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 procyclical 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 United States, the Euro Area, the United Kingdom, Australia, and Canada. We show that this is inconsistent not only with the basic NK model, but also 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 markups do not respond in the way NK models predict. (JEL: E23, E32, C52)

1. Introduction

Widely used structural models for monetary policy (MP) analysis that rely on price (and wage) rigidities establish clear transmission mechanisms from MP shocks to real

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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, an MP tightening should lead to an increase in the markup and a decrease in the income share of labor because prices cannot react immediately to the fall in demand. This effect reduces unit labor costs, leading to a downward pressure on inflation. For this transmission mechanism to be operative, MP shocks should affect the cyclical behavior of the labor share in ways that are consistent with these theoretical predictions. Despite its importance, studies on the effect of MP shocks on the labor share are very scarce.[1]

Our first objective is to fill this gap and provide a cross-country comprehensive study on the effects of MP on the labor share. Using state-of-the-art vector autoregressive (VAR) identification techniques, we present a new and robust set of facts for the United States, the Euro Area (EA), the United Kingdom, 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 MP analysis able to jointly match the response of the labor share and real wages? This is an important question given the above-mentioned reliance of models on specific MP transmission channels.[2]

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

To analyze whether theories are consistent with these robust stylized facts, we study the properties of New Keynesian (NK) models commonly used in macroeconomics for the analysis of MP. 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

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 intergenerational 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.

properties of a larger model incorporating a combination of different rigidities that allow the model to separate the dynamics of the labor share from that of the markup.[4] We derive measures of the labor share from the model and look at their response to an 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. Second, 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 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 procyclical (the price markup is countercyclical) conditional on an 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 MP 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 an 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, because 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 (countercyclical) 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 separate the dynamics of the labor share from the markup or 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.[5] The relationship between the markup, the labor share, and their cyclicality

4. We focus here on the model by Christiano, Eichenbaum, and Trabandt (2016), but we also provide a comprehensive analysis of other types of models in Online Appendix H and in a previous version of this paper (Cantore, Ferroni, and León-Ledesma 2019).

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

is the focus of, amongst many others, Bils (1987), Rotemberg and Woodford (1999), Galí, Gertler, and López-Salido (2007), Hall (2012), Barattieri, Basu, and Gottschalk (2014), Karabarbounis (2014), and Bils, Klenow, and Malin (2018). These papers are closely related to the cyclical behavior of the so-called labor-wedge. Whereas papers such as Galí, Gertler, and López-Salido (2007) conclude in favor of a larger role of wage rigidities to explain the cyclical behavior of the labor wedge, Bils, Klenow, and Malin (2018) revive the role of price stickiness as they find a countercyclical price markup. The conditional correlation of the labor share to demand shocks is still empirically and theoretically an open question.[6] However, most of these related studies focus on the dynamics of markups. Whereas 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 by analyzing national account 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 (2013). 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 procyclical or acyclical in the United States. Like us, they also show a countercyclical response of the labor share conditional on an MP shock. Their conclusions, like ours, cast doubts on the standard transmission mechanism of NK models. Our approach differs from theirs because, as mentioned previously, 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 an MP shock and that obtained in the VARs. We also make use of a wider variety of potential frictions that can decouple the dynamics of the labor share from markups. Finally, our empirical evidence on the conditional response of the labor share spans several countries and is more systematic. Importantly, whereas Nekarda and Ramey (2013) 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

6. Empirically, Christiano, Eichenbaum, and Evans (2005) and Altig et al. (2011) showed, only for the United States and in a broader context, how wages and labor productivity respond procyclically 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.

to output effects. They show that, with wage rigidity, profits become procyclical. However, the share of output accruing to profits (i.e., the markup) is still countercyclical as wage rigidity can affect only its magnitude and persistence but not its sign.[7] Thus, the problems faced by these types of models in reproducing the dynamics of the labor share also persist when we introduce distributional effects with heterogeneous agents.

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

In the rest of this 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 this paper. Section 3 presents the quantitative analysis on medium-scale DSGE models using a three-step approach. We conclude in Section 4.

2. The Labor Share and Monetary Policy: Empirics

The share of labor in total income can be measured directly from national accounts. Loosely speaking, it represents the fraction of total income that is attributable to labor earnings. Unlike markups, measuring it does not require any specification of the production side of the economy. Its precise measurement is, however, complicated by issues associated with how to impute certain categories of income to labor and/or to capital earnings. The existence of self-employment income, the treatment of the government sector, the role of indirect taxes and subsidies, household income accruing from owner-occupied housing, and the treatment of capital depreciation are common problems highlighted in the literature (see, e.g., Gollin 2002; Gomme and Rupert 2004; Muck et al. 2015). As in Gomme and Rupert (2004), we consider the labor share in the nonfinancial corporate sector. Neither proprietors' income nor rental income is 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 EA and the United Kingdom, we define the labor share as compensation of employees over nominal gross value added at factor costs.[8]

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

8. In the Online Appendix, we describe in more detail the data construction. In particular, we consider seven different proxies for the labor share in the United States for the post-World War II period. The Bureau of Labor Statistics provides measures of the labor share in the nonfarm business and in the nonfinancial corporation sectors. Cooley and Prescott (1995), Gomme and Rupert (2004), and Fernald (2012) offer

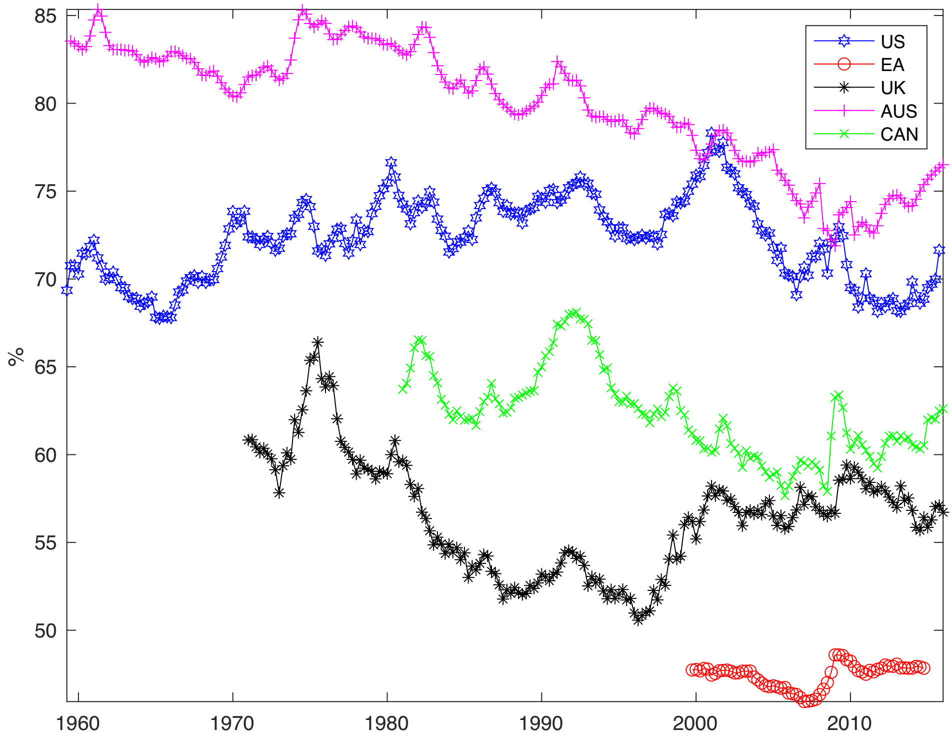

FIGURE 1. Cross-country labor share.

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 countercyclical 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 United Kingdom and the EA. Table 1 presents the 95% confidence intervals of the estimated correlation between the labor share and hodrick prescott (HP) filtered output and between the labor share and the short-term interest rate.

In these five major economies, the labor share fluctuates over the business cycles possibly in response to different types of shocks. The question is then: Can an unexpected MP accommodation or tightening modify the share of labor income? By looking at the unconditional correlation between the labor share and the policy rate, little can be inferred. As interest rates can vary for a variety of reasons, their comovement could be the result of the systematic response of MP to other shocks hitting the economy, for

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 this paper. For the other countries, where available, we used similar approaches and measurements.

TABLE 1. Correlation with HP filtered output and policy rate.

Country	Sample	Output	Policy rate
US	1955:1–2015:3	[−0.29, 0.04]	[0.28, 0.60]
EA	1999:1–2014:4	[−0.91, −0.37]	[−0.76, −0.28]
UK	1971:1–2016:1	[−0.41, 0.11]	[−0.52, 0.08]
AUS	1959:3–2013:4	[−0.23, 0.12]	[0.49, 0.70]
CAN	1981:2–2013:4	[−0.56, −0.07]	[0.45, 0.72]

Notes: Generalized methods of moments 95% confidence intervals and sample coverage.

example, 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 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 microfounded 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 comovements of our key macroeconomic variables can be described by a VAR of order p, which takes the following form:

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

where ε_t is a vector of normal zero mean i.i.d. shocks with $\Sigma = E(\varepsilon_t \varepsilon_t')$. Φ_0, Φ_1, $\ldots$, Φ_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 a linear combination of structural uncorrelated innovations, that is,

$$e_t = \Omega \nu_t,$$

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

The first approach relies on an explicit observable measure of the MP surprise, that is, the external/instrumental variable (IV) approach as pioneered by Stock and Watson (2012) and by Mertens and Ravn (2013). The basic idea of the structural VAR with an 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 us to recover the first column of the rotation matrix Ω, and thus to recover impulse responses and the transmission mechanism.

We examined a number of proxy variables for the MP shock.[9] For the United States, we considered jointly three different proxies or instruments: the Romer and Romer (2004) narrative instrument based on federal open market committee (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 MP communications; and the Miranda-Agrippino (2016) high-frequency variation of the federal funds rate adjusted for the information set (or signaling effect) of FOMC. For the EA, we considered the MP surprise constructed by Andrade and Ferroni (2016) based on the high-frequency variations of euro overnight index average swaps around the time when MP decisions and communications are publicly released by the European Central Bank Governing Council. For Canada, we considered as instrument the MP surprise constructed by Champagne and Sekkel (2018) using Bank of Canada's staff projections.[10]

The second strategy to retrieve the MP innovation from the rotation matrix, Ω, is to assume a recursive timing restriction on the real variables of the VAR. The identification assumption is that a shock to the policy rate has only an instantaneous effect on the short-term interest rate. This implies that all the other variables do not react contemporaneously to changes in the interest rate. It also implies that the policy rate does respond contemporaneously to all the macroeconomic shocks affecting prices and real variables. The specific ordering 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, for example, Australia. Moreover, as it will become apparent soon, these two approaches deliver very similar results.

Each country-specific VAR model consists of the log of real gross domestic product (GDP), log of the GDP deflator, log of an index of commodity prices, log of the consumer price index (CPI), log of real wages, log of the labor share, and short-term interest rates.[11] The sample spans used for each-country VAR cover the Great Moderation period. Because we are interested in the relationship between the labor share and MP, we restrict the samples to periods where MP was not constrained by the effective lower bound.[12]

Figure 2 reports the responses of the variables of interest to an MP shock (tightening) normalized to generate a 25 basis points (bps) increase in the short-term interest rate. The black solid line reports the median response using a recursive

9. More details on each proxy variable of monetary surprise can be found in Online 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 United Kingdom, the results of which are discussed in footnote 13.

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

12. In particular, we consider 1984:1–2007:4 for the United States, 1999:4–2011:3 for the EA, 1985:1–2009:4 for Australia, 1985:1–2011:1 for Canada, and 1986:1–2008:1 for the United Kingdom. We use three lags for the United States, Australia, and Canada, two lags for the United Kingdom, and one lag for the EA, and VAR parameters are estimated using Bayesian methods with uninformative priors.

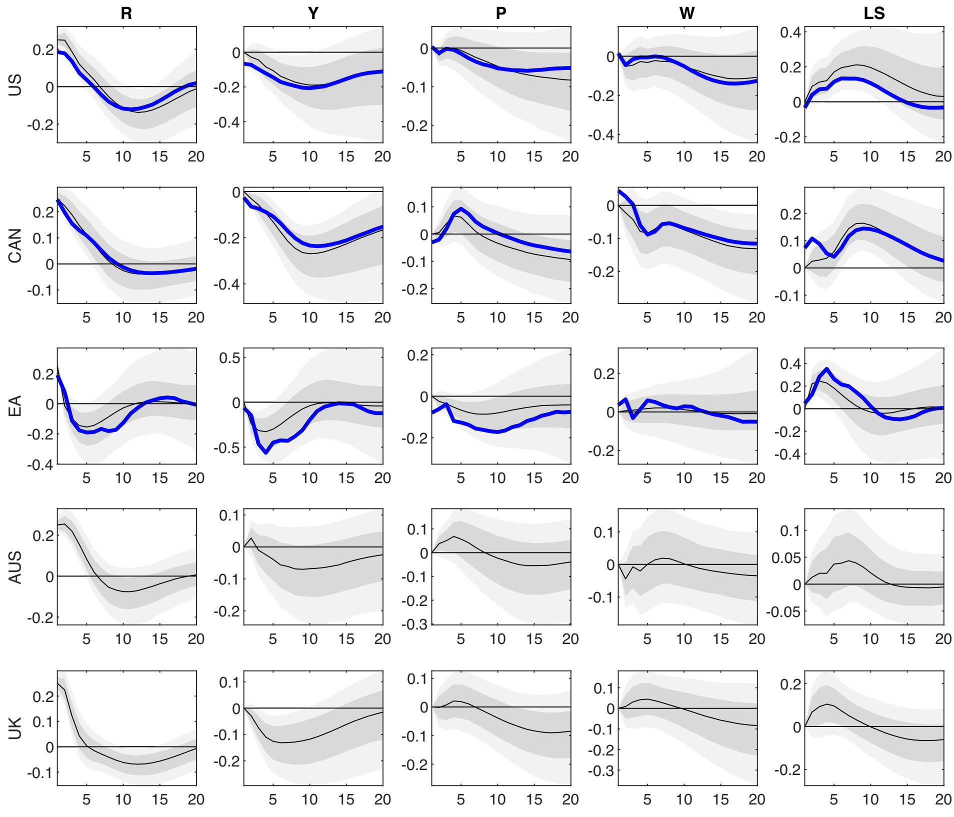

FIGURE 2. Impulse response function to a 25 bps increase in the short-term interest rate using an identification scheme based on recursive ordering and proxy variables or IVs for the shock of interest. The black solid line reports the median IRF using a recursive identification scheme and the light (dark) gray line reports 90% (68%) bands. The blue line indicates the response of 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).

identification scheme and the light (dark) gray line reports the 90% (68%) confidence sets; the blue line indicates the response using the identification scheme based on the IVs for the shock of interest. From the top to bottom row, we have the United States, Canada, the EA, Australia, and the United Kingdom. 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 MP: 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 United

States, Canada, and Australia and before five quarters for the United Kingdom and the EA. Furthermore, the response of the shares is 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 United States with the recursive identification, we observe that the median response of output after ten quarters is almost 20 bps down, whereas the increase in the labor share peaks at 20 bps 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 United States and Canada, these responses virtually overlap (first and second rows). Typically, we notice some differences on impact, which occur by construction as a result of the recursive identification. Otherwise, the responses with these two identification schemes are very similar. This is not entirely surprising when looking at the correlation between these instruments and the recursive identified innovations, which are in the range of 0.2–0.5 (not shown here). Albeit less striking than for the United States and Canada cases, the responses with the two identification strategies are also very similar in the EA (third row). Although 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 United Kingdom and Australia, the recursive identification generates similar patterns, which are in the ballpark of the estimates of other countries.[13]

The total contribution of monetary and nonmonetary policy shocks to the variables in levels is small because 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 United States is displayed in Table 2. These shocks explain less than 10% of the forecast error volatility of output at business-cycle 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, an 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

13. For the United Kingdom, we also considered the IV identification and results are somehow puzzling (see Figure B9 in the Online Appendix). Although the sign implications are identical, that is, 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. For example, a 10 bps increase in the short-run interest rate generates a 100 bps decline in inflation after 3 years. These numbers are off the chart relative to standard magnitudes. Understanding the reason of this difference is beyond the scope of this paper.

TABLE 2. Forecast error variance decomposition of the monetary policy shock in the United States.

Variable	Next quarter	1 year	2 years	5 years
Real GDP	0	2	6	10
GDP deflator	1	0	1	11
CPI	0	0	0	10
Commodity prices	0	0	2	5
Real wage	0	1	1	3
Labor share	2	6	11	7
Interest rate	70	32	18	13

shock. That is, real wages do not increase after an MP tightening. To set our stylized fact on a sound ground, we carried out a number of experiments to check whether the empirical results are robust to alternative specifications, which we describe next.

2.1. Robustness

The key message here is that we find that the rise in the labor share (and nonpositive response of real wages) following an 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 Online Appendix.

- For the United States, Australia, and Canada, we use multiple measures of the labor share (see Online Appendix A). All proxies constructed generate similar impulse responses profiles.
- For the United States, we studied different subsamples. Basu and House (2016) and Ramey (2016) show that using samples with more recent data the impulse response functions (IRFs) change substantially relative to the ones obtained in Christiano, Eichenbaum, and Evans (2005), who use a less recent time span. Ramey (2016) concludes that the most likely reason for the breakdown in the later sample is simply that we can no longer identify MP shocks well. Thus, we estimate the VAR with the baseline information set for the 1965:1–1995:3 and 1965:1 until 2007:4 samples. Subsample estimates and larger information sets do not alter our main empirical finding.
- For the United States, we considered a VAR specification, including the baseline variables plus the Fernald (2012) measure of utilization adjusted total factor productivity (TFP), labor productivity, and the Gilchrist and Zakrajšek (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 an MP shock:
  - increased the short-term nominal interest rate at $t = 0, 1, 2$;
  - decreased prices, that is, 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 restriction relative to the recursive identification. Implicit is the idea that an MP tightening should at least raise the interest rate, and depress the price level and monetary aggregates for at least three quarters. Although one could impose more restrictions, these ones are uncontroversial and common to a wide variety of structural models with different types of frictions. We generate candidate draws for the rotation matrix satisfying these restrictions using the algorithm developed in Rubio-Ramírez, Waggoner, and Zha (2010). Figure B2 in the Online Appendix plots the results for all the countries. Although there are quantitative differences between this and the Cholesky identification restrictions, the qualitative results are unchanged. That is, after an 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 nonnegative, which is the same result obtained by Uhlig (2005) for the United States.

- 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. That is, 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 an 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[14]:

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

Therefore, to compare the empirical results with theory models, we focus on the labor share and real wages because, in the models,[15] these two objects will automatically define the behavior of labor productivity.

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 an ambiguous income from proprietors, housing, and interest payments (see Online Appendix A). Only in the case in which this

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.[16] This bias would not affect the labor share as it is a ratio of two potentially biased responses (see Basu and House 2016). In the case of real wages (or labor productivity), this bias may potentially affect our results. However, because we find that real wages fall or remain constant after an 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 Online 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, Gertler, and López-Salido 2007; Nekarda and Ramey 2013). Rearranging the linear version of the NK Phillips curve (NKPC) as in Galí (2015), we have

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

where mc_t represents real marginal costs (inverse of the price markup), β is the discount factor, π_t is inflation, and κ_p is the slope. From this expression, it is clear that a temporary decline in inflation (because of tighter MP, 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[17] 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 an NKPC such as equation (1), the finding that the labor share increases after an 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 an 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 ($\theta_p = 0.6$, $\beta = 0.99$).[18] Figure 3 shows, given the response

decomposition is exact, like in the case of the US's nonfinancial 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, Huckfeldt, and Trigari (2020), who argue that wages of existing workers are a better guide to the cyclicality of the marginal cost of labor due to the cyclicality of match quality.

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

18. Online Appendix E shows the details of this derivation.

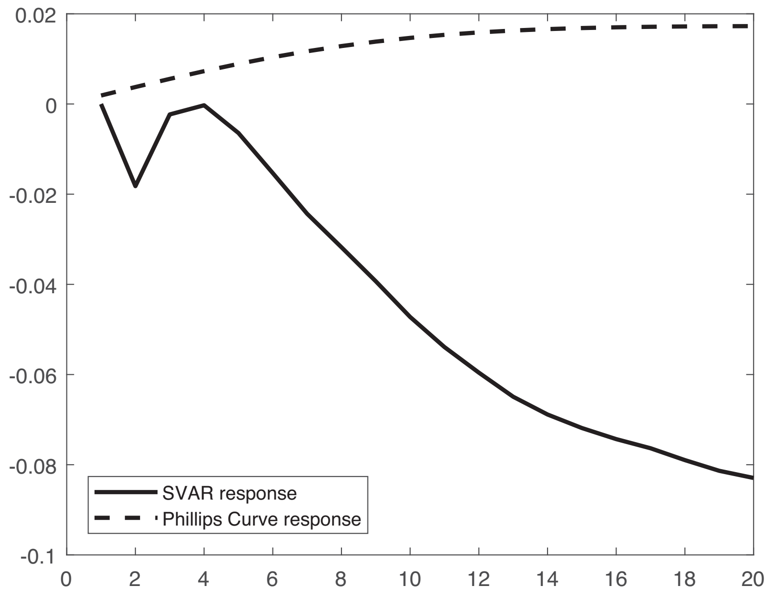

FIGURE 3. Median response of price level to a 1% MP shock in the VAR and response implied by an NKPC given the response of the labor share. Baseline VAR using recursive identification.

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.[19] Hence, either the labor share is not a good proxy for marginal costs or the NKPC is not a good representation of inflation dynamics.[20] In the next section, we discuss theoretical mechanisms that could separate the dynamics of the marginal cost and the labor share and hence potentially generate a positive response.

3. The Labor Share and Monetary Policy: Theory

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

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 an NKPC given the response of the labor share would by far exceed the increase observed in the first few quarters in the data.

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 Online Appendix F, we also look at the response of the labor share to TFP and cost shocks for the United States and show that the results are mixed.

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 is output. In a competitive labor market, labor is paid its marginal product and hence $w_t = mc_t + y_t - h_t$, where mc_t is the real marginal cost (the inverse of the price markup). This then implies that $mc_t = ls_t$, a standard result in NK models. When production uses only labor and the production function displays constant returns to scale (CRS), $y_t = h_t$, then $mc_t = ls_t = w_t$. In principle, thus, the labor share could increase if nominal wages are more rigid than prices. After an 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 this result analytically, we use a simple NK model with price and wage rigidities as in Galí (2015). The set of equations describing the model are

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

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

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

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

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

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

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

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

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

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

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

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 $\varepsilon_t^{\mathrm{MP}}$, the MP shock.[21] Written in terms of deviations from r^n, this then implies that

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

Online Appendix G shows the full derivation of the results. 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:

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

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

Because coefficients λ_p and λ_w are decreasing functions of the degree of price and wage stickiness, it is clear that real wages could increase after an 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 an MP tightening ($\varepsilon_t^{\mathrm{MP}} > 0$) the labor share will go up only if (from equation (13))

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

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

Given the above-mentioned definitions of λ_p and λ_w, this would imply

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

which contradicts equation (10). Thus, whatever be the degree of wage stickiness, the labor share and, by implication, marginal costs must decrease after an MP contraction. The intuition behind this result is that it must be the case that a shock that reduces demand must be met by a decrease in supply in equilibrium. This can only happen if the demand for labor falls and, hence, so does its real unit cost. The labor share, which equals real marginal costs in a model with only labor in production, will then fall *regardless of the relative degree of wage and price rigidity*.

3.2. Medium-Scale Models

The analytical results show that the relative degree of wage to price rigidity affects the responses of real wages and the labor share to an 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 full-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 MP (see Ravenna and Walsh 2006; Surico 2008) introduces a direct effect of the interest rate on the marginal costs because 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 procyclical and help generate a countercyclical 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 wages (Bils 1987; Nekarda and Ramey 2013). This is usually implemented through the introduction of fixed costs in production. Generalizing the production function to the CES family, as in Cantore et al. (2014), introduces a wedge between the labor share and marginal costs, which depends on labor productivity and the elasticity of capital–labor substitution. Open economy models also offer a way to break the link between the labor share and marginal costs. In these models, the labor share equals the marginal cost times the terms of trade. If the elasticity of substitution between home and foreign varieties is low and/or the degree of home bias is high, this could potentially increase the labor share even if marginal costs fall. Finally, relaxing the assumption of competitive labor markets and assuming search and matching (Galí 2010; Christiano, Eichenbaum, and Trabandt 2016) implies that the real wage is related to the bargaining power of workers. In this setting, wages do not move anymore only proportionally to the markup and labor productivity.[22]

Because there is a wide array of possible models, here we focus on one of the benchmark medium-scale NK-DSGE models in the literature, namely, the *Calvo-sticky-wage* DSGE model presented in Christiano, Eichenbaum, and Trabandt (2016). It is an NK model containing several of these channels, including fixed costs, a cost channel of MP through working capital, price, and wage rigidities. Wage rigidity is introduced via the standard sticky wages Calvo setup, which makes it very similar to the models in Christiano, Eichenbaum, and Evans (2005) and Smets and Wouters (2007). Nevertheless, Christiano, Eichenbaum, and Trabandt (2016) show that this model, conditional on an MP shock, is observationally equivalent to a model where labor market and wage rigidities are microfounded using a model of alternating offer bargaining. Therefore, while we focus on the Calvo-sticky-wage model here, we consider it as also encompassing a wider array of labor market frictions (and we verify this in Online Appendix K). Moreover, in Online Appendix H and previous versions of this paper,[23] 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, Sims, and Victor 2018), an open economy NK model (as in Galí and Monacelli 2005), and a standard Diamond–Mortensen–Pissarides search and matching model. Our results using all these variations quantitatively point in the exact same direction as those obtained using the benchmark Christiano, Eichenbaum, and Trabandt (2016) model used here.

Following Christiano, Eichenbaum, and Trabandt (2016), we assume that the MP shock is not in the current (period t) information set of agents. This ensures that the timing assumptions implicit in the 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.[24] 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 in the following.

3.3. *Quantitative Analysis: Missing the Link*

The three steps taken to analyze the quantitative ability of the model to replicate the VAR responses is as follows. We first ask whether there are combinations of parameters

22. Online 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, Ferroni, and León-Ledesma (2019).

24. In their setup, $\varepsilon_t^{\mathrm{MP}}$ is i.i.d., whereas we make it AR(1).

that can, at least a priori, replicate the response of the labor share and real wages.[25] 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.[26] To advance our main result, we find that, although 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 NK 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 nonlinear relationships between the structural and the reduced-form solutions. However, Monte Carlo 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), 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, for example, impulse responses. Many replicas of the latter generate an empirical distribution of the model- and prior-implied statistics of interest.[27] 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), whereas fixed costs in production are set in order to maintain steady-state profits equal to 0.[28] 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.

25. As mentioned previously, 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 correctly identify DSGE model shocks (see Erceg, Guerrieri, and Gust 2005). For this reason, in the spirit of the Sims–Cogley–Nason approach, we tested whether the 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 Online Appendix I.

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

28. The model also has nonzero inflation, growth rate of output, and growth rate of investment in a steady state. We keep the same calibration of Christiano, Eichenbaum, and Trabandt (2016) for these parameters.

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	$U[0, 1]$

TABLE 4. Results from prior sensitivity analysis.

Restrictions					
Two to five quarters			Five to eight 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.

Table 4 summarizes the numerical analysis. Numbers in the table represent 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 an opposite sign, to the real wage. Finally, we combine both together. We repeat the exercise by imposing the same restrictions from quarter 5 to 8.[29]

Looking at the first column, we see that the model has a nonnegligible portion (11.2%) of the parameter space able to reproduce the sign of the labor share from quarter 2 to 5. This percentage increases substantially (42.2%) when looking at restrictions over quarters 5–8. However, notice that the probability of replicating the full profile, that is, from quarter 2 to 8, is the product of these two percentages. In columns (2) and (5), we look at the proportion of the parameter space that generates

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

negative real wages. In this case, the percentage declines over the IRF horizons but remains around 40% from quarter 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 nonzero 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 aforementioned 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 mentioned previously because it requires an inverse mapping. Monte Carlo 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 Smirnoff test offers, implicitly, a statistical ranking of parameters from the most to the least influential. Finally, it unveils important relationships among parameters.

Details about this stage of the analysis and results are summarized in Online Appendix J.[30] 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 response to an MP shock arises 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 c.d.f. when the labor-share IRFs are positive for two to five 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 c.d.f. is computed. As stands out that the two distributions are different. In particular, most of the probability mass of the red c.d.f. 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 an MP shock.

30. Online Appendix 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.

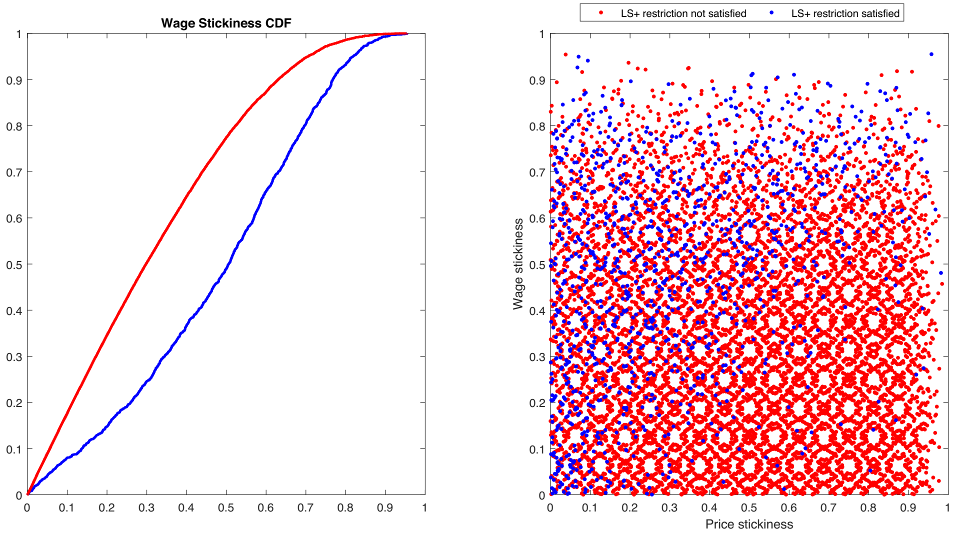

FIGURE 4. The wage stickiness c.d.f. on the left panels; in blue (red), the c.d.f. that does (not) generate a positive response of the labor share. In the right panels, the combination of random draws from price and wage stickiness that do (not) verify the labor share IRF in blue (red).

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

In sum, the 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, that is, 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 a 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 the persistence of the MP shock. The working capital fraction, wage and price indexation, and the curvature of the investment

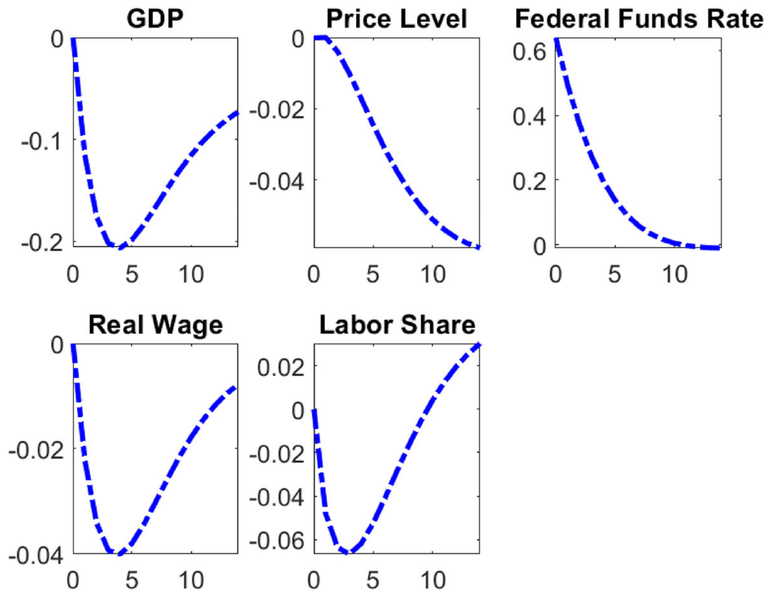

FIGURE 5. Implied labor share in the Christiano, Eichenbaum, and Trabandt (2016) Calvo-sticky-wage model.

adjustment cost 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 IRF 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 macrovariables to an MP shock? The answer to this question is not trivial. Because 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 an MP shock in the Calvo-sticky-wage model of Christiano, Eichenbaum, and Trabandt (2016) using their original estimation values. The labor share response in the model not only moves in the opposite direction to the one found in the VAR, but the magnitude is not quantitatively large either.

The question is: How would this picture change if we estimated the parameters trying to match the labor share response as well?

To do so, we reestimate the model parameters using the same Bayesian IRF matching approach of Christiano, Eichenbaum, and Trabandt (2016), and originally developed in Christiano, Trabandt, and Walentin (2010), which allows us to impose economically meaningful priors on the structural parameters. This estimation procedure consists of 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.[31] The IRF matching is performed using the VAR results for the United States 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 (Online Appendix), we can see that the bands around the proxy responses are larger than for the Cholesky responses. Therefore, the Cholesky VAR seems to be more precise and we choose to use it for estimation.[32]

The model parameter space is partitioned into two subsets. One comprises calibrated parameters that are held fixed in estimation and the other comprises parameters estimated to minimize the distance between the VAR and DSGE model IRFs. Calibrated parameters in this exercise are again the household discount factor (0.99) and capital depreciation (0.025) plus another two that do not appear empirically relevant in the MCF exercise in the previous section. These are the wage markup (1.2) and technology diffusion into government spending (0.0136) for which we keep the same calibration as in Christiano, Eichenbaum, and Trabandt (2016). Table 5 summarizes the priors used in estimation. We use a Beta distribution 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.[33] All priors are centered around values chosen in line with the literature on Bayesian estimation of DSGE models.

In the third column of Table 5, we report the parameter 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 a 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

31. 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.

32. The objective function of the IRF matching exercise is to minimize the (squared) distance between the responses of the empirical and structural models, 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 centered around the estimated standard deviation value in the VAR.

TABLE 5. Prior and posterior estimates—Bayesian impulse response matching as in Christiano, Trabandt, and Walentin (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)

Notes: Distributions: Γ—Gamma, *B*—Beta. Values report means of the posteriors (95% HDP interval in parentheses).

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 six 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 the PSA, we know that there is a subset of the parameter space that can reproduce *qualitatively* the positive response of the labor share to an 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.[34] 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

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 Online Appendix L.

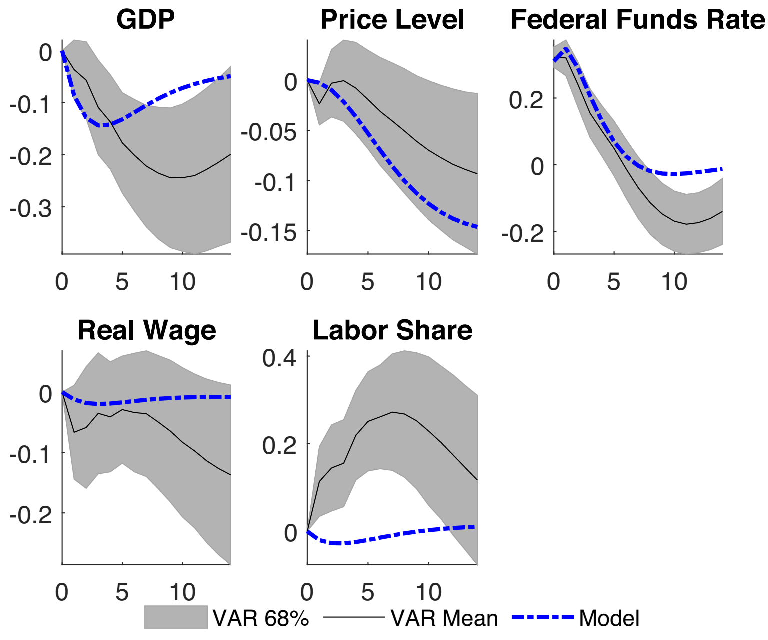

FIGURE 6. Bayesian impulse response matching—VAR versus DSGE models.

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 MP shocks in NK models works through the effect of MP shocks on markups, which have direct implications for the dynamics of the labor share. In its simplest version, the NK model implies that, after an MP shock, markups increase and the labor share falls. The direct link between the markup and the labor share, however, breaks down into a variety of models, which introduce aspects such as different production functions, fixed costs, labor market frictions, and/or a cost channel of MP. 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 MP on the labor share and real wages for a set of five economies: the United States, the EA, the United Kingdom, Australia, and Canada.

Using state-of-the-art VAR identification techniques, our evidence shows that, cyclically, an 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 MP 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 setups. 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 an MP shock. Our results then imply that either models are unable to separate the dynamics of the labor share from marginal costs or marginal costs do not respond in the way models predict.

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Supplementary Data

Supplementary data are available at *JEEASN* online.