities are micro-founded using a model of alternating offer bargaining. Therefore, while we focus on the Calvo sticky wage model here, we consider it as also encompassing a wider array of labor market frictions (and we verify this in Appendix K). Moreover, in Appendix H and previous versions of this paper<sup>23</sup> we have considered the role of several other factors or combinations of them. These are: CES production (Cantore et al., 2015), the combination of working capital and firm networking (see Phaneuf et al. (2018)), an open economy NK model (as in Galí and Monacelli (2005)), and a standard Diamond-Mortensen-Pissarides search and matching model. Our results using all these variations quantitatively point in the exact same direction as those obtained using the benchmark Christiano et al. (2016) model used here.

Following Christiano et al. (2016), we assume that the MP shock is not in the current (period  $t$ ) information set of agents. This ensures that the timing assumptions implicit in the VAR impulse responses identified using a recursive structure are comparable with the information set in the model. The only change we make to the model is to allow for extra persistence in the MP shock in the Taylor rule.<sup>24</sup> This will help the model match the persistence of the variables obtained in the VAR.

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

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

23. See, for instance, Cantore et al. (2019).

24. In their set up  $\varepsilon_t^{MP}$  is iid while we make it AR(1).

### 3.3. Quantitative analysis: missing the link

The three steps taken to analyse the quantitative ability of the model to replicate the VAR responses is as follows. We first ask whether there are combinations of parameters that can, at least a priori, replicate the response of the labor share and real wages.<sup>25</sup> Second, we single out the parameters/frictions that are important to generate those responses. Finally, we ask the model to replicate as close as possible the VAR impulse response functions of our key macroeconomic variables by estimating the parameters that determine those key frictions.<sup>26</sup> To advance our main result, we find that, while the structural model does a decent job at matching the dynamic propagation of inflation and real quantities, it cannot replicate the propagation of the labor share and real wages.

*3.3.1. Is the workhorse medium scale New Keynesian model able to replicate the empirical findings?* Only in very particular situations we can use analytical mappings between model structural parameters and the impulse response patterns of models. For most models, these linkages are blurred by the non linear relationships between the structural and the reduced form solution. However, Montecarlo techniques allow us to assess the likelihood of a model replicating certain moments of interest. As explained by Canova (1995), Lancaster (2004) and Geweke (2005), prior sensitivity analysis (PSA) is a powerful tool to shed light on complicated objects that depend on both the joint prior distribution of parameters and the model specification. By generating a random sample from the prior distributions, one can compute the reduced form solution and the model-implied statistics of interest, e.g. impulse responses. Many replicas of the latter generates an empirical distribution of the model- and prior-implied statistics of interest.<sup>27</sup> In other words, we can assess the likelihood that the model generates a set of sign patterns that are consistent with those observed in the data conditional on the model and the specification of priors.

To this end, we attach uniform prior distributions to almost all the parameters of the model. The only two parameters held fixed are the discount factor and capital depreciation (calibrated to 0.99 and 0.025 as standard) while

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

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

27. These techniques have been used to compute the prior sensitivity of fiscal multipliers implied by different DSGE models, see Leeper et al. (2017) and Féve and Sahuc (2017).

TABLE 3. Uniform Distribution bounds for PSA and MCF.

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

fixed costs in production are set in order to maintain steady state profits equal to 0.<sup>28</sup> Table 3 shows the bounds of the uniform distributions we attach to all the other parameters. We allow for any economically meaningful value of the parameters, even for extreme values such as full price flexibility. We then generate a random sample from the prior distributions, compute the reduced form solution, and the model-implied impulse responses of interest. We repeat this many times and generate an empirical distribution of the model- and prior-implied impulse responses.

Table 4 summarizes the numerical analysis. Numbers in the table represents the percentage of the prior support that matches all the restrictions imposed on the impulse response functions. We proceed in steps and first impose only the restriction that the impulse response of the labor share needs to be positive from quarters two to five inclusive and then impose separately the same restriction, with opposite sign, to the real wage. Finally we combine both together. We repeat the exercise by imposing the same restrictions from quarters five to eight.<sup>29</sup>

Looking at the first column we see that the model has a non-negligible portion (11.2%) of the parameter space able to reproduce the sign of the labor share from quarter two to five. This percentage increases substantially (42.2%) when looking at restrictions over quarters five to eight. However, notice that

28. The model also has non zero inflation, growth rate of output and growth rate of investment in steady state. We keep the same calibration of Christiano et al. (2016) for these parameters.

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

TABLE 4. Results from prior sensitivity analysis.

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

Note: % of the prior support that matches the restrictions.

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

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

*3.3.2. What are the frictions that matter?* In order to understand the relative importance of each specific friction in driving the above results we now turn to our second step: finding the parameters that are more important to generate the response patterns in the 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 the model that are more important to drive a positive (negative) movement of the labor share (wages) in response to a contractionary MP shock. MCF has clear advantages over calibration sensitivity exercises. First, unlike sensitivity exercises, all parameters move simultaneously. Second, the Smirnov test offers, implicitly, a statistical ranking of parameters from the most to the least influential. Finally, it unveils important relationships among parameters.

Details about this stage of the analysis and results are summarized in Appendix J.<sup>30</sup> A few regularities emerge from it. First of all, as expected, both price and wage stickiness are identified as crucial. In particular, when looking only at the restriction on the labor share, a positive responses to a MP shock arise typically when there is substantial wage rigidity and when wages are less flexible than prices. The left panels of Figure 4 report the wage stickiness Cumulative Density Functions (CDF) when the labor share IRFs are positive for 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 stands out that the two distributions are different. In particular, most of the probability mass of the red CDF is located to the right of 0.75. This indicates that with relatively flexible wages we are unable to generate a positive response of the labor share to a MP shock.

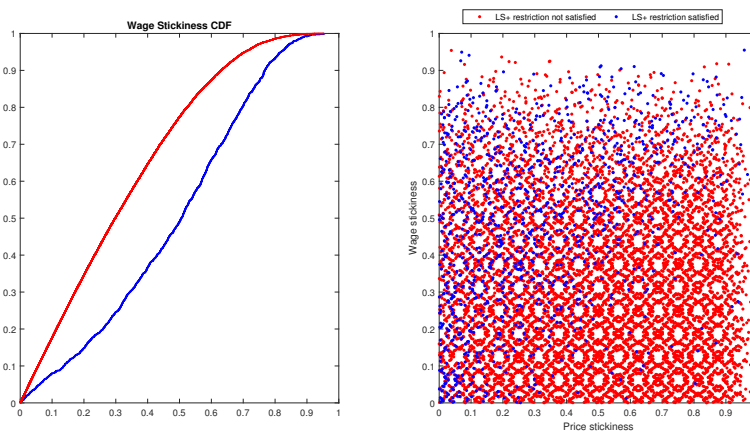


FIGURE 4. The wage stickiness Cumulative Density Function (CDF) on the left panels; in blue (red) the CDF that does (not) generate a positive response of the labor share. On the right panels, the combination of random draws from price and wage stickiness that do (not) verify the labor share IRF in blue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

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

30. Table J1 highlights parameters in the model that have a p-value of the Smirnov statistic lower than the critical value of 0.001 over the same horizons of Table 4.



corner (more flexible prices than wages), the likelihood of generating a positive response of the labor share to a MP shock increases.

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

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

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

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

Figure 5 shows the impulse responses to a MP shock in the Calvo-sticky-wage model of Christiano et al. (2016) using their original estimation values. The labor share response in the model not only moves in the opposite direction to the one found in the VAR, but the magnitude is not quantitatively large

either. The question is, how would this picture change if we estimated the parameters trying to match the labor share response as well?

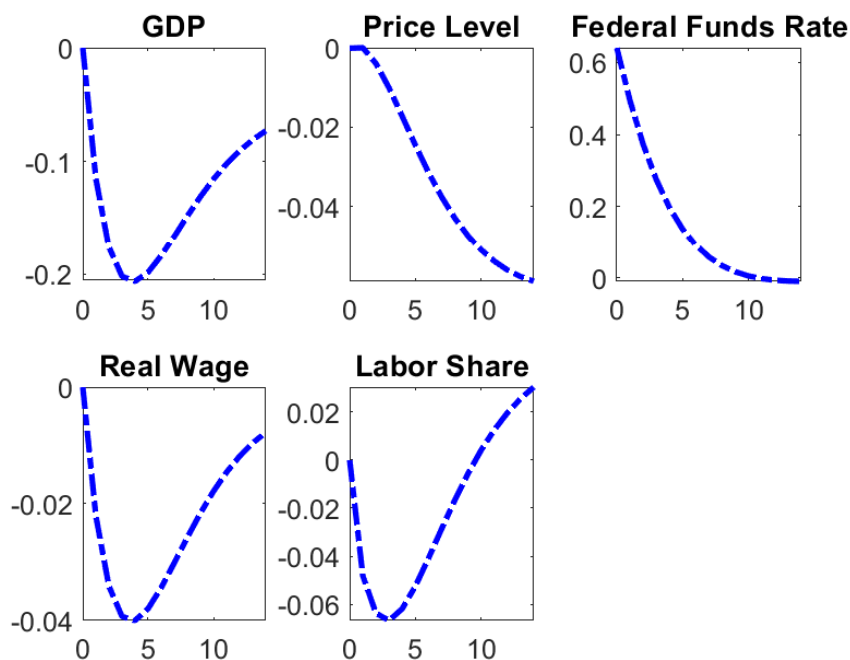


FIGURE 5. Implied Labor Share in Christiano et al. (2016) Calvo-sticky-wages model.

To do so, we re-estimate the model parameters using the same Bayesian IRF matching approach of Christiano et al. (2016), and originally developed in Christiano et al. (2010), which allows us to impose economically meaningful priors on the structural parameters. This estimation procedure consists in choosing the values of selected parameters in the DSGE model that minimize a measure of the distance between the VAR impulse responses and the DSGE model-based ones.<sup>31</sup> The IRF matching is performed using the VAR results for the US presented in section 2. As shown, the responses using proxy and Cholesky identification virtually overlap for all five variables. However, comparing confidence sets in Figures 2 and B1, we can see that the bands around the proxy responses are larger than for the Cholesky responses.

31. As we follow closely Christiano et al. (2010) and Christiano et al. (2016), we refer the readers to those sources for details on the minimum distance estimator used.

Therefore the Cholesky VAR seems to be more precise and we choose to use it for estimation.<sup>32</sup>

The model parameter space is partitioned into two subsets. One comprises calibrated parameters that are held fixed in estimation and the other parameters estimated to minimize the distance between the VAR and DSGE models IRFs. Calibrated parameters in this exercise are again the households discount factor (0.99) and capital depreciation (0.025) plus another two that do not appear empirically relevant in the MCF exercise in the previous section. These are the wage markup (1.2) and technology diffusion into government spending (0.0136) for which we keep the same calibration as in Christiano et al. (2016). Table 5 summarizes the priors used in estimation. We use a Beta distributions for probabilities, habits, interest rate smoothness and working capital fraction. A Gamma distribution is used for investment adjustment costs, capital utilization, price markup, Taylor rule responses to inflation and output, and persistence of the MP shock.<sup>33</sup> All priors are centred around values chosen in line with the literature on Bayesian estimation of DSGE models.

In the third column of Table 5 we report the parameters estimates and 95% confidence intervals. Results are in line with what is usually found in similar models estimated using full-information Bayesian maximum likelihood methods. Notably we obtain very similar degree of price and wage stickiness and their respective indexation to past inflation.

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

The results in Figure 6 are in line with the intuitive discussion of the mechanisms present in the model. Although this model contains several elements that can separate the dynamics of the labor share from that of marginal costs, these mechanisms are not well equipped to generate a dynamic response that is consistent with the one obtained in the VAR analysis. From

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

33. Note that the MP shock standard deviation prior is centred around the estimated standard deviation value in the VAR.

TABLE 5. Priors and posterior estimates - Bayesian Impulse Response Matching as in Christiano et al. (2010).

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

Note: Distributions:  $\Gamma$  Gamma,  $B$  Beta. Values report means of the posteriors (95% HDP interval in parenthesis).

the PSA analysis we know that there is a sub-set of the parameters space that can reproduce *qualitatively* the positive response of the labor share to a MP tightening. However, this subset is not selected when the whole model is estimated to match the IRFs of several variables of interest. In other words, models that can do a reasonable job at reproducing the dynamic responses of real and nominal variables cannot simultaneously match the dynamics of the labor share.<sup>34</sup> This fact sheds doubts on the transmission mechanism of MP in these models. Moreover, in estimated DSGE models for policy analysis, it is common practice to proxy marginal costs with the labor share as an observable (see, for instance, Del Negro et al. (2013)). However, if we take the evidence presented in Section 2 at face value, then the transmission mechanism assumed with this practice is at odds with the behavior of data and this can have important consequences for estimates of the model parameters.

#### 4. Conclusions

A key transmission channel of monetary policy shocks in New Keynesian (NK) models works through the effect of monetary policy (MP) shocks on markups that have direct implications for the dynamics of the labor share. In its simplest

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

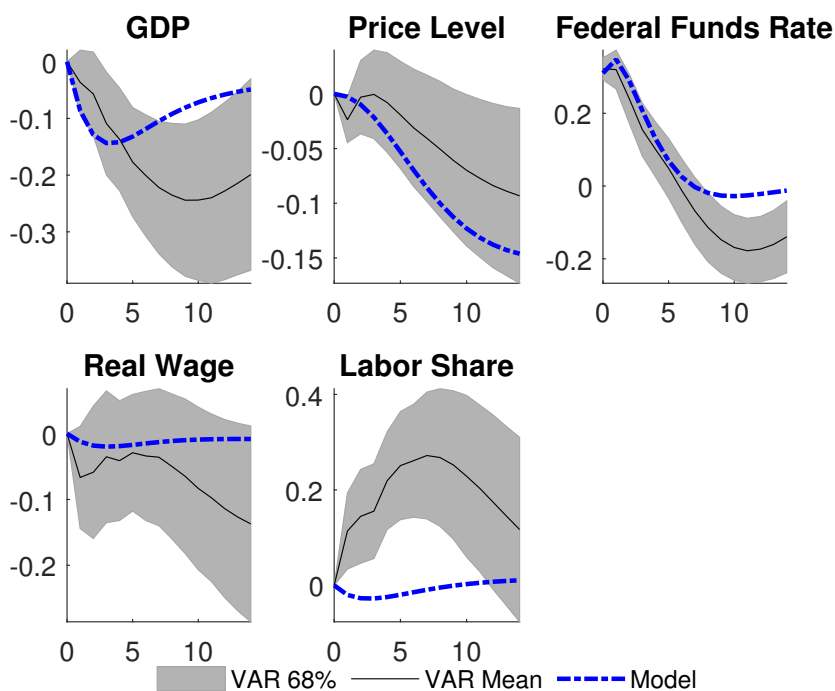


FIGURE 6. Bayesian Impulse Responses Matching - VAR vs DSGE model

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

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

We then analyze the ability of medium scale models for monetary policy analysis to reproduce these important facts. Unlike the previous related literature that focuses on the dynamics of the markup, our approach is to obtain measures of the labor share and real wages from models and analyze whether their response to MP shocks is consistent with the one observed in

the data. We first show, analytically, that a simple NK model with price and wage rigidities is unable to reproduce the increase in the labor share after a contractionary MP shock. We then study a medium scale model with capital, adjustment costs, a working capital channel, fixed costs, and nominal wage rigidities. Because of the impossibility of obtaining analytical results, we take a numerical approach that consists of three steps. We first analyze whether there is a subset of the parameter space of the model that is qualitatively consistent with the responses obtained in the VAR. We then select the subset of parameters that are important drivers of the response of the labor share and real wages. Finally, we estimate these parameters in the model using impulse response matching and compare the response of the labor share to an MP shock with that obtained in the VAR.

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

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