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Accounting for post-crisis inflation: A retro analysis ☆

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ABSTRACT

Why was there no deflation and what accounts for inflation after 2008? Is the missing deflation puzzle an indictment of Phillips-curve-type analysis, or is all well and good if one fixes the model with the appropriate features? To shed light on this issue and in order to avoid confounding the answer with post-crisis model adaptations, we provide a "retro analysis" and employ the original benchmark of Smets and Wouters (2007) model. We show that this model implies that shocks to price and wage markups alone are nearly enough to account for inflation before 2008, and that they do so substantially post 2007 as well. While markup shocks account for most of the inflation movements, they do not play a significant role in the accounting of employment: the Phillips curve tradeoff is weak after 2007 according to the model, but also before 2007. We thus argue that the asserted post-crisis model failures were visible pre-crisis already. Extending the retro analysis with features introduced by the most recent part of the literature does little to alter our key insights.

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1. Introduction

Retro (adj.): Esp. of fashion, music, or design: characterized by imitation or revival of a style from the (relatively recent) past; (more generally) backward-looking, nostalgic, esp. affectedly so. *Oxford English Dictionary*

Why was there no deflation after the severe financial crisis and downturn of 2008 and what accounts for the subsequent inflation that occurred? Some have argued that the absence of deflation demonstrates a failure of the Phillips curve and New Keynesian theories linking economic slackness to deflationary pressure. In Hall (2011)'s Presidential Address, he argues that "the inflation rate hardly responded to conditions in product and labor markets, else deflation might have occurred." He concludes that theories based on the concept of Non-Accelerating Inflation Rate of Unemployment (NAIRU) fail to explain the dynamics of inflation during the recent crisis.

By contrast, Del Negro et al. (2015) argue that a standard New Keynesian Dynamic Stochastic General Equilibrium (DSGE) model, amended with financial frictions features proposed prior to the 2008 crisis, successfully predicts a sharp contraction in economic activity along with a modest decline in inflation. They argue that the missing deflation was due to high expected future marginal costs. Relatedly, Christiano et al. (2015) explain the small drop in inflation during the Great Recession using a fall in the total factor productivity and the rise in the cost of working capital.

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However, these authors agree, in essence, that the models prominently used prior to the crisis of 2008 need repair or replacement. Even Del Negro et al. (2015) amend the Smets and Wouters (2007) model considerably. While we agree that substantial and worthwhile research progress has been made based on the experience and lessons of 2008, it is also worth pointing out that examining the missing deflation puzzle with models which have been constructed or amended after the fact is not an out-of-sample prediction exercise. One may see this as akin to arguing that the profession is capable of delivering models that can predict or consider what will or may happen only after we have seen the data. It leaves the question open as to whether the New Keynesian transmission channel is broken or whether it is alive and well, as long as we keep fixing things here and there. Is there hope that this process will converge eventually?

We provide an altogether different perspective in this paper. We first draw on the Smets and Wouters (2007) model for our exercise, as this was perhaps the most popular New Keynesian pre-crisis DSGE model. Various central banks have given it much attention and therefore policy relevance. We shall use that model as originally devised to account for the behavior of inflation. Likewise, we examine movements in employment to shed light on the Phillips curve trade-off, which is central to (New) Keynesian analyses.

On purpose and in the spirit of the out-of-sample prediction exercise, we do not amend the model with greater considerations of the financial sector, nonlinearities and policy changes arising from the Zero Lower Bound (ZLB) considerations, or a time-varying inflation target, as has been done in Del Negro et al. (2015). We provide our benchmark perspective and account for the movements of inflation and employment per decomposing them into their reactions to present and past shocks, according to the linear and original Smets and Wouters (2007) model. We take this "retro perspective" by design.

The original model treats the difference between a negative nominal interest rate predicted by a linear Taylor rule and an actual nominal interest rate of zero as a surprise tightening; we do so as well. The negatives of this approach are discussed in section 8, where we argue that the impact of the ZLB on inflation generally is ambiguous and depends on fine modeling details and assumptions about monetary policy. We provide a numerical example in which the way we model the monetary policy in our paper is either underestimating or overestimating the actual impact effect of the ZLB on output and inflation. The sign of the effect depends on the type of monetary policy followed by the central bank during the ZLB episode. In this light, ours is a reasonable benchmark for the evaluation of the role of the monetary policy at the ZLB.

The key insight from our analysis follows. We find that inflation through the entire sample is accounted for almost entirely by price- and wage-markup shocks, with some (unsurprising) additional impact from the ZLB post-2008. Moreover, price- and wage-markup shocks post-2008 are not unusual in size. The model does not predict much deflation absent in these shocks in any case. The ZLB-implied "surprise" tightening of monetary policy post-2008 only contributes a downward pressure on inflation of about two percent.

Furthermore, we find that the shocks accounting for inflation do not account for much of the movements in employment. The built-in Phillips curve tradeoff is of minor importance for understanding the data over the entire sample, not just post-2008. The Smets and Wouters (2007) model does allow for a financial friction in the form of a wedge, somewhat similar to Chari et al. (2007). This wedge plays some role post-2008.

These results can be read in two ways, but both disagree with the literature perspective discussed above. One may wish to argue that the Smets and Wouters (2007) model was sufficient prior to 2008 in accounting for inflation. But then, one must concede that the model is reasonably fine post-2008 as well in terms of accounting for the inflation. The severe crisis of 2008 does not provide much news here. Conversely, one may argue that the model fails to appropriately account for inflation post-2008, that its mechanisms make little sense in context and that it therefore needs repair or replacement. But since that account does not differ much from the account for pre-2008 inflation, this indictment of the model is just as valid when examining the data prior to the crisis.

While our sympathy is with this second perspective, its message is more fundamental and hopeful than the dismal perspective of always having to fix models ex-post of the current literature. The financial crisis was unnecessary for questioning the inflation accounting capability and the importance of the Phillips curve tradeoff in prominent pre-crisis models, such as Smets and Wouters (2007). Put differently, there is hope in seeking to construct models that can reasonably account for macroeconomic outcomes, even in the face of a future crisis of unknown origin. A crisis such as 2008 is obviously an opportunity and instigation for improving the models further, for greater attention to the role of the financial sector, or for adding vigor to pursuing other agendas. But if the data prior to 2008 did not lead us to invalidate the Smets and Wouters (2007) model for the question at hand of accounting for inflation, the crisis of 2008 shouldn't either.

With our preferred reading of the results — and we concede that an alternative reading is conceivable — the missing deflation puzzle post-2008 (and with our preferred reading of the results) is simply a new version of the insight already available in 2008. There is no good understanding of what drives inflation based on New Keynesian theories such as Smets and Wouters (2007). We therefore sympathize with Hall (2011), when he argues that inflation behaves in a near-exogenous fashion. Importantly, we add that this is even more accurate before 2008. We agree with King and Watson (2012), who challenge the ability of New Keynesian models to explain inflation dynamics, and consider our result to be in line with theirs.

Accounting for or explaining the behavior of inflation is the theme of a large and active body of literature. Coibion and Gorodnichenko (2015) argue that the missing deflation puzzle can be explained by a rise in inflation expectations. Similarly, in Stock's discussion of Ball and Mazumber (2011), he argues that the missing puzzle disappears when we consider PCE-XFE, headline CPI, headline PCE, and median CPI inflation. The borrowing cost channel is explored by Gilchrist et al. (2015).

Building on the fiscal theory of the price level, Cochrane (1998), Cochrane (2011), and Leeper and Zhou (2013), Leeper (2013) argue that the expansion of government debt may have led to higher inflation. The inflation-employment-stimulating effects of government spending from a Phillips-curve perspective has been a substantial subject of the literature, such as Cogan et al. (2010), Drautzburg and Uhlig (2011), Shoag (2013), Kaplan and Violante (2014), and Wilson (2012). This has been called into question by Dupor and Li (2015) and Conley and Dupor (2013).

Our findings on the role of price- and wage-markup shocks account for inflation during the Great Recession are related to Bassetto et al. (2013), who document that statistical models predict disinflation during the Great Recession, which does not occur due to offsetting residuals. Related, Linde and Trabandt (2018) stress the importance of nonlinearities in price and wage setting. Gilchrist et al. (2015) argue that the missing deflation puzzle originated from the relation between firm pricing decisions and liquidity constraints.

In section 2, we describe our approach. Section 3 presents the main point of the paper. The following sections provide additional details. Sections 4, shows the results for inflation for the entire sample from 1948 to 2014. In section 5, we "zoom in" on the crisis and post-crisis episode, starting in 2007, and provide some counterfactuals. Section 6 focuses on employment and on the Phillips curve. In section 7, we analyze the interest rate implied by the Taylor rule after the crisis. Section 8 discusses the role of the ZLB. Section 9 examines three alternative models. We allow for a time-varying inflation target, and we study Del Negro et al. (2015) and Christiano et al. (2015) through the lens of our approach. Section 10 offers some final discussion and conclusion.

2. Our approach

Although Smets and Wouters (2007)'s model is well-known, it is worth mentioning the main features here. The model assumes a representative household, whose utility function is nonseparable in consumption and leisure, with external habits in consumption. Households can save by investing in capital or by buying government bonds. In addition, households choose the level of capital and of capital utilization. Investing in capital, households incur a non-linear cost. Labor unions and firms set wages respectively and prices according to a Calvo pricing mechanism. Both wages and prices are partially indexed to inflation.

Finally, the interest rate is set according to a Taylor rule. Weights are on both inflation and output gap, and the government expenditure is assumed to be exogenous. Further details can be found in Smets and Wouters (2007), as well as in the online appendix to this paper.

The original model features seven shocks: shocks to the technological process, to the consumer's preferences, to the government expenditure, to the investment-specific technology, to a price- and a wage-markup shock, and to a monetary policy shock. The assumptions of the model and the choice of the shocks restrict the set of possible explanations for the observed movements of the variables. Although limited, the structure of the model provides a fair amount of flexibility.

In spite of the fact that financial frictions are not explicitly modeled, the shock in the Euler equation is a reduced form for all sources of financial friction that distort the intertemporal choices.[1] Moreover, frictions that modify firms' behavior are captured by the shocks to the price markup if they affect the firms' price setting decision. Furthermore, the interpretation of shocks as financial frictions to investment-specific technology is an intriguing possibility.

We solve and re-estimate the model using Dynare and a sample for the period 1984-2007, rather than the sample 1948-2004, as in their original paper. We explored the conclusions of the paper when using different samples for the estimation (1948-2007 and 1984-2015). The results are not much effected by the choice of sample, and are available upon request.

With this exception, we use the same procedure as Smets and Wouters (2007). We use a Bayesian approach and prior, as well as the same (extended) time series, i.e., the seven US time series on the log difference of the real GDP, real consumption, real investment, real wage, log hours worked, log difference of the GDP deflator, and the federal funds rate. Details and robustness checks are in the online appendix.

The sample start date of 1984 is motivated by the significant shift in the economy around the time. Although estimates are sensitive to this choice, the qualitative results are not altered by including the period before 1984.

Successively, we use the estimated model to calculate a (Wold) shock decomposition. This is a standard method in the literature, see Fernandez-Villaverde et al. (2007), a brief outline of which shall suffice. After log-linearization, the model can be written as a system of linear equations.[2]

Given the seven observables and an initial condition, we can solve for the time series of the seven shocks. With this, we can now decompose the movements of inflation and employment into the sequence of present and past shocks.

This approach also allows us to calculate a variance decomposition for the variances of the four-quarter forecast error as well as the unconditional variance (or infinite-horizon forecast error[3]). We compute them at the posterior mean

[1] See Drautzburg and Uhlig (2011), for instance.

[2] Linde and Trabandt (2018) show that there are significant differences between the log-linear and non-linear versions of the NK model, especially when using the Kimball aggregator, as done by Smets and Wouters (2007). Here we choose to follow the original approach.

[3] For practical reasons, we calculate a variance decomposition of the 200-period forecast error.

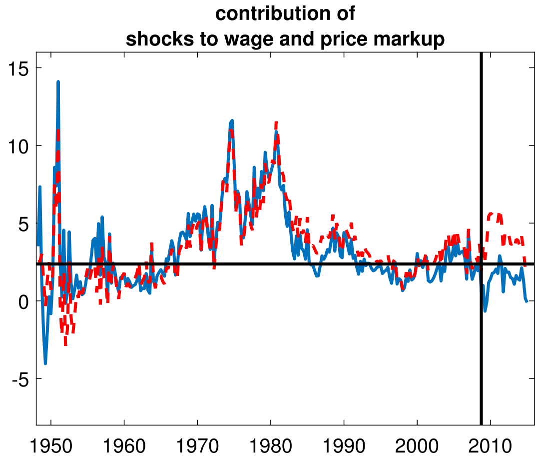

Fig. 1. Actual inflation versus the portion accounted for by price- and wage-markup shocks for the period 1948Q1-2015Q1. The solid line is actual inflation. The dashed line is inflation predicted by price- and wage-markup shocks. The horizontal line is the long-run average level of inflation.

for the coefficient matrices and the posterior mean for the shock variances. To compare the contributions of the shocks across subsamples, we use the estimated variances for u_t for these subsamples as well. We report both the historical shock decomposition and the variance decomposition because the results stemming from the two approaches do not coincide necessarily.

The model links inflation, π_t, to the real economy via a Phillips curve,[4]

$$\pi_t = \pi_1 \pi_{t-1} + \pi_2 E_t \pi_{t+1} - \pi_3 \mu_t^p + \epsilon_t^p, \tag{1}$$

where π_1, π_2, π_3 are coefficients, μ_t^p is the price markup (equal to the difference between the marginal product of labor and the real wage), and ϵ_t^p is a price markup disturbance. This Phillips curve displays both time-dependence from the past and dependence on the future. It links inflation to the real economy via the price markup.

Even though the model is a system of equations, researchers often like to think of the Phillips-curve equation as "determining" inflation. One way to read our paper is that the disturbances play a key role in this equation. This intuition will be explored more in detail when discussing employment accounting.

3. Main story

The main story of our analysis is told by Fig. 1. It shows the actual inflation rate versus the portion of the inflation rate that is explained by just the price- and wage-markup shocks and the sample mean. It is visually clear that these two shocks together practically account for inflation entirely.

The importance of wage- and price-markup shocks in accounting for the inflation dynamics is confirmed by the variance decomposition. Between 1948 and 2015, the two shocks combined account for 87.04% of the variance of inflation at one-year horizon (first column of Table 1). The table reports the variance decomposition for the entire period (left column), the pre-crisis period (center column), and the post-crisis period (right column). The measures in the three samples only differ for the variance of the shocks, restricted to the sample period considered in each column. The Wold coefficients are the same throughout the three columns, and they are computed using the full sample. Although the role of price-markup shocks following the oil shocks of the 80s is reduced, the combination of the two shocks still accounts for the majority of the variance of inflation in the period 1984-2015.

In our view, the overwhelming importance of the shocks to price- and wage-markup hints at a general failure of the model to explain the inflation dynamics. Our finding is related to a number of other studies on the issue. It corroborates King and Watson (2012), who show that inflation dynamics can be decomposed in part due to changes in the marginal cost and in part due to changes in inflation expectations. They find that inflation expectations are the most important component.[5]

However, it has also been argued that the lack of responsiveness of the inflation to the economic slackness could be a proof of the central bank's success implementing a stabilizing monetary policy. Following this line of reasoning, inflation was stable during the 90s because the central bank successfully stabilized it, whereas it was high during the 70s because the monetary policy was too lax. This may be so.

[4] Equation (10) in Smets and Wouters (2007).

[5] Based on a similar result, Hall (2011) and Michaillat and Saez (2014) postulate that the inflation rate follows an exogenous path.

Table 1
4-Quarters ahead variance decomposition.

Inflation				
	1948-2015	1948-2007	1984-2007	2008-2015
Technology	1.78	1.70	2.46	3.33
Price Markup	69.48	71.45	55.09	42.94
Wage Markup	10.13	8.11	23.92	42.25
Risk Premium	0.48	0.47	0.28	0.66
Inv. Spec. Tech.	4.45	4.12	5.98	3.72
Gov't Exp	1.76	1.76	2.25	1.81
Monetary Policy	11.91	12.39	10.01	5.31
Employment				
	1948-2015	1948-2007	1984-2007	2008-2015
Technology	5.77	5.68	6.86	9.36
Price Markup	16.74	17.71	11.42	8.97
Wage Markup	8.82	7.26	17.90	31.86
Risk Premium	9.70	9.81	4.91	11.48
Inv. Spec. Tech.	25.72	24.52	29.77	18.63
Gov't Exp	13.59	13.98	14.93	12.11
Monetary Policy	19.67	21.04	14.22	7.59

Fortunately, this is not part of the specification in the Smets-Wouters model.[6] In the next section, we will discuss about possible stories found in the literature linking these shocks to the financial crisis. Our main argument does not rely on the cogency of the anecdotal evidence provided to explain the shocks to the markups.

The fact that limited shocks are solely responsible for inflation movements for a large part of our sample is not in itself a red flag. Similarly, the type of shocks accounting for inflation is not in itself a red flag. Problematically, we find that these shocks have a lesser role in accounting for other economic variables, most notably employment. We argue that these disturbances explain little else besides inflation, and they do not particularly have a quantitatively important role in accounting for the low-frequency movements in employment.

A different picture emerges from the variance decomposition of employment (Table 1, second panel). Across all the subsamples considered, price- and wage- markup shocks account for only 8% of its variance, whereas the other shocks play more important roles.

The concerns regarding the threat of deflation are typically motivated by its link to the level of unemployment via some Phillips-curve tradeoff. This section analyzes this tradeoff before and after 2008. By plotting different versions of the Phillips curve, we conclude that the relationship is not tight. This is true not only for the last years, but for the entire period considered.

Moreover, these results cast doubts on the belief that "inflation is always and everywhere a monetary phenomenon",[7] and on the ability of any Phillips curve, independently of the preferred specification, to describe the relationship between inflation and economic slackness. Nevertheless, we do not wish to go as far as sentencing our model to death based on such considerations, and we leave the conclusion on this matter to the reader.

Fig. 2 reports the textbook version of the Phillips curve, using the time series of employment. As is already well-known in the literature, we do not find evidence of a clear relationship between inflation and slackness in the economy. This holds for the whole sample considered, but not exclusively, since the Great Recession.[8]

The model we use has already embedded a Phillips-curve type of relationship. One may wonder if, once we control for the lagged inflation and the model-based expectations of future inflation, we observe a clear Phillips-curve relationship between employment and inflation. The model implied Phillips curve is plotted in Fig. 3.

We define the inflation component as $\pi_t - \pi_1\pi_{t-1} - \pi_2 E_t\pi_{t+1}$ and the price-markup component as μ_t^p. We conclude that even in this case, the markup disturbances are large enough that the relationship between the two variables is weak for the entire period. Unsurprisingly, the loose relationship between inflation and employment is confirmed by the fact that the two variables are accounted for by different shocks.

[6] Both King and Watson (2012) and Hall (2011) reach a similar conclusion from different starting points. From a theoretical point of view, our paper bridges a gap between them. We bring together the quasi-exogeneity of inflation with the controversy over the financial crisis, primarily motivated by the strongly felt need in the last years to revise and readjust the models as a result its failure to predict the economy.

[7] Friedman (1956).

[8] Based upon this and similar empirical evidence, a few years after its original formulation, the Phillips curve was soon criticized and then augmented to introduce agents' expectations to the picture. With this expectation-augmented or accelerationist Phillips curve in mind, Bernanke (2007) advanced the anchored expectations hypothesis to solve the missing deflation puzzle of the post-2008 period. He argued that the Federal Reserve's policy was able to fully anchor expectations during the Great Recession, and that this fact explained the surprisingly high inflation. Following a similar reasoning, Coibion and Gorodnichenko (2015) use direct estimates of inflation from the Michigan Survey of Consumers to explain this puzzle.

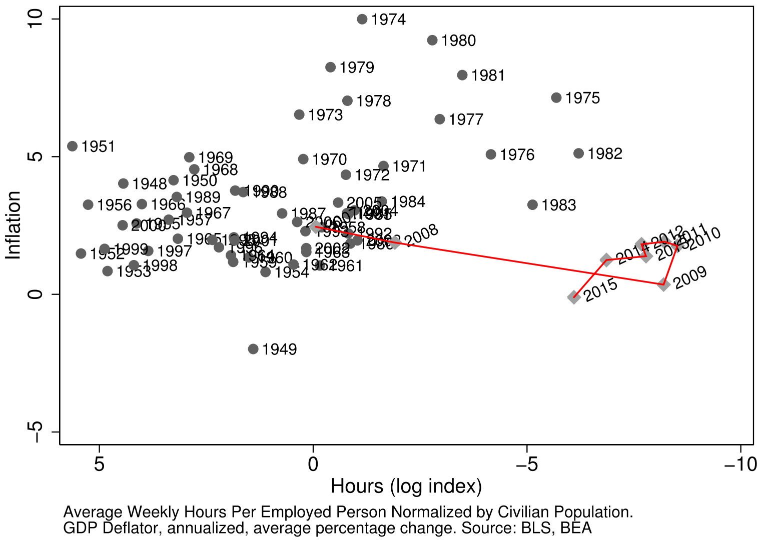

Fig. 2. Phillips curve using the negative of hours as a measure of slackness. Average weekly hours per employed person normalized by civilian population. GDP Deflator. Source: BLS, BEA.

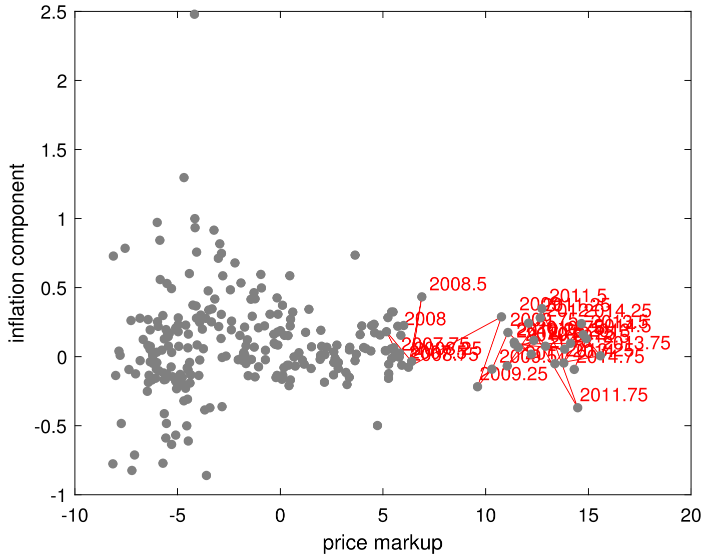

Fig. 3. Phillips curve implied by the model.

It is worth emphasizing that there is a distinction between the Phillips Curve and a Phillips Curve tradeoff. According to the traditional Keynesian view, shocks to the economy will move both unemployment and inflation along the downward sloping Phillips Curve, which can then be treated as a "menu".[9] In equilibrium, one would then not observe a downward sloping Phillips Curve, but rather a vertical scatter plot at that fixed unemployment rate. Other relationships may result in equilibrium, depending on the monetary policy chosen. For example, McLeay et al. (2018) argue that optimal monetary policy may, in fact, result in the type of cloud exhibited here, even if there is a genuine Phillips Curve tradeoff.

4. Accounting for inflation: full sample

From Fig. 1, the biggest exception to this story is the post-crisis inflation rate, where the discrepancy is considerable. According to the model, without any other shocks, the inflation rate would have been close to six percent rather than the near-zero rates we have observed.

9 E.g., monetary policy may fix the unemployment rate.

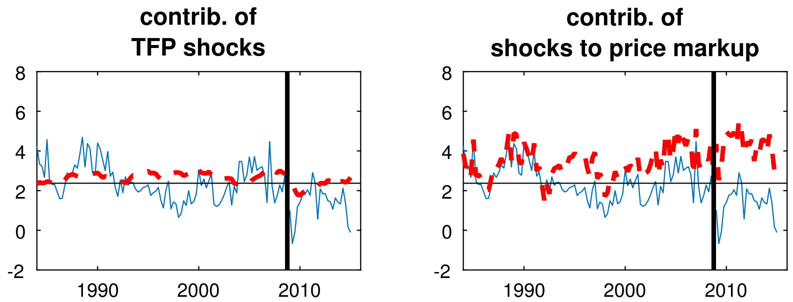

Fig. 4. Historical shocks decomposition of inflation (relative to long-run constant) for the period 1984Q1-2015Q1. The solid line is actual inflation. The dashed line is inflation predicted by each shock individually. The horizontal line is the long-run average level of inflation.

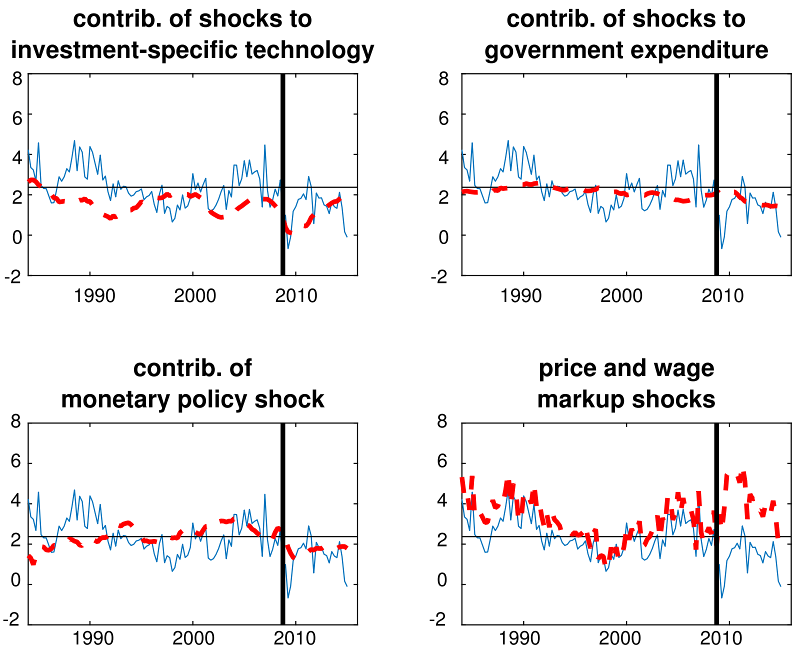

Fig. 5. Historical shocks decomposition of inflation (relative to long-run constant) for the period 1984Q1-2015Q1. The solid line is actual inflation. The dashed line is inflation predicted by each shock individually. The horizontal line is the long-run average level of inflation.

Post-crisis, deflationary forces are pushing inflation downwards. These forces have received considerable attention in the "missing deflation" debate. In particular, monetary policy was tighter than would have been indicated by simply following the Taylor rule. We will examine these various influences in greater detail in section 5 below.

To put that discussion into context, however, it is important to take the full-sample birds-eye perspective first. Figs. 4 and 5 provide the contribution of each individual shock series to inflation. In these figures, we restrict the analysis to the time period since 1984, to exclude the previous phase of high inflation. Wage- and price-markup shocks move inflation considerably, as discussed above. Although the contribution of the other shocks is non-zero in the pre-crisis period as well

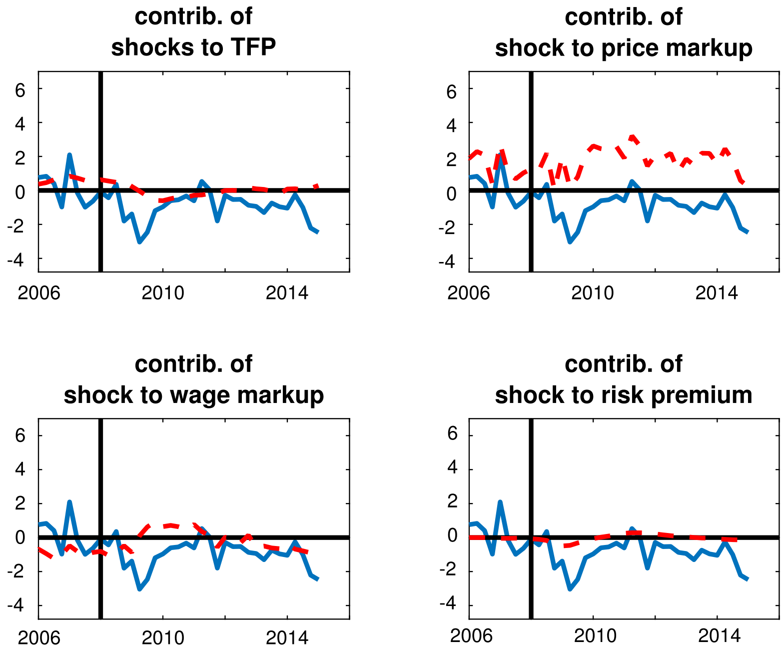

Fig. 6. Historical shock decomposition of inflation (relative to long-run constant) for the period 2006Q1-2015Q1. The solid line is actual inflation. The dashed line is inflation predicted by each shock individually. The horizontal line is the long-run average level of inflation.

as post-crisis, these figures clearly illustrate that the post-crisis period does not differ much in terms of the drivers of inflation compared to what has happened before.

Examine the contribution of monetary policy, for example. Given the ZLB experience, monetary policy shocks, as measured by the log-linear Smets and Wouters (2007) model, exerted a downward pressure post-crisis as expected. Although it is surprising that this downward pressure does not look particularly large.

We concede that this result partly stems from the fact that the model assumes constant parameters for the Taylor rule over the entire time period ranging from 1984 to 2015. We do not wish to argue that this is a particularly sensible choice. It is not the purpose of the current analysis to invent a better time-varying Taylor rule. In section 8, we discuss more extensively the implications of assuming such a monetary policy and its role in accounting for inflation.

Fig. 1 suggests that inflation, even in the early 80s, is nearly fully explained by the price- and wage-markup shocks alone. Essentially, the relatively modest inflation-dampening effects of monetary policy shocks in the early 80s were largely offset by the remaining shocks pointing in the other direction. This is not the conventional narrative about the inflation decline in the early 80s, but it is the narrative of this model.

Independent of whether we agree with or hoped for this kind of result, that this model narrative was available before the financial crisis of 2008 is an important insight. The post-crisis portion of the inflation time series in Fig. 1, which would have resulted out of price- and wage-markup shocks alone, does not look unusual compared to the time series prior to the crisis. Inflation was high in the post-crisis period because of the price- and wage-markup shocks, the same shocks responsible for the accounting of inflation in the entire sample period.

A skeptical reaction to the post-crisis portion of the counterfactual in Fig. 1 is natural: what could have been the "smoking gun" for causing such a rise in inflation? Conventional wisdom suggests that loose monetary policy should be the cause of such an inflation spike. But the model tells a different story: inflation is largely driven by price-and-wage markup shocks.

One may or may not find that logic satisfying, and we share the same skepticism. The key point, though, is that the post-crisis account of the model for inflation is very much in line with the pre-crisis account of the model for inflation. The financial crisis does not alter this fact. If one thinks that the post-crisis model account for inflation or the lack of deflation is absurd, then one should have likewise concluded that the model account for inflation before the crisis is absurd as well.

5. Accounting for inflation after 2008

We now seek to "zoom in" on the post-crisis episode. As already shown above, the model finds that markup shocks exert upward pressure on inflation, offsetting the role of the other shocks.

Therefore, there was no deflation and, in fact, some inflation because of the price- and wage-markup shocks (second panel of Fig. 6). While inflation was almost entirely explained by price- and wage-markup shocks prior to the crisis of 2008, inflation responded more to the other shocks after 2008, contrary to the conventional wisdom about unusual post-crisis irresponsiveness of inflation to the economic slackness.

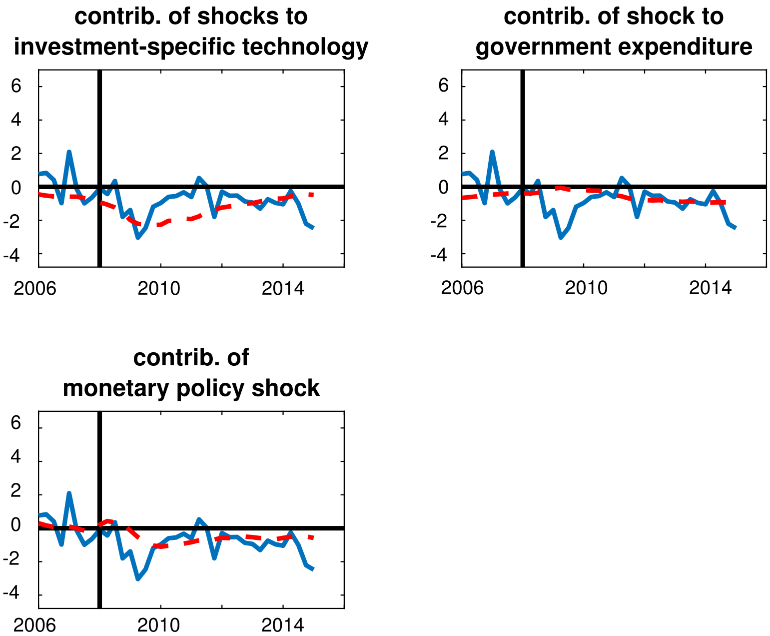

Fig. 7. Historical shock decomposition of inflation (relative to long-run constant) for the period 2006Q1-2015Q1. The solid line is actual inflation. The dashed line is inflation predicted by each shock individually. The horizontal line is the long-run average level of inflation.

Table 2
Standard deviation of the estimated shocks.

	1948-2015	1948-2007	1948-1983	1984-2007	2008-2015
Technology	0.53	0.52	0.57	0.34	0.55
Price Markup	0.18	0.18	0.22	0.09	0.11
Wage Markup	0.34	0.31	0.26	0.29	0.52
Risk Premium	0.43	0.44	0.53	0.18	0.38
Inv. Spec. Tech.	0.56	0.55	0.64	0.37	0.39
Gov't Exp	0.65	0.66	0.78	0.41	0.50
Monetary Policy	0.22	0.23	0.28	0.11	0.11

Presumably, monetary shocks capture the effect of the ZLB on inflation. The model is log-linearized and it does not incorporate any constraint on the monetary rule, effectively assuming that the central bank can lower the nominal rate below zero. When observations of zero nominal rates come in, the agents in the model treat these as a surprising tightening. It should therefore be expected that these pseudo-shocks to monetary policy had the effect of reducing inflation.[10]

The sign of the monetary policy shocks during the ZLB episode is positive as expected, indicating it is tighter than expected. While the standard deviation of these shocks is not remarkable in historical comparison (0.11 in the post-crisis period, compared to 0.22 in the pre-crisis period), their effects accumulate due to being virtually all the same sign. These suggest that the effect of ZLB monetary policy shocks is limited (see Fig. 7).

A word of caution is due. The Wold decomposition, by construction, represents a variable as the sum of the contribution of the shocks introduced in the model. Consequently, it identifies which shocks would justify the observed pattern in inflation and employment. Equivalently, by construction, the sum of the contributions of the shocks entirely explain the movements in inflation. Thus, the absence of response in inflation will be mechanically interpreted as some combination of offsetting shocks. Hence, it is not surprising that the model provides an answer to the missing deflation puzzle.

We provide a brief analysis of the price- and wage-markup shocks. However, the opportunity to indict this model is beyond the scope of this paper. For the sake of our argument, we do not need to determine whether the markup shocks are reasonable. We merely want to stress that the model is fundamentally telling the same story before and after the crisis.

We look at the statistical properties of the shocks before and after the Great Recession and conclude that there are no remarkable differences between the two periods. Table 2 compares the standard deviation of the shocks in the sample periods considered. It is surprising to notice that the standard deviation of the shocks is extremely similar before and after 2008.

[10] In section 8, we show that treating the ZLB as a sequence of unexpected events may either underestimate or overestimate the effect of the liquidity trap on inflation, depending on the monetary policy rule followed by the central bank during the liquidity trap.

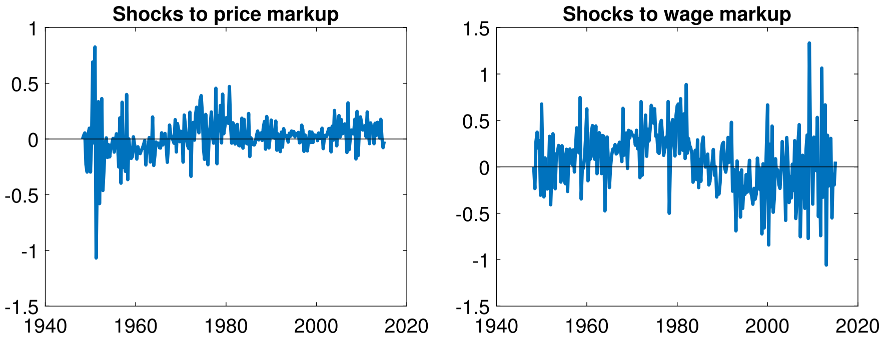

Fig. 8. Price- and wage-markup shocks estimated from the model.

With the exception of the wage-markup shocks, the standard deviation of the shocks after the crisis is comparable to the same quantities before the crisis. This is mostly due to the fact that the pre-crisis period is the combination of the more volatile period until the 80s and the Great Moderation. As a matter of fact, the post-crisis economy is more volatile than the Great Moderation, with the shocks to risk premium being twice as volatile as the previous period. Interestingly, the standard deviation of the price-markup shocks remains stable throughout the entire period.

Fig. 8 plots the time series of the shocks to price- and wage-markup. It confirms that, although the price-markup shocks do not seem to display a different pattern before and after 2008, wage-markup shocks are more volatile. Care should be taken with regard to the wage-markup shocks. Although these shocks are significantly more volatile in the post-crisis period than before, the most concerning pattern is instead related to the pre-crisis period.

These shocks clearly display a significant degree of persistence before the crisis, and, if anything, they are closer to white noise after 2008. Therefore, from this perspective as well, we conclude that if the reader believes the post-crisis model displays some inherent features that make it unsuitable to deal with inflation, this was also evident before the crisis. Vice versa, if the reader deems the model satisfactory to account for inflation before 2008, the financial crisis should not modify her conclusions.

There is good evidence in the literature on the sources of the shocks to the monetary policy, to the risk premium, to the investment-specific technology, and to the government expenditure, responsible for a downward pressure on inflation (see Hall (2011) for a discussion on the issue). Contrastingly, there is less evidence on the increase in price markup that could justify the shocks estimated by the model for the period of the financial crisis and its aftermath.

An appealing interpretation to the price markups is linked to the supply side effect of financial frictions. If, for instance, financial frictions apply to the financing of the working capital of the firm, these will appear as price markups in our model. The shocks to the price markups can also be due to strategic complementarities (see Atkeson and Burstein (2008) among others), round-about production structure (Basu (1995)), or a demand featuring non-constant elasticity of substitution (Klenow and Willis (2006)). We view this literature as broadly consistent with our results and a complement to the more recent literature.

6. Accounting for employment

The shock-by-shock decomposition of employment for the entire sample is provided in Figs. 9 and 10. The overall secular movements seem to be well explained by the wage-markup shock, but other shocks also play a role, particularly shocks to risk premium and monetary policy. Importantly, the role of the price-markup shocks in accounting for employment is overshadowed by the other shocks.

For 2007 and beyond, Figs. 11 and 12 provide a decomposition for employment. Investment-specific shocks as well as government expenditure, wage markups, and (to a lesser degree) monetary shocks contributed to the drop in employment in the post-crisis period.

7. Taylor rule

The model estimates a great degree of slackness in the economy after 2008. Indeed, Fig. 13 confirms that the output gap dropped dramatically after 2008 and it remained negative and large. This is consistent with a growing literature documenting and theorizing the slow recovery after financial crises.[11]

The ZLB resulted in a tightening monetary policy after 2008, pushing inflation down. However, the magnitude of this effect on the nominal interest rate is rather modest. According to the model, the inflation drop due to the liquidity trap, were all the other shocks absent, would have been only two points below zero and short-lived. The Taylor-rule implied

11 See, for instance, Hall (2010) and Reinhart and Rogoff (2014).

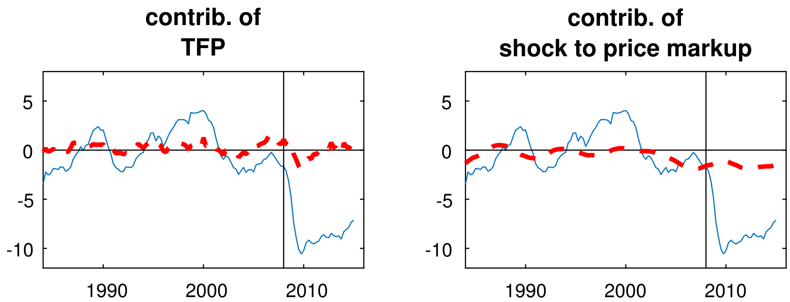

Fig. 9. Historical shock decomposition of employment for the period 1984-2015. The solid line is actual employment. The dashed line is employment predicted by each shock individually. The horizontal line is the long-run average level of employment.

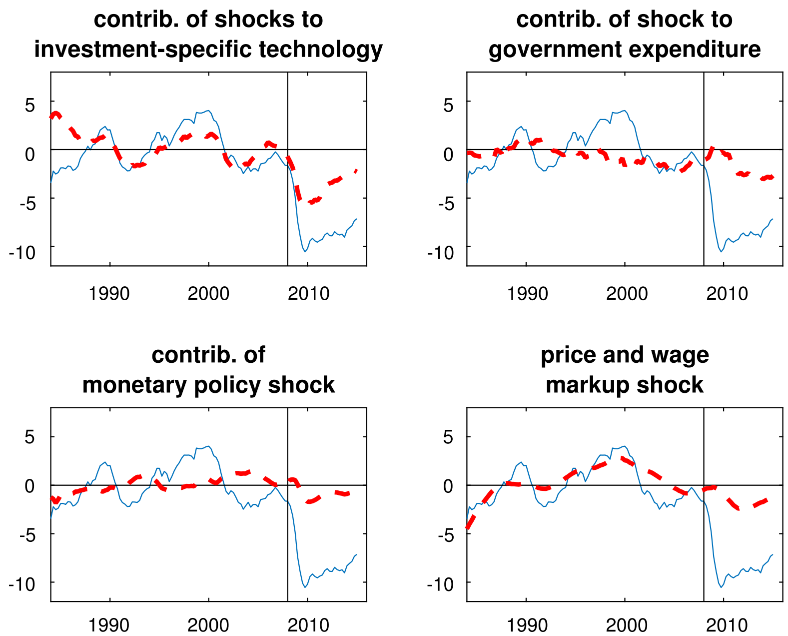

Fig. 10. Historical shock decomposition of employment for the period 1984-2015. The solid line is actual employment. The dashed line is employment predicted by each shock individually. The horizontal line is the long-run average level of employment.

nominal interest rate was negative only until 2011, and it remained close to zero afterwards. We study the Taylor rule more closely to better understand the interest rate dynamics and its determinants.

It is worth recalling the Smets and Wouters (2007) version of the Taylor rule,

$$i_t = \bar{i} + \rho_R i_{t-1} + (1-\rho_R)(\psi_1 \pi_t + \psi_2 x_t) + \psi_3 (x_t - x_{t-1}) + \epsilon_t^r, \tag{2}$$

where x_t is the output gap, $\psi_1 = 1.87$, $\psi_2 = 0.11$, $\psi_3 = 0.13$.

It turns out the output gap growth is the key component rather than the output gap itself. Fig. 14 decomposes the interest rate rule into its components, and allows us to identify the role of each economic variable. The drop of the desired

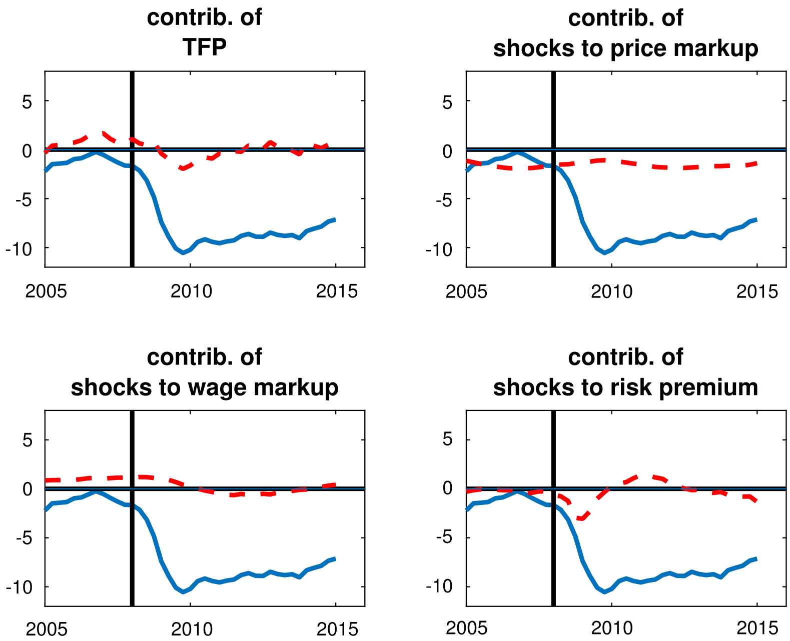

Fig. 11. Historical shock decomposition of employment for the period 2005-2015. The solid line is actual employment. The dashed line is employment predicted by each shock individually. The horizontal line is the long-run average level of employment.

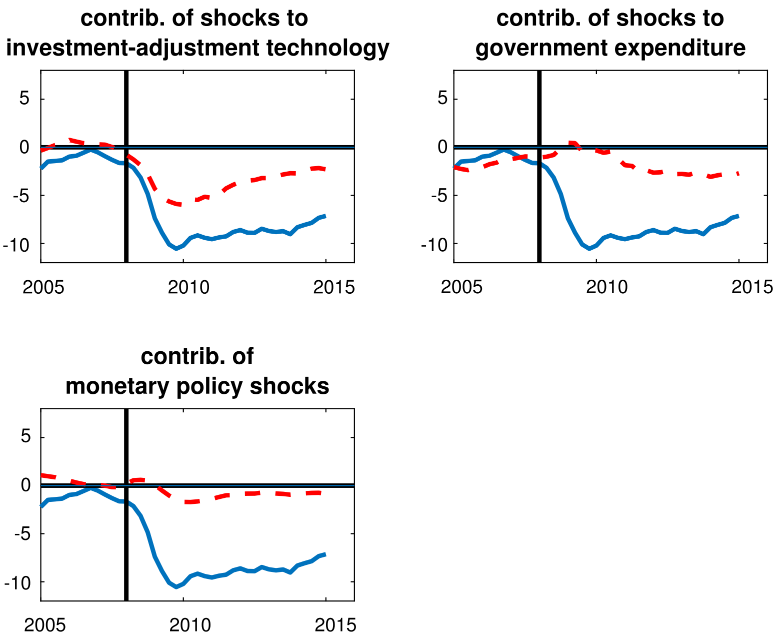

Fig. 12. Historical shock decomposition of employment for the period 2005-2015. The solid line is actual employment. The dashed line is employment predicted by each shock individually. The horizontal line is the long-run average level of employment.

interest rate below zero is mainly due to the output gap growth, while the other components of the Taylor rule play a minor role. This is either because their deviation from the target is small, as is the case of inflation, or because the parameter in the Taylor rule is small, as is the case of the output gap. When the output gap dramatically dropped, the interest rate implied by the Taylor rule decreased below zero. Afterwards, however, the output gap remained negative but stable. As a consequence, the Taylor-rule interest rate slowly moved back closer to the ZLB.

This Taylor rule may differ from other specifications studied in the literature, some of which create a considerably larger gap between the implied interest rate and zero. It is here, though, where the "retro" part of our analysis is a particularly important disciplining device. It forces us to stick to the Smets and Wouters (2007) specification rather than allow us to

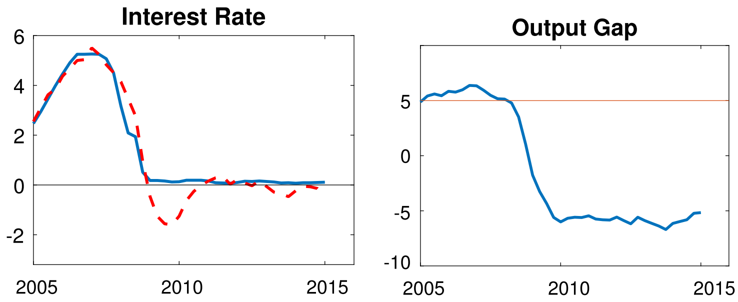

Fig. 13. A comparison between interest rate and the output gap. The left panel shows the actual interest rate (solid blue line) and the estimated interest rate in absence of monetary shocks (dashed red line). The right panel shows the output gap, which remains considerably below zero long after 2008.

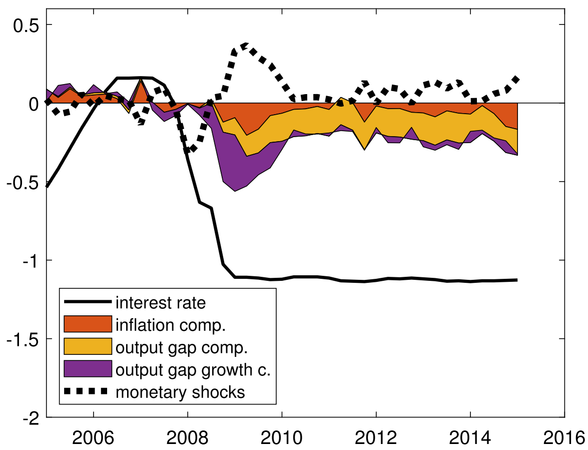

Fig. 14. Decomposition of the nominal interest rate according to the Taylor rule from the model. The solid black line is the time series for the nominal interest rate in deviations from its long-run average. The monetary shocks are represented by the dotted line. The shaded areas are defined as the contributions of each component to inflation: from equation (2), the inflation component is defined as $(1-\rho_R)\psi_1\pi_t$; the output gap component is $(1-\rho_R)\psi_2 x_t$; the output gap growth component is $\psi_3(x_t - x_{t-1})$.

"pick" the importance of the ZLB post-crisis.[12] We view this as a strength of our approach, as opposed to a drawback, and a complement to the more recent literature. In section 9.1, we extend this model and we study the role of a time-varying inflation target.

8. Zero lower bound

One possible objection to our approach may be that the analysis does not explicitly take into account the ZLB. We do not argue that the local linearization we used in this paper is the correct way to deal with the ZLB. On the contrary, in this section we argue that our approach provides a useful benchmark.

We examine this intuition in a simple three-equation New Keynesian model. This provides cleaner insights than performing this examination in the full-fledged model. We show that the effect of the ZLB depends on the endogenous response of the monetary authority, and that the linear benchmark may underestimate or overestimate the effect of the ZLB on inflation and output, depending on the degree of forward guidance by the monetary authority.

We use the simple framework developed in Galí (2008), Chapter 3. Inflation and the output gap evolve according to the following equations:

$$\pi_t = \beta E_t \pi_{t+1} + \kappa x_t, \tag{3}$$

$$x_t = -\frac{1}{\sigma}(i_t - E_t\pi_{t+1} - r_t^e) + E_t x_{t+1} + \mathbb{1}_{t=1}\xi_x. \tag{4}$$

These equations link inflation, π_t, and the output gap, x_t, to the interest rate. The natural interest rate is given by $r_t^e = \rho + \sigma(E_t x_{t+1} - x_t)$, and ξ_x represents a period-1 initial shock to the output gap. For further information on the assumptions behind the model, see Galí (2008).

[12] See Christiano et al. (2015) for a different specification of the monetary policy that includes the ZLB and some form of forward guidance.

The equation for the interest rate i_t closes the model. There is a standard Taylor rule

$$\tilde{i}_t = \rho + \alpha\pi_t + \gamma x_t \tag{5}$$

for a "shadow rate" $\tilde{i}_t$, but it may prescribe $\tilde{i}_t < 0$. We consider three cases for setting i_t and the beliefs of the household.

Case A. For the first case, the monetary authority follows a standard Taylor rule, subject to the ZLB,

$$i_t = \max\{0, \tilde{i}_t\}, \tag{6}$$

where $\tilde{i}_t$ is the (possibly negative) interest rate provided by the Taylor rule (5). The liquidity trap lasts for $t = 0, \dots, T$, where T is the last date, for which $\tilde{i}_t < 0$, and where the households fully understand (6) and know T.

Case B. For the second case, we mimic the strategy in our main analysis above and model the ZLB as an unexpected exogenous positive shock. That is, we assume that the households assume i_t to follow

$$i_t = \tilde{i}_t + \epsilon_t^m,$$

where $\tilde{i}_t$ follows (5), and where

$$\epsilon_t^m = \max\{-\tilde{i}_t, 0\}, \tag{7}$$

where households (erroneously) assume $E_t[\epsilon_t^m] = 0$. As in our analysis above, agents are then surprised each period by a monetary policy tighter than the Taylor-rule implied rate in the periods when $\tilde{i}_t < 0$.

Case C. For the third and final case, we assume that the monetary authority provides forward guidance per credibly announcing at date $t = 1$ a path for the shift $s_t, t \geq 1$ of deviations from the standard Taylor rule, $\tilde{i}_t$, independent of the conditions of the economy. The size of the deviation depends on s_t.

$$i_t = \max\{0, \tilde{i}_t + s_t\}.$$

We assume that s_t is set such that $i_t \equiv 0$ for $t = 0, \dots, T^*$, where $T^* \geq T$. If $T^* = T$, then this case would be equivalent to Case A. In the numerical exercise, we will consider a value $T^* > T$ instead. This captures the idea of Eggertsson and Woodford (2005), that forward guidance is key to escaping the ZLB trap without too much harm to the economy. s_t follows an AR(1) process.

The forward guidance announcement from the central bank corresponds to the realization of a negative shock to the shift s_t in period 1 concurrent with the shock to the output gap. After the initial shocks at time $t = 1$, the path of the interest rate is known to the agents. In this specification, we do not directly choose T^*. Instead, for a given initial shock to the shift s_t, an initial shock to the output gap, and the persistence of the two stochastic processes, the interest rate set by the central bank is above zero when $\tilde{i}_t + s_t > 0$, and therefore T^* is defined as the last period in which $\tilde{i}_t + s_t \leq 0$. Note that when $T^* > T$, the path of the interest rate for the periods $t \in [0, T]$ is the same as in Case A. However, the two cases differ. In Case C, agents understand the future path of the interest rate and they take into account the forward guidance announced by the monetary authority when making decisions.

While the model is simple enough to allow for a full analytical characterization, we utilize OccBin[13] instead. We numerically solve the simplified model for the three cases. Case A is easily modeled with the aid of OccBin by introducing a zero constraint on the nominal interest rate. To solve for Case B, we use the policy and transition functions from the model without ZLB. We compute the interest rate implied by the Taylor rule, $\tilde{i}_t$. If this is negative, we compute the monetary shocks using equation (7). Case C is solved as Case A, where we also identify an initial shock to the shifter of the nominal interest rate large enough to satisfy the condition $T^* > T$.

Results are reported in Fig. 15. For the shock to the IS curve, the autocorrelation is 0.8. For the shadow shock and the monetary surprises, the autocorrelation is 0.6. The other parameters are the same as Galí (2008). The initial shock to the output gap (ξ_1) is a 5% deviation from the steady state. The initial shock to the shifter in the monetary policy in Case C is a 70% deviation from the steady state. T and T^* are residually determined by the parameter choices on the autocorrelation of the two disturbances and the initial size of the shocks.

The nominal interest rate in Case A and B follows the same path. The drop on output is deeper in case A, i.e., when the agents incorporate the lower bound in their expectations, as already emphasized in Gust et al. (2012). By contrast, the output drop in Case C is less severe, as agents expect the interest rate to remain low upon exit of the ZLB, as emphasized by Eggertsson and Woodford (2005).

13 Guerrieri and Iacoviello (2013).

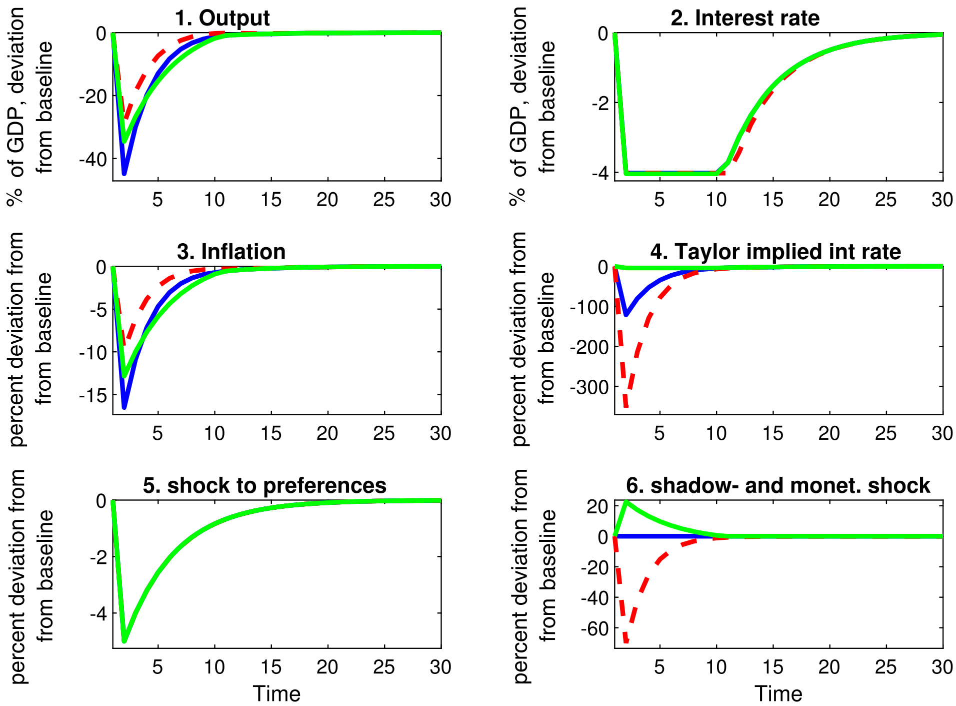

Fig. 15. Effect of ZLB and forward guidance. The solid blue line is the case in which the ZLB is binding and afterwards the monetary authority follows a simple Taylor rule (Case A). The solid green line is the case in which in each period the agents are "surprised" by monetary shocks such that the interest rate is equal to zero (Case B). The dashed red line is the case in which the monetary authority simultaneously announces forward guidance (Case C). (For interpretation of the colors in the figure(s), the reader is referred to the web version of this article.)

This simple example therefore illustrates how a full treatment of the liquidity trap requires subtle choices regarding the expectations of agents regarding the path of future monetary policy variables at the onset of the 2008 crisis. The degree of forward guidance, as suggested by Eggertsson and Woodford (2005), is crucial.

One can read Fig. 13 as demonstrating a version of Case C, as it apparently kept the nominal interest at zero despite the exit of the ZLB constraint around mid-2010. According to the model, full-sample estimates show that exit more decisively. Kulish et al. (2015) estimate a model with forward guidance and confirm that the sign of the ZLB on inflation depends on the expected duration in which the interest rates are kept low.

The approach in our main analysis corresponds to Case B, and happens to be the intermediate case in the simple model above. It is a happy medium between Case A, doggedly sticking to a Taylor rule subject to the ZLB, and Case C, providing credible and considerable forward guidance. We therefore argue that it may provide a useful benchmark.

9. Alternative models

Our conclusions on the performance of Smets and Wouters (2007) model points to an oversized role of price- and wage-markup shocks in accounting for the inflation dynamics. We utilized the original Smets and Wouters (2007) model and avoided extensions and modifications introduced since the financial crisis purposefully. Potentially, it may be interesting to examine the robustness of our conclusions to these innovations in the literature. For this purpose, we present three different extensions and evaluate their performance before and after the crisis.

In subsection 9.1, we allow for a time-varying inflation target. In subsection 9.2, we explore the model by Del Negro et al. (2015), who extended Smets and Wouters with financial frictions. As a final variation, we examine the model by Christiano et al. (2015) in subsection 9.3.

9.1. A time-varying inflation target

Inflation shows a secular pattern, increasing until the end of the 70s and declining subsequently. It may be plausible to ascribe these movements to a change in the inflation target, but they are not featured in the original Smets and Wouters (2007) model used so far. We therefore extend the model here.

Specifically we introduce a time-varying inflation target in the Taylor rule. We assume that the inflation target, π^*, follows an AR(1) process. That rule now becomes

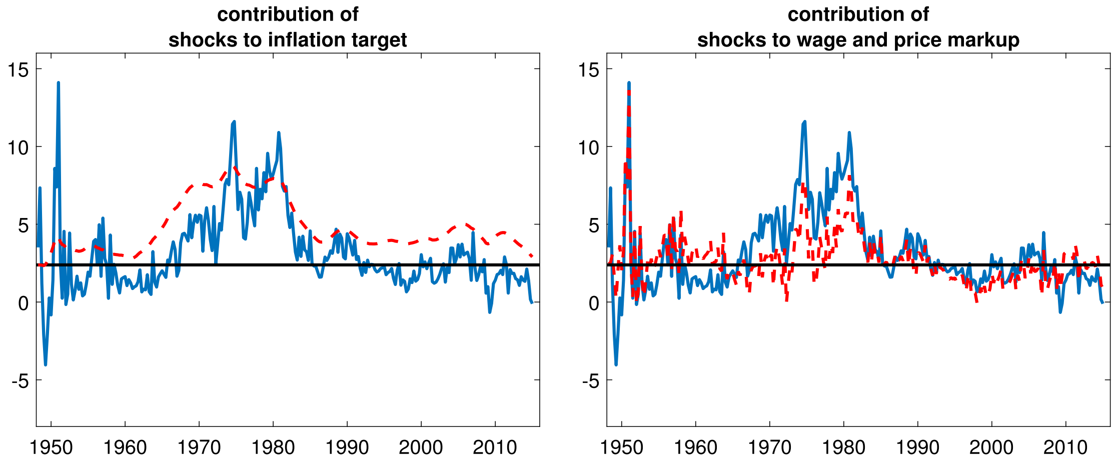

Fig. 16. Accounting for inflation in a model with a time-varying inflation target, using the posterior mode for the autoregressive coefficient for the inflation target, estimated to be 0.5141.

$$
\begin{aligned}
i_t =& \bar{i} + \rho_R i_{t-1} + (1-\rho_R)(\psi_1(\pi_t - \pi_t^*) + \psi_2 x_t) + \psi_3(x_t - x_{t-1}) + \epsilon_t^r \\
\hat{\pi}_t^* =& \rho_{\pi^*} \hat{\pi}_{t-1}^* + \sigma_{\pi^*} \epsilon_t^{\pi^*},
\end{aligned}
$$

where ρ_{π^*} and σ_{π^*} are parameters respectively modeling the persistence of the AR process and its volatility.

Everything else is left unchanged. In particular, we do not introduce any additional time series to the model. We use a Beta prior with parameters 0.5 and 0.2 for the autoregressive parameter and an inverse Gamma prior with parameters 0.1 and 2 for the standard deviation of the shock to inflation target. The choice of the sample period does not alter the results. We present the main results for the full sample. The full estimation results and additional figures on inflation accounting are reported in the online appendix.

We shall pursue three questions. First, how much does the time-varying inflation target account for the inflation dynamics? Second, do the mark-up shocks *cum* inflation target now account for essentially all of the inflation dynamics pre-2007, analogously to our results so far? And finally, does this three-shock perspective alter our conclusion regarding the impact of the inflation-driving shocks for the real side of the economy?

To answer these questions, we first estimate the autoregressive process for the inflation target along with all other parameters of the model. The posterior mode is 0.5141 for the autoregressive parameter, ρ_{π^*}, and 0.0587 for the standard deviation, σ_{π^*}. The estimated persistence is remarkably low, implying a half-life of only one quarter.

With these estimates, it may not be a surprise that the role of the time-varying inflation target is negligible. The contribution towards the inflation dynamics is essentially a straight line near the full-sample average for inflation, as the left panel of Fig. 16 shows. Consequently, the role of shocks to markups is unchanged from the baseline model, as seen in the right panel of Fig. 16. The analysis above with a constant inflation target remains practically entirely unchanged. These results are in line with Liu et al. (2011) who find that a DSGE model with a regime-switching inflation target performs as well as a model with a constant inflation target in fitting the US time-series data.

One may suspect — and we do — that the low persistence of the inflation target is the culprit. Indeed, many authors advocate the role of a slow-changing inflation target for inflation dynamics and inflation forecast. We simply calibrate the autoregressive process for the inflation target to be $\rho_{\pi^*} = 0.99$, as Del Negro et al. (2015), implying considerable persistence.

Results are reported in the online appendix. The wage-and-price markup shocks still continue to play a substantial role. In contrast to our previous results, these three shocks together now also account for much of the inflation dynamics after the crisis, thus leaving less room for, say, ZLB considerations to push inflation into deflationary territory.

9.2. Del Negro et al. (2015)

Del Negro et al. (2015) argue that financial frictions are able to explain the missing deflation puzzle. In this section, complementing their analysis, we account for inflation as above using their model instead. We confirm Del Negro et al. (2015)'s finding that financial frictions introduce a strong force, moving inflation. We show that one can still largely account for inflation with price- and wage-markup shocks. Adding financial frictions now only creates substantial deviations from the observed inflation paths, which are then compensated for by offsetting shocks elsewhere.

Following Del Negro et al. (2015), we retain the interest rule with a time-varying inflation target as in the previous section. Additionally, like Del Negro et al. (2015), we assume that entrepreneurs face an idiosyncratic disturbance that

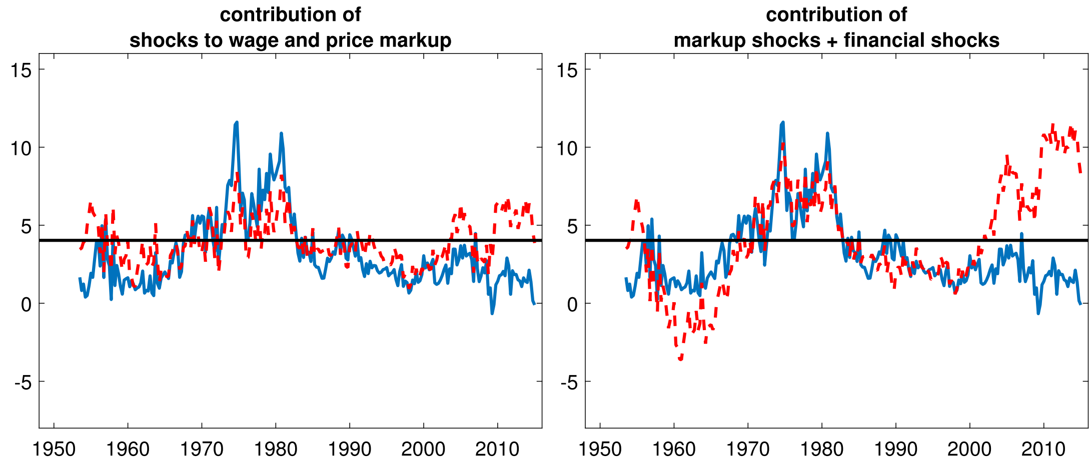

Fig. 17. Del Negro et al. (2015). In the left panel, actual inflation versus the portion accounted for by price- and wage-markup shocks. In the right panel, the portion accounted for by price-, wage-markup-, and financial-shocks, for the period 1948Q1-2015Q1. The solid line is actual inflation. The dashed line is inflation predicted by price- and wage-markup shocks.

affects their ability to manage capital, ϵ^n, following an AR(1) process. Banks pool their risk and charge a spread over the deposit rate,

$$E_t[R^k_{t+1} - R_t] = b_t + \xi_{sp,b}(Q_t + \bar{k}_t - n_t) + \epsilon^n_t. \tag{8}$$

R^k_t is the gross nominal return on capital for the entrepreneurs, b_t and ϵ^n_t are exogenous process, $\hat{Q}_t$ is the value of capital in terms of consumption, $\bar{k}_t$ is the stock of capital, and n_t is entrepreneurial equity. The gross returns on capital for entrepreneurs are linked to the returns on capital, $\hat{r}^k_t$, by the following relation:

$$R^k_t - E_t\pi_{t+1} = \frac{r^k_*}{r^k_* + 1 - \delta} E_t r^k_{t+1} + \tag{9}$$

$$+ \frac{1-\delta}{r^k_* + 1 - \delta} E_t Q_{t+1} - Q_t + \frac{\sigma_c(1 + h/\gamma)}{1 - h/\gamma} b^2_t. \tag{10}$$

As in Del Negro et al. (2015), the entrepreneurs' net worth evolves according to the condition[14]

$$n_t = \alpha_1(R^k_t - \pi_t) - \alpha_2(R_t - \pi_t) + \alpha_3(Q_{t-1} + \bar{k}_{t-1}) + \alpha_4 n_{t-1} - \alpha_5\omega_{t-1}, \tag{11}$$

where $\alpha_1, \alpha_2, \alpha_3, \alpha_4, and \alpha_5$ are parameters and ω_t is an exogenous process.

We calibrate the model according to Del Negro et al. (2015).[15]

Fig. 17 (left panel) shows the comparison of actual inflation with inflation accounted for only by wage- and price-markup shocks in this Del Negro et al. (2015)-extension of the model. Fig. 17 (right panel) adds the financial friction portion to the portion explained by wage- and price-markups. Similar to our benchmark analysis, wage- and price-markups do a good job accounting for the overall movements in inflation, though the gaps are now somewhat larger. Similar to our benchmark exercise, the Great Recession corresponds to the broadening of a gap between actual inflation and the contribution of the markup shocks. It is now even wider and more persistent than in the analysis above, accounting for even more of the "missing deflation" than before.

In contrast to our prior analysis, the other shocks still matter. In particular, the financial friction shock now matters substantially, as Fig. 17 (right panel) shows. These financial frictions now create an additional upward pressure on inflation so that these three shocks combined would create an inflation rate above 10% from 2008 onwards, starting from a high post-2000 level.

Conversely, these three shocks together would have produced a substantial deflation in the early 60s. The model fully accounts for inflation, of course, so other shocks now matter for inflation too. When added to the portion accounted for by these three shocks, they bring them back in line with the data. Interestingly, monetary policy shocks and inflation target shocks only play a very small role in this counterbalancing, as shown in further calculations and graphs available in an online appendix.

[14] For more details on the model, we must refer to Del Negro et al. (2015). The flexible-price economy is assumed to be devoid of financial frictions.

[15] The calibration for all parameters is reported in the online appendix.

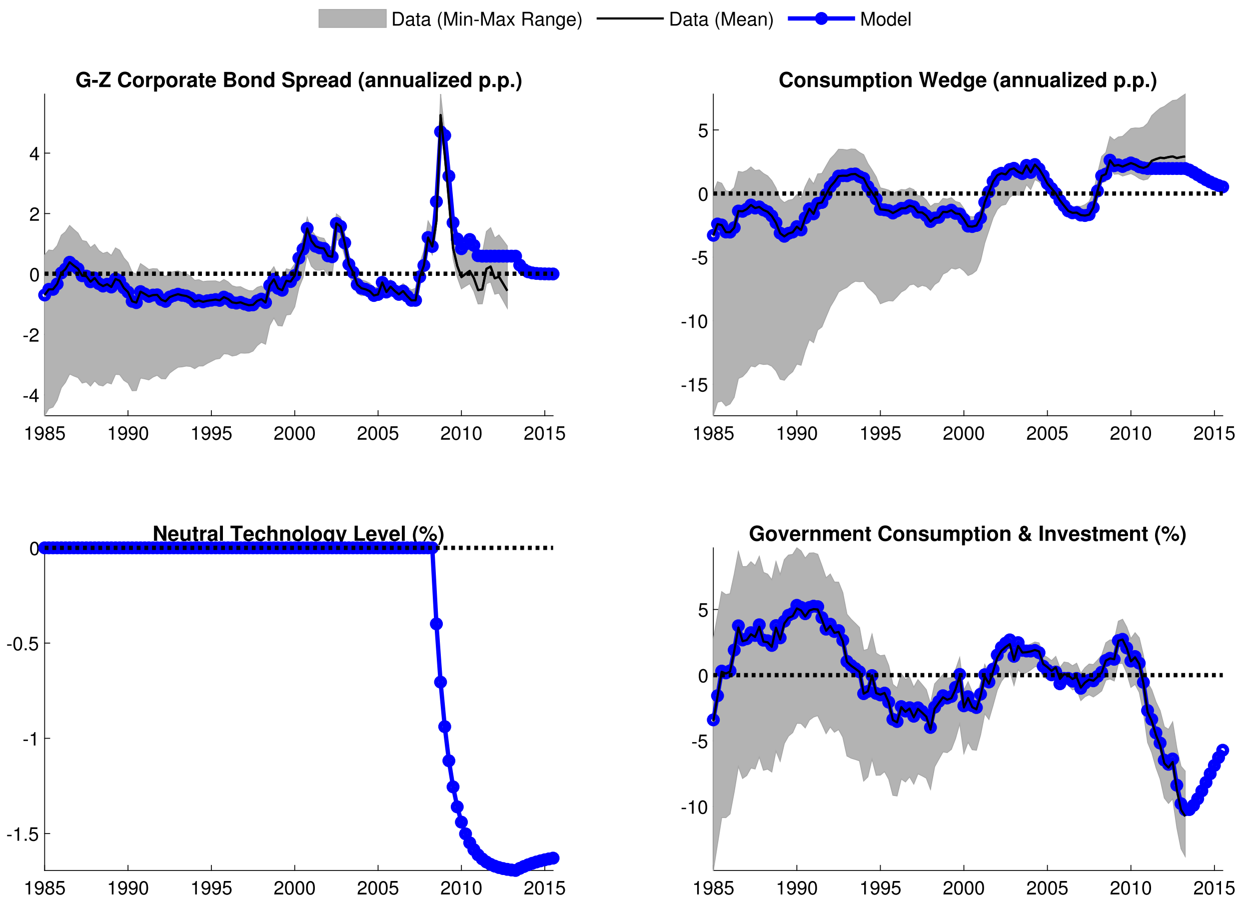

Fig. 18. Stochastic disturbances in Christiano et al. (2015). Extended sample. Assumptions on the evolution of the shocks for the entire time period considered in our analysis. Whenever the time period overlaps, we used the same assumptions as in Christiano et al. (2015).

Confirming Del Negro et al. (2015)'s findings from a different perspective, financial frictions provide an additional, complementary answer to the missing deflation puzzle. Both markup disturbances and financial disturbances produce an inflationary pressure in the economy, counteracting other and substantial forces in the economy. Many of the mostly non-monetary forces are tugging at inflation that way and this. Whether this is ultimately a satisfying explanation for inflation is a question for future research. It may be that it is. Our aim here is merely to present this complementary accounting exercise.

9.3. Christiano et al. (2015)

Another key alternative model is the one proposed by Christiano et al. (2015). Their approach differs significantly from both ours and Del Negro et al. (2015) theoretically and empirically. The main deviation from our model is the incorporation of a search and matching mechanism in the labor market.

Negotiation costs are insensitive to the conditions of the aggregate economy. Delays in negotiations translate into slowly moving wages. Their estimation procedure is based on an impulse response matching method, devised by Christiano et al. (2015). The reader may be referred to the original source for additional detail.

Due to the considerable differences in solution technique and approach between their papers and Smets and Wouters (2007), we need to proceed slightly differently for the inflation-accounting exercise. We do not alter the model nor the methodology used for the estimation. We also use their solution method, which allows us to incorporate the ZLB and forward guidance in the analysis. We use the same model, estimation, and solution method. We simply extend their simulation backwards to also include the years since 1985. The dynamics are driven by the same stochastic disturbances as theirs: a consumption wedge, a financial wedge, total factor productivity shocks, and government consumption shocks. Here, we describe how we estimated the shocks and in what ways our methodology extends theirs.

Their analysis of the Great Recession simulates the evolution of the main economic variables for the period 2008Q2-2013Q1. We follow their approach for this sample. First, we use the same data and extend it backwards until 1985. Second, we estimate the shocks using the same target gap ranges. For each variable, we fit a linear trend from date X

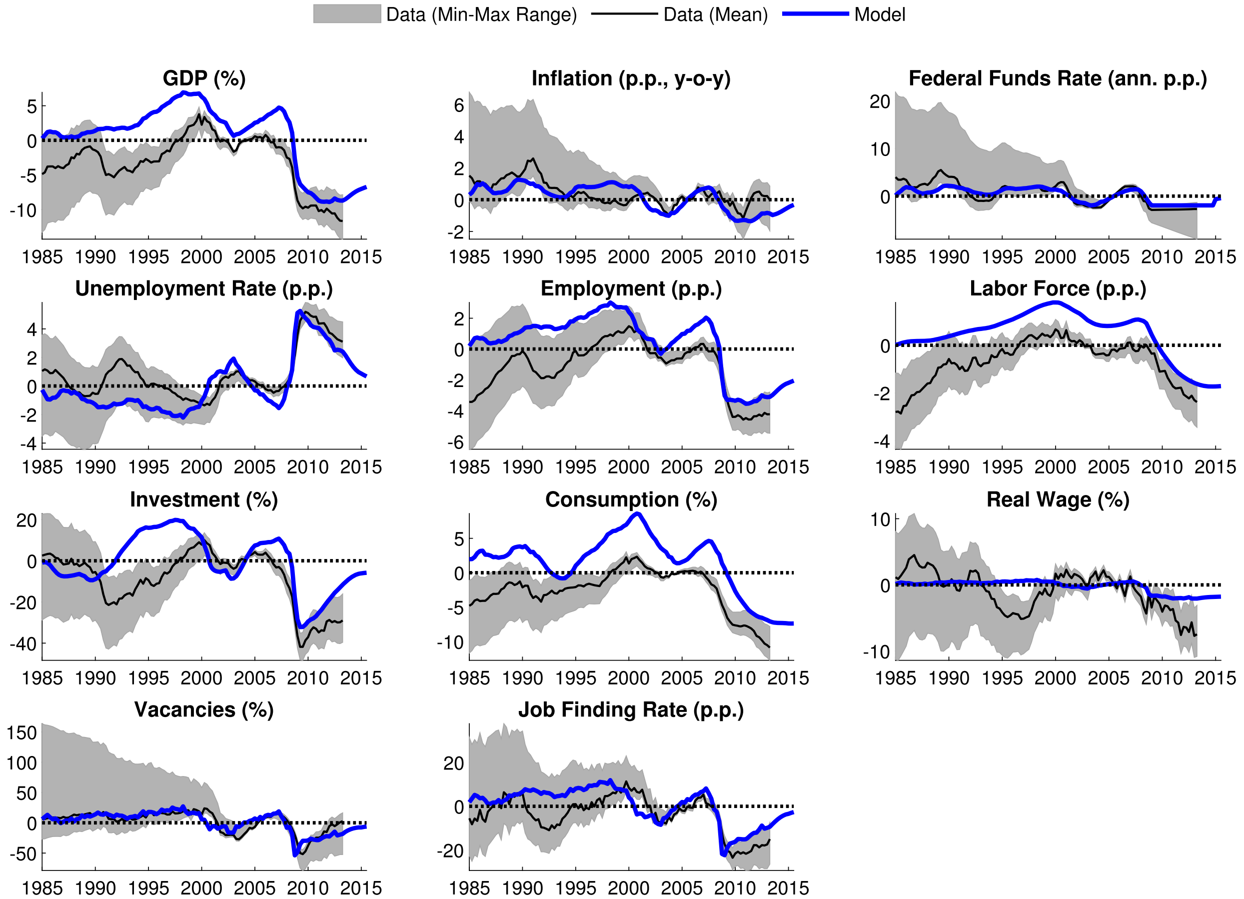

Fig. 19. Endogenous variables in Christiano et al. (2015). Extended sample. The shaded area represents the min-max range of the distribution of deviations from the linear trends. The solid black line is the mean of the same distribution. Finally, the solid blue line is the simulation of Christiano et al. (2015)'s model using the assumptions on the shocks as described in Fig. 18.

to 2008Q2 for $x \in [1985Q1, 2003Q1]$. For each time period and for each stochastic disturbance, we define a distribution of deviations from the linear trends. For the sample available, we maintain their choices for estimation of the shocks. For the consumption wedge, they use the mean target gap until 2010Q4, and for the periods after they use the value of 2010Q4, which is lower than the target mean. For the financial wedge, they use the mean target gap in 2008Q2, then the minimum of the target gap range in 2008Q3, 90% of the maximum target range in 2008Q4, 97.5% of the maximum target range in 2009Q1, and the maximum target range for the periods after. For the TFP shock, they assume a one-time shock at the beginning of their sample and a slow convergence to the steady state afterwards. For the government consumption shocks, they use the target gap mean.

Note, however, that to extend the sample backwards and include the period before the financial crisis, we need to make some choices. We use the mean of the target gaps, with the exception of the TFP shock that we set equal to its steady state (Fig. 18). Given their choices, we believe that our methodology to extend the exogenous processes for the period before the crisis is as close in spirit as possible to the authors.

The simulations are reported in Fig. 19. It is worth noting that it is perhaps not appropriate to directly compare the performance of Christiano et al. (2015) to Smets and Wouters (2007) or Del Negro et al. (2015), since Christiano et al. (2015) have less flexibility and a lower number of shocks than the others. Nonetheless, the results here confirm our main insights to some degree.

Their model provides a reasonable fit to inflation post-crisis. Pre-crisis, however, the model provides a substantial range for inflation, possibly indicating considerable sample uncertainty. This creates challenges in using the model for accounting and ultimately understanding inflation for the entire post-war period. Such an understanding would surely be useful, however, as we move back into more normal times regarding monetary policy and economic fluctuations. Resolving these matters for the Christiano et al. (2015) is far beyond the scope of this paper.

It is also worth emphasizing that estimation uncertainty has not been taken into account in our analysis of the Smets and Wouters (2007) model. We suspect it would also further mitigate the ability of that model to provide a succinct account for inflation not based on wage- and price-markup shocks. We do not mean our analysis of Christiano et al. (2015) to present a critique of their approach. Our aim here is merely to document what this alternative and recent model offers regarding an accounting-for-inflation exercise.

10. Conclusion

In spite of widespread fears, the US did not experience a period of deflation during the recession following the events of 2008. During these years, inflation has been low but positive and stable, even in the presence of robust evidence of a certain degree of slackness in the economy. Is the missing deflation puzzle an indictment of Phillips-curve-type analyses, as Hall (2011) has argued? or is all well and good if one fixes the model appropriately with new features or those available prior to 2008, as Del Negro et al. (2015) have found?

We sought to understand whether the explanation, or the lack thereof, could have been understood from the perspective of a leading pre-crisis model, rather than allowing us to modify the model in light of recent experiences. We choose the prominent Smets and Wouters (2007) to address this issue. By design, we use the model "as is."

The key insight from our analysis is this. Inflation through the entire sample is accounted for almost entirely by price- and wage-markup shocks, with some (unsurprising) additional impact from the ZLB post-2008. Moreover, the shocks do not have an unusual size post-2008. The model does not predict much of a deflation absence in these shocks in any case; the zero-lower-bound-implied "surprise" tightening of monetary policy post-2008 only contributes a downward pressure on inflation of about 2%. We furthermore find that the shocks accounting for inflation do not account for much of the movements in employment. The built-in Phillips curve tradeoff is of minor importance for understanding the data over the entire sample, not just post-2008. We find that the picture is enriched, but not substantially altered, once taking into account such matters as more careful considerations for the ZLB, time-varying inflation targets, or recent extensions of the Smets-Wouters framework.

The message here is more fundamental and more hopeful than the dismal perspective of always having to fix models ex-post of the current literature. It did not need the financial crisis for questioning the inflation-accounting-capability and the importance of the Phillips curve tradeoff in prominent pre-crisis models, such as Smets and Wouters (2007). Put differently, there is hope in seeking to construct models that can reasonably account for macroeconomic outcomes, even in the face of future crisis of unknown origin.

Appendix A. Supplementary material

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.red.2019.05.005.

References

Atkeson, A., Burstein, A., 2008. Pricing-to-market, trade costs, and international relative prices. The American Economic Review 98, 1998–2031.
Ball, L., Mazumber, S., 2011. Inflation Dynamics and the Great Recession. IMF working paper.
Bassetto, M., Messer, T., Ostrowski, C., 2013. Forecasting Inflation and the Great Recession. Economic Perspectives. Federal Reserve Bank of Chicago.
Basu, S., 1995. Intermediate goods and business cycles: implications for productivity and welfare. The American Economic Review 85, 512–531.
Bernanke, B., 2007. Inflation Expectations and Inflation Forecasting. Speech. Monetary Economics Workshop of the National Bureau of Economic Research Summer Institute.
Chari, V., McGrattan, E., Kehoe, P.J., 2007. Business cycle accounting. Econometrica 75, 781–836.
Christiano, L.J., Eichenbaum, M.S., Trabandt, M., 2015. Understanding the great recession. American Economic Journal: Macroeconomics 7, 110–167.
Cochrane, J., 1998. A Frictionless View of US Inflation, vol. 13, pp. 323–421.
Cochrane, J., 2011. Understanding policy in the great recession: some unpleasant fiscal arithmetic. European Economic Review 55, 2–30.
Cogan, J.F., Cwik, T., Taylor, J.B., Wieland, V., 2010. New Keynesian versus old Keynesian government spending multipliers. Journal of Economic Dynamics and Control 34, 281–295.
Coibion, O., Gorodnichenko, Y., 2015. Is the phillips curve alive and well after all? Inflation expectations and the missing inflation. American Economic Journal: Macroeconomics 7, 197–232.
Conley, T.G., Dupor, B., 2013. The American recovery and reinvestment act: solely a government jobs program? Journal of Monetary Economics 60, 535–549.
Del Negro, M., Giannoni, M.P., Schorfheide, F., 2015. Inflation in the great recession and new Keynesian models. American Economic Journal: Macroeconomics 7, 168–196.
Drautzburg, T., Uhlig, H., 2011. Fiscal Stimulus and Distortionary Taxation. Working paper 2011-005. Becker Friedman Institute for Research In Economics, University of Chicago.
Dupor, B., Li, R., 2015. The expected inflation channel of government spending in the postwar U.S. European Economic Review 74, 36–56.
Eggertsson, G.B., Woodford, M., 2005. The zero lower bound on interest rate and optimal monetary policy. Journal of Money, Credit, and Banking 37.
Fernandez-Villaverde, J., Rubio-Ramirez, J., Sargent, T., Watson, M., 2007. Abcs (and ds) for understanding vars. The American Economic Review 97, 1021–1026.
Friedman, M., 1956. Studies in the Quantity Theory of Money. University of Chicago Press.
Galí, J., 2008. Monetary Policy, Inflation, and the Business Cycle: An Introduction to the New Keynesian Framework. Princeton University Press, Princeton, NJ.
Gilchrist, S., Schoenle, R., Sim, J.W., Zakrajsek, E., 2015. Inflation dynamics during the financial crisis. The American Economic Review.
Guerrieri, L., Iacoviello, M., 2013. Occbin: a toolkit for solving dynamic models with occasionally binding constraints. Manuscript. Federal Reserve Board.
Gust, C.J., López-Salido, D., Smith, M.E., 2012. The Empirical Implications of the Interest-Rate Lower Bound.
Hall, R., 2011. The long slump. The American Economic Review 101, 431–469.
Hall, R.E., 2010. Why does the economy fall to pieces after a financial crisis? The Journal of Economic Perspectives 24, 3–20. http://www.jstor.org/stable/20799170.
Kaplan, G., Violante, G.L., 2014. A tale of two stimulus payments: 2001 versus 2008. The American Economic Review 104, 116–121.

King, R.G., Watson, M.W., 2012. Inflation and unit labor cost. Journal of Money, Credit, and Banking 44, 111–149.
Klenow, P.J., Willis, J.L., 2006. Real Rigidities and Nominal Price Changes. Research working paper. Federal Reserve Bank of Kansas City.
Kulish, M., Morley, J., Robinson, T., 2015. Estimating DSGE Models with Forward Guidance. Working paper.
Leeper, E.M., 2013. Fiscal limits and monetary policy. Central Bank Review 13, 33–58.
Leeper, E.M., Zhou, X., 2013. Inflation's Role in Optimal Monetary-Fiscal Policy. NBER working papers 19686. National Bureau of Economic Research.
Linde, J., Trabandt, M., 2018. Resolving the Missing Deflation Puzzle. Working paper.
Liu, Z., Waggoner, D.F., Zha, T., 2011. Sources of macroeconomic fluctuations: a regime-switching dsge approach. Quantitative Economics 2, 251–301.
McLeay, M., Tenreyro, S., et al., 2018. Optimal Inflation and the Identification of the Phillips Curve. Technical Report.
Michaillat, P., Saez, E., 2014. An Economical Business-Cycle Model. NBER working papers 19777. National Bureau of Economic Research, Inc. http://ideas.repec.org/p/nbr/nberwo/19777.html.
Reinhart, C.M., Rogoff, K.S., 2014. Recovery from financial crises: evidence from 100 episodes. The American Economic Review 104, 50–55. http://www.jstor.org/stable/42920909.
Shoag, D., 2013. Using state pension shocks to estimate fiscal multipliers since the great recession. The American Economic Review 103, 121–124.
Smets, F., Wouters, R., 2007. Shocks and frictions in us business cycles: a Bayesian dsge approach. The American Economic Review 97, 586–606.
Wilson, D.J., 2012. Fiscal spending jobs multipliers: evidence from the 2009 American recovery and reinvestment act. American Economic Journal: Economic Policy 4, 251–282.