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The cost channel of monetary policy: the case of the United States in the period 1959-2018

Maria Chiara Cucciniello*; Matteo Deleidi**; Enrico Sergio Levrero*[1]

Abstract

In light of the literature on the 'price puzzle', this paper shows that a positive effect of a tightening of monetary policy on the level of prices should be considered a normal phenomenon rather than an 'anomaly' or a 'specific regime phenomenon' connected to passive behaviour of the Central Bank in response to changes in the inflation rate. In order to assess this effect of monetary policy on the level of prices, we estimate SVAR models based on US monthly data for the period 1959-2018. Alternative measures of price and inflation expectations are also taken into consideration to avoid feasible spurious correlation. Finally, all selected models are estimated along four different sub-samples to consider different monetary policy regimes. Our findings show that the 'price puzzle' exists irrespective of both the passive (active) behaviour of the Central Bank and the inclusion of price expectations.

Keywords: Price Puzzle, Structural Vector Autoregressions, United States

JEL Classification: B220, E310, E430, E440, E520

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1. Introduction

The co-movement of prices and interest rates has been referred to as the Gibson's paradox (Keynes, 1930), the Cavallo-Patman effect (L. Taylor, 1983) and the "price puzzle" (Bernanke and Blinder, 1992; Eichenbaum, 1992; Christiano et al., 1994). It is one of the "more hotly debated" phenomena in economics (Fisher, 1930, p. 399) and challenges the idea that monetary policy tightening is followed by a decrease in the price level (or lower future inflation) as a result of the demand side channels of the monetary transmission mechanism.

A recent explanation of this "puzzle" refers to a lack of responsiveness of the Central Bank to signals of higher future inflation. For the United States, for instance, it is argued that a positive correlation between changes in the federal funds rate and changes in the price level was seen during the 1960s and 1970s because the Federal Reserve responded to supply shocks by raising the federal funds rate, though not enough to prevent a higher increase in the aggregate price level. This explanation has been confirmed when *vector autoregression* (VAR) models have been used to isolate exogenous movements in the policy interest rate (i.e., monetary policy shock) uncorrelated with other variables included in the model. In this framework, it has also been argued that the price puzzle is "resolved" when a variable signalling anticipated future inflation to the Central Bank is included in the VARs (see, for example, Sims, 1992; Christiano et al., 1994).

These interpretations have been reinforced by Castelnuovo and Surico (2010). By re-examining the empirical evidence on the price puzzle, they argued that the positive response of prices to a monetary policy shock is historically limited to sub-samples associated with a *weak* Central Bank response to inflation (and thus with inflation expectations that were not well anchored) such as prior to the appointment of Paul Volcker as Fed Chairman in August 1979. Moreover, they claimed that the omission from VARs of a variable capturing the high persistence of *expected* inflation accounts for the price puzzle. Finally, using a calibrated micro-founded New Keynesian model, they showed that it never generates a positive inflation response to a policy shock, even when the nominal interest rate responds less than fully to inflation. Therefore, they rejected the cost-push channel of monetary policy usually associated with the price puzzle and claimed that the traditional (inverse) demand-side relationship between interest rates and inflation is the dominant one for the transmission mechanisms of monetary policy.

Considering the case of the United States for the period 1959-2018 and using SVAR models, the aim of this paper is to assess whether the positive effect of the rate of interest on the level of prices stems from specific policy regimes and/or omitted information in the estimated VAR models. In Section 2, a brief historical overview of the debate on the Gibson paradox is provided. Section 3 illustrates data, methods and our multiple identification strategies, whereas Section 4 provides our main findings. We show that the price puzzle is also traceable in the post-1979 period, namely in the presence of an "active" monetary policy regime. Moreover, in line with Christiano et al. (1999), we also show that monetary policy tightening leads to a fall in real wages since the increase in prices is not compensated for by a rise in money wages. Finally, Section 5 analyses the role of expectations through alternative measures of expected prices demonstrating that they partially mitigate but do not solve the price puzzle. Section 6 concludes.

2. Prices and interest rates: an overview

After Tooke (1838, 1844), where a positive relationship between the interest rates and the price level was predicted since the former was viewed as an element of the monetary costs of production, the main interpretations[2] that have been proposed to explain the co-movement of

[2] Here we will only briefly summarise the literature written over twenty years ago. No reference is made, for instance, to Hawtrey (1923), Kitchin (1923) and Macaulay (1938).

prices and interest rates – named by Keynes the Gibson paradox[3] – reverse Tooke's causality going from interest rates to prices and explain this stylized fact by the adjustment process of the real interest rate towards its "natural level" after a previous increase in the price level. The differences in these interpretations consist mainly of the monetary regimes which that stylized fact was ascribed to and the elements viewed as shaping the discrepancy between the "market" interest rate and its natural level – namely, the level determined by "productivity and thrift" (Wicksell, 1906, p. 193).

Under the hypothesis that at the equilibrium the nominal interest rate equals the natural rate of interest plus the expected inflation rate, Irving Fisher (1930) argued that the source of the "Gibson paradox" would be in the slow adjustment of price expectations after a change in price inflation fuelled by a change in the growth rate of money supply which would bring about fluctuations in the actual *real* interest rate around its natural level. More precisely, when, after a higher increase in prices, lenders start to require a higher nominal interest rate after adjusting their price expectations, a co-movement over time between prices and the *nominal* interest rate will be observed together with an adjustment of the actual *real* rate of interest towards its natural level.

While Fisher's estimation of expected inflation using long distributed lags of actual inflation rate has been considered as inconsistent with investor rationality (Sargent, 1973; Shiller and Siegel, 1977), a view similar to that advanced by Fisher is traceable in models where the co-movement of prices and interest rates is explained by changes in nominal output relative to the amount of money supply exogenously set by the monetary authorities. In these models, factors such as prices and output elasticities to aggregate demand, the sensitivity of price inflation to output changes and of price expectations to actual prices, are combined in a way

[3] In *A Treatise on Money* Keynes refers to the "extraordinarily close correlation" for more than a century between the interest rate on consols and the price level as reported in a series of articles published by Gibson in the Banker's Magazine (see Gibson, 1923).

that generates a path of prices and interest rates moving in the same direction during the cycle (see, for instance, Friedman and Schwartz, 1982; Sargent, 1973).

By contrast, a criticism of Fisher's "monetary" explanation of the Gibson paradox was advanced by Keynes (1930) who maintained that the positive correlation between prices and the interest rate occurs in the long- or medium-run rather than being a cyclical phenomenon as suggested by Fisher. Moreover, Keynes stressed that Gibson considered movements that "so far from being compensatory, are aggravating in their effect on the relation between lender and borrower", so that Fisher's explanation cannot hold. The fall in bond prices that follows the increase in the interest rate due to the increase in the price level implies in fact that lenders will possess a value capital in *money terms* which is lower than before whilst "the variations in the rate of interest earned during the year in question" would be "too small to make much difference" (Keynes, 1930, II, p. 202-203) and would not be able to compensate the capital loss.

Keynes therefore reproposed Wicksell's (1898 and 1906) "real" explanation of the Gibson paradox according to which the market rate of interest is relatively sticky compared with the natural rate (the rate that equals savings and investments at full employment) so that, when there is a long run tendency of the natural rate of interest to move due for instance to technical changes, a continuous slow movement of deflation or inflation arises[4] which is subsequently followed by a movement of the market interest rate in the same direction as prices. Keynes also refuted Fisher's objection that the price level would depend on the money supply (modified by the velocity of circulation of money) and be independent of the rate of profit, arguing that Central Banks tend to adapt their behaviour to changes in gold supply relative to

[4] For instance, a market interest rate lower than the natural rate will determine a continuous increase in the price level.

the demand for money because they have gold reserves which can be increased or decreased in order to leave prices unaffected (see also Shiller and Siegel, 1977).[5]

If several contributions have limited the phenomenon of Gibson paradox to a gold standard regime (see, for instance, Friedman and Schwartz, 1982; Barsky and Summers, 1988)[6] or more generally to periods where inflation is weakly persistent (see, Barsky, 1987; Cogley et al., 2011), the presence of a co-movement of prices and interest rates has been recognized in the literature on the price puzzle even for fiat money economies and periods of high inflation persistence, typically by using *vector autoregression* (VAR) models (see Sims, 1992; Balke and Emery, 1994; Giordani, 2004; Hanson, 2004; Boivin and Giannoni, 2006; Castelnuovo and Surico, 2010). However, unlike the previous contributions by Fisher, Keynes and Wicksell, co-movement has been interpreted as the result of "statistical illusions" stemming from model misspecification or, alternatively, as the effect of interest rate being an element of production costs as originally suggested by Tooke (1838, 1844).[7]

According to conventional wisdom, the price puzzle anomaly is due to omitted information on the systematic part of monetary policy. In particular, the VAR may be misspecified if it fails to include a proxy for future inflation. As stated by Sims (1992, p. 998) "policy authorities might know that inflationary pressure is about to arrive and contract to dampen the effects of these pressures. Then prices would rise after the monetary contraction

[5] However, unlike Keynes, Shiller and Siegel suggested that Gibson's paradox can stem from wealth redistribution in favour of debtors arising from price inflation. It would lower the demand for nominal denominated assets relative to their supply and therefore, raise the rate of interest.

[6] Barskey and Summers argued that productivity shocks—which are translated into real interest rate shocks in a gold money economy—would change the equilibrium *real* price of gold and that an (officially) pegged nominal price for gold would thus lead to a change in the price level. For example, an increase in the real interest rate would lower the demand for gold both for non-monetary uses and for monetary gold as long as the latter demand is elastic to the rate of interest. Therefore, the real price of gold as determined in the gold market would fall and since the authorities peg the *nominal* price of gold as constant in a metallic standard, this would be accompanied by a rise in the general level of prices.

[7] If this was criticized by Wicksell because – in a gold money economy – variations in the interest rate would be accompanied by changes in the relative and not absolute prices, it can be advanced again in a fiat money economy. However, even with a money commodity an interpretation different from that suggested by Wicksell can hold. In these circumstances, the Gibson paradox may stem from the adjustment of nominal interest rates on long-term financial securities in the presence of changes in the price level determined by changes in the method of production of the money commodity relative to the methods of production of the other commodities (see Smith, 1996).

[...]”. Therefore, when inflation expectations are not included in the VAR, the results of endogenous and/or anticipatory responses by the Central Bank would emerge as a co-movement of prices and interest rates. A predicted upcoming surge in inflation would be followed by an increase in the policy rate, a decrease in the output gap, and – as long as the monetary policy tightening is not such to fully offset the inflationary shock – a rise in current inflation. If VAR omits expected inflation and if expected inflation and current inflation are not strictly linked (i.e. current inflation is not a “sufficient statistic” for measuring the expected inflation), the VAR reproduces the price puzzle.

The idea proposed by Sims (1992) ameliorated the picture but did not solve the puzzle. A rationale for justifying these empirical findings was thus advanced in terms of the supply-side cost channel effect (Ramey, 1989; Rehman, 2015). Barth and Ramey (2002) observed that on average over the period 1959-2000, US firms held gross working capital (value of inventories plus trade receivables) equivalent to 17 months of sale revenues. Therefore, a change in the amount of interest to be paid on this working capital would identify a cost channel that might dominate the standard demand-side effect on prices. Christiano et al. (2005) reached the same conclusion using aggregate data for the US economy whereas Dedola and Lippi (2005) provided evidence of the importance of working capital for the transmission of interest rate shocks in France, Germany, Italy, and the UK using disaggregated industry data for 21 manufacturing sectors.[8] Similarly, Peersman and Smets (2005) estimate the effects of monetary policy on 11 industries in 7 Euro area countries, finding considerable cross-industry heterogeneity in interest policy sensitivity that is statistically related to differences in output durability, financial structure and firm size.[9] Evidence of the existence of a cost channel is also

[8] Their results show that sectoral output responses to monetary policy shocks are systematically related to industrial characteristics corroborating the hypothesis of Barth and Ramey (2002) that systematic differences in working capital needs are behind sectoral differences in the responses to monetary policy impulses.
[9] Similar results are achieved by Gaiotti and Secchi (2006) for Italy employing a panel covering some 2,000 Italian manufacturing firms with 14 years of data on prices and interest rates paid on several types of debt.

advanced by: Adolfson et al. (2005) for Europe; Chowdhury et al. (2006) for the G7 countries (except Germany and Japan) in the period 1980-1997; and Ravenna and Walsh (2006) for the US for the period 1960-2001. It is a channel that has been rationalized into the New-Keynesian DSGE models by assuming that factors of production have to be paid by borrowing from financial intermediaries before the proceeds from the sale of output are received (Bruckner and Schabert, 2003; Ravenna and Walsh, 2006; Tillman, 2008). Interest rates would therefore affect the firms' marginal costs of production which in turn would drive inflation dynamics.

However, contrary to the view that the cost-push channel effect of monetary policy dominates the more traditional demand-side effect, Rabanal (2003, 2007) argued that the cost channel is irrelevant in both the US and the Euro area when estimating a New Keynesian DSGE model that embodies the working capital. More precisely, using a likelihood-based estimated structural model, he supported the view that inflation and interest rates move in opposite directions after a monetary policy shock. Moreover, he argued that the result is not influenced by the assumption that only a fraction of firms needs to borrow money to pay their wage bill.[10] Even when the model is estimated by assuming that all firms need to do this, no positive response of inflation to a monetary policy contraction is observed. Rabanal (2003, 2007) therefore concluded that policy makers should not be concerned about short-run increases in inflation after monetary policy tightening. He also stated that his estimates confirm Romer and Romer (2004) who found that the price puzzle would become irrelevant when constructing with a narrative approach a series of monetary policy shocks after controlling for the endogenous response of the Federal Reserve to its own forecasts of output growth, inflation and unemployment.

[10] Rabanal points to a low elasticity of inflation with regard to changes in the nominal interest rate, with a posterior mean of just 0.15. Hence, the posterior probability of observing an increase in inflation following a tightening of monetary policy would be zero.

These results reinforced the idea that estimates displaying an increase in inflation after monetary policy tightening would stem from a misspecified Central Bank's reaction function. As Hanson (2004) stresses, the practice suggested by Sims (1992) to avoid the price puzzle including additional variables, such as commodity prices, does not work for all sub-sample periods, especially in the pre-1980 period (Boivin and Giannoni, 2006). However, the price puzzle would disappear when a larger information set is used or when the output gap (Giordani, 2004)[11] or a new measure of monetary policy shocks free of endogenous or anticipatory movements are included (Romer and Romer, 2004).[12]

This change in the inflation response due to different policy regimes is explained by Castelnuovo and Surico (2010) both through a DSGE and an SVAR model. They find a price puzzle as the result of a passive monetary policy regime in the pre-1979 period. Moreover, by employing a sticky price DSGE model for the US economy at the theoretical level, they found that on impact, a positive inflation response to a monetary policy shock does not arise. On the basis of Montecarlo simulations, they thus argued that the price puzzle can be the artefact of a specification error in the VAR models. The misspecification comes from the omission of a "latent" variable which exists only when the monetary policy rule is passive. While, on the one

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[11] On omitted information that is essential to the monetary authority's decision process, see also Bernanke et al. (2005) and Bovin et al. (2009). Giordani (2004) shows that the omission of potential output in standard trivariate VARs may severely bias impulse responses and be responsible for the price puzzle. In fact, if the Central Bank has the output gap in its inflation equation and there are lags in the transmission of monetary policy, then policy affects output first and then inflation. If this is the case, the omission of output gap causes interest rates to react positively to output gap increases and act as a proxy of the omitted variable. A similar argument has been advanced by Leeper and Roush (2003) for economies in which a double-causal link between money and interest rate may have occurred. In particular, if the Central Bank reacts contemporaneously to monetary aggregates and if money demand is contemporaneously driven by the nominal interest rate, then the omission of money will lead to a misspecification of the monetary policy shock. The results regarding the price puzzle are also influenced when the form of the matrix contemporaneously linking structural shocks and reduced-form residuals is set according to theory (see Kim and Roubini, 2000; Uhlig, 2005) or when long-run restrictions are imposed in order to identify monetary policy shocks. However, in almost 33% of the responses computed using these strategies, the price puzzle still occurs (see Havranek et al., 2011). Moreover, the results become more strongly influenced by theoretical assumptions on the model.

[12] It has also been argued that accommodative behaviour by the Central Bank would be consistent with a determinate regime if fiscal policy is active and the fiscal theory of the price level holds. As Leeper and Leith (2016) claim, in this case there would be nothing puzzling in a jump in the price level after monetary tightening. Under the fiscal theory of the price level, an increase in the nominal interest rate raises the market value of debt and households' interest receipts. The resulting wealth effects, not offset by the government that undertakes an active fiscal policy, would raise the price level.

hand, expected inflation is found to approximate this omitted variable reasonably well, on the other, the arguments in Sims (1992) and Bernanke (2004) on omitted variables would be supported in the context of a structural model only when monetary policy is passive and therefore expectations are not well anchored.[13] Only in this case, in fact, inflation expectations become very informative regarding the dynamics of the economy and help to identify a monetary policy shock correctly. Castelnuovo and Surico (2006) also add that, in the case of anchored inflation expectations, the price puzzle can show up when a cost channel is introduced into a DSGE model only when price rigidity is low and/or wage rigidity is high (see also Henzel et al., 2009). The responsiveness of inflation to the marginal cost in the Phillips curve depends on a coefficient that is negatively related to price stickiness: with high price rigidity, inflation is less responsive to the real marginal cost. Furthermore, flexible wages prevent the smooth response needed to make supply effects prevail. Therefore, the price puzzle can be avoided even when a cost channel is at work: a high level of price rigidity which is greater than wage rigidity may suffice.[14] Hence, after 1979, the price puzzle also disappeared because, starting in the Nineties, as inflation goes down, wage rigidity goes down too and price rigidity is always higher than wage rigidity.

Summing up, there is some agreement that the price puzzle is not necessarily a false finding that pertains only to misspecified VARs but could be a “genuine” phenomenon. However, in the more recent literature, the “puzzle” is often confined to passive monetary policy regimes and/or to specific conditions concerning price and wage flexibility, often by appealing to New-Keynesian DSGE structural models. In the next sections, we will test the presence of the price puzzle in the US economy by using SVAR models, hence minimizing the influence of theoretical assumptions on model estimates. We will identify two models that will

[13] According to Castelnuovo and Surico (2010), a passive (active) behaviour of monetary authorities occurs when Central Banks move less (more) than proportionally the rate of interest in relation to a change in the inflation rate.
[14] In this way, they rationalize Rabanal’s (2003) results mentioned above.

allow us to discuss this phenomenon and verify if changes in the interest rates can have an effect on income distribution as in Christiano et al. (1999). Furthermore, we will test the role of expectations in explaining the Gibson paradox and whether the price puzzle is a phenomenon which has to be confined to specific monetary regimes, namely depending on the active or passive behaviour of the Central Bank.

3. Data, Models and Methods

3.1. Data

The empirical analysis uses aggregate monthly data provided by the Organization for Economic Co-operation and Development (OECD) and the Federal Reserve Economic Data (FRED) for the US economy for the period January 1959 – August 2018. In order to assess the Gibson paradox, the following variables are employed: (i) the Effective Federal Funds Rate (FF); (ii) the Consumer Price Index (P); the Industrial Production Index (Y); and the level of monetary hourly earnings (W). Additionally, several measures of price and inflation expectations will be taken into account. Specifically, we will make use of: (i) Future Prices Paid (FPP) released from the Federal Reserve Bank of Philadelphia; (ii) Inflation Expectations provided by the University of Michigan (INF_EM); (iii) 'Greenbook' Inflation Expectations released by the Federal Reserve (INF_FED) (Romer and Romer, 2004). Although P, Y and W are transformed into a logarithmic form, the remaining variables are not converted into a log-form. All considered variables are summarized in Appendix A and Table 1.

Table 1. Variables and Description

Acronyms	**Description**	**Time span**
FF	Effective Federal Funds Rate	1959:01-2018:08
P	Consumer Price Index for All Urban Consumers: All Items	1959:01-2018:08
Y	Industrial Production: Total index	1959:01-2018:08
W	Hourly Earnings	1959:01-2018:08
FPP	Future Prices Paid; Diffusion Index for the Federal Reserve Bank of Philadelphia	1968:05-2018:08
INF_FED	Green Book Inflation Expectations, FOMC	1966:09-2013:12
INF_UM	University of Michigan: Inflation Expectation	1978:01-2018:08

3.2. Models

In order to assess whether the Central Bank is able to generate positive effects on the level prices by increasing the Federal Funds Rate, we estimate two baseline models:

Model 1: FF – P – Y;
Model 2: W – FF – P – Y.

Whereas in the first model we use the effective federal funds rate, the level of prices and the industrial production index, in the second one — in line with the 'cost channel' literature of the price puzzle (Barth and Ramey, 2002; Christiano et al., 2005; Dedola and Lippi, 2005)[15] – we add monetary wages as a variable that could affect prices. Additionally, inspired by Christiano et al. (1997; 1999), Model 2 allows us to assess whether changes in interest rates produce a variation in the distribution of income, i.e. in real wages.

In addition, since part of the recent literature regards the fact that the price puzzle derives from different monetary policy regimes (Giordani, 2004; Hanson, 2004; Castelnuovo and Surico, 2010), we estimate the aforementioned models for the whole period (1959:01–2018:08) and along different time spans. The identification of selected sub-samples is dictated by periodization based on the development of alternative US monetary policies regimes and changes in the FED's procedures. In October 1979, when Paul Volcker was appointed Chairman of the FED, there was a change in the FED operating procedures. The US Central Bank began tight control over monetary aggregates, namely non-borrowed reserves and M1 (Mishkin, 2001). Subsequently, in October 1982, when inflation was under control, the FED started to slacken the control over non-borrowed reserves and, only in February 1987, the US

[15] As seen in Section 2, the cost channel perspective which sees the monetary policy as producing supply-side effects by increasing the costs of firms, has been questioned and minimised by Rabanal (2007) and Henzel et al. (2009). Specifically, by using DSGE models, they argue that the demand-side effects dominate the supply-side ones.

monetary authority announced that it would no longer target M1. Therefore, we select October 1979, October 1982 and February 1987 as the main breaks in the US monetary policy and the identified sub-samples range from: (i) 1959:01 to 1979:09; (ii) 1979:10 to 2018:08; (iii) 1982:10 to 2018:08; (iv) 1987:02 to 2018:08.[16] The exclusion of the period 1979-1982 – when models 1 and 2 are estimated in the subsamples 1982:10-2018:08 and 1987:02-2018:08 – allows us to identify a more precise monetary policy shock through the use of the federal funds rate.[17]

3.3. Methods and identification strategies

In order to estimate Models 1 and 2, we use SVAR models (Kilian and Lütkepohl, 2017). This class of models enables us to identify monetary policy shocks by imposing restrictions on a reduced-form VAR model in levels represented in equation (1):

$$y_t = c + \sum_{i=1}^{p} A_i \, y_{t-p} + u_t \ (1)$$

y_t is the $k \ x \ 1$ vector of considered variables, c is the constant term, A_i is the $k \ x \ k$ matrix of reduced-form coefficients and u_t is a $k \ x \ 1$ vector consisting of error terms. To obtain a Structural VAR (SVAR), an identification strategy must be imposed at equation (1). An SVAR is represented as follows in equation (2):

$$B_0 y_t = a + \sum_{i=1}^{p} B_i \, y_{t-p} + w_t \ (2)$$

[16] Following Castelnuovo and Surico (2010), we perform a Chow test on the reduced form federal funds rate equation based on Model 1. Findings confirm the choice of the selected breaks by rejecting the null hypothesis of ‘No breaks at specified breakpoints’. Specifically, we found a p-value of: 0.0000 in October 1979; 0.0004 in October 1982; and 0.0478 in February 1987.

[17] According to Bernanke and Mihov (1998), during the 1979–1982 Volcker experiment, nonborrowed reserves (rather than the federal funds rate) are considered the right indicator for capturing a monetary policy shock.

where B_0 represents the matrix of contemporaneous relationships between the k variables in y_t, B_i is the $k\ x\ k$ matrix of autoregressive slope coefficients, and w_t is the vector of structural shocks.[18]

In line with Christiano et al. (1999) and Castelnuovo and Surico (2010), an exogenous monetary policy shock is isolated through a lower-triangular structure based on a Cholesky factorization. Following Bernanke and Blinder (1992) and Christiano et al. (1999), we assume two alternative identification which enable us to provide a robust analysis of the Gibson paradox. The first identification strategy for Models 1 and 2 is summarized in (3) and (4):

Model 1: $$\mathrm{B_0 y_t} = \begin{bmatrix} - & 0 & 0 \\ - & - & 0 \\ - & - & - \end{bmatrix} \begin{bmatrix} \mathrm{FF_t} \\ \mathrm{P_t} \\ \mathrm{Y_t} \end{bmatrix} \qquad (3)$$

Model 2: $$\mathrm{B_0 y_t} = \begin{bmatrix} - & 0 & 0 & 0 \\ - & - & 0 & 0 \\ - & - & - & 0 \\ - & - & - & - \end{bmatrix} \begin{bmatrix} \mathrm{W_t} \\ \mathrm{FF_t} \\ \mathrm{P_t} \\ \mathrm{Y_t} \end{bmatrix} \qquad (4)$$

where '$-$' indicates an unrestricted parameter and '0' represents a zero restriction. Following Bernanke and Blinder (1992), Leeper et al. (1996), Sims (1992; 1998) and Sims and Zha (1998), Model 1 allows the federal fund rate (FF_t) to be the most exogenous variable.[19] We assume that "authorities react immediately to the variables they can observe without delay (commodity prices, monetary aggregates, and financial variables), and only with a delay to variables that they can observe only with a delay, such as GDP and the GDP deflator" (Sims, 1998, p. 940) and, because of the information lag, "policy shocks could reasonably be assumed to be independent of contemporaneous economic disturbances" (Bernanke and Blinder, 1992,

[18] The covariance matrix of structural errors is normalized: $\mathbb{E}(\mathrm{w_t w_t'}) = \sum_{\mathrm{w}} = \mathrm{I_K}$.
[19] Bernanke and Blinder (1992) propose the federal funds rate as an indicator for capturing a monetary policy shock. Moreover, they propose two alternative identification strategies in which the federal funds rate is ordered both as the first and last variable.

p. 902). In the second equation, the level of prices (P_t) can only respond contemporaneously to a monetary policy shock and, in the third equation, the level of economic activity (Y_t) can be affected both by the interest rate and the level of prices. In Model 2, a similar identification strategy is assumed by adding the level of nominal earnings (W_t) as the first ordered variable. We are assuming that nominal wages are exogenous within the monthly observation for three main reasons: (i) wages are determined by a bargaining process influenced by several institutional factors (see, for instance, Akerlof, 1982; Bewley, 1999; Solow, 1980); (ii) the bargaining process is affected by information delays motivated by the fact that data are released with different delays and therefore trade unions and labour market institutions could not react immediately to variables that they cannot observe; (iii) monetary wages tend to be affected by nominal rigidities and the process of wage adjustment occurs slowly and over a period of time that is longer than the monthly observation. Monetary wages are not strictly related to the business cycle fluctuations since the wage bargaining process occurs periodically rather than ceaselessly (Taylor, 1979; Azariadis and Stiglitz, 1983). In Model 2, monetary wages are added – being part of the monetary costs of firms – as concurred in the determination of the level of prices. Furthermore, following Christiano et al. (1999), we are also interested in assessing the effect of monetary policy on real wages.

The identification strategies imposed in (3) and (4) assume that monetary policy does not observe Y_t and P_t during the process of setting the rate of interest FF_t. However, when targeting FF_t, the Central Bank could know both Y_t and P_t. According to Christiano et al. (1999, p. 83), such an assumption seems plausible as does the one which assumes that the FED does not know the current level of economic activity and prices in the process of setting the rate of interest. For these reasons, we impose a second alternative identification based on the following recursive ordering: $[Y_t, P_t, FF_t]$ for Model 1 and $[W_t, Y_t, P_t, FF_t]$ for Model 2.[20] Such an ordering assumes a monetary policy reaction function (e.g., a Taylor rule) and a private sector that responds slowly to changes in federal reserve policy variables (Christiano et al. 1999; Bernanke et al., 2005; Castelnuovo and Surico, 2010; Giordani, 2004; Hanson, 2004).[21] The implementation of different identification strategies will allow us to provide a robust and clear picture of the price puzzle in the US economy.

Once restrictions are imposed and structural shocks are estimated, impulse response functions (IRFs) are calculated to detect and quantify the causal relationships between the selected variables. Standard errors are estimated through a Monte Carlo procedure (1000 repetitions) and IRFs will be reported with two-standard error bands, namely considering a 95% confidence interval.

4. Findings and discussion

In this section, we report and discuss the IRFs estimated for Models 1 and 2. For the sake of simplicity, we discuss the peak effect on the price level generated by monetary policy tightening which is normalized and equal to one percentage point on impact. Initially, in order to manage models accurately, the optimal lag length of each VAR is estimated by minimizing the Akaike Information Criterion (AIC). This test is estimated for all considered periods and all results are summarised in Appendix B, Table B.1.[22]

[20]Christiano et al. (1999) impose a recursive structure by testing both the idea of a federal funds rate ordered as first and last variable. According to their estimates, results are robust and unaffected by the different identification strategies assumed.

[21] Due to space constraints, the IRFs based on (3) and (4) are reported in the main text whereas findings of the second recursive ordering are provided in Appendix C. Results are similar to the ones obtained with identification strategies (3) and (4) confirming the intuition of Christiano et al. (1999, p. 97).

[22] The number of lags estimated in the VARs led us to use different lags for any selected time span. More specifically, in Model 1, we make use of lag 9 for the entire sample and for the 1979:10–2018:08 period, 3 for the 1959:01–1979:09 sub-sample and 6 for the 1982:10–2018:08 and 1987:02–2018:08 periods. When Model 2 is considered, lag 9 is used for all the sample and for the 1979:10–2018:08 period, lag 4 for the 1959:01–1979:09 and 1987:02–2018:08 periods and finally lag 6 for the 1982:10–2018:08 period. Findings are robust when the number of lags is kept fixed across the considered sub-samples, i.e., when we make use of a lag equal to 9.

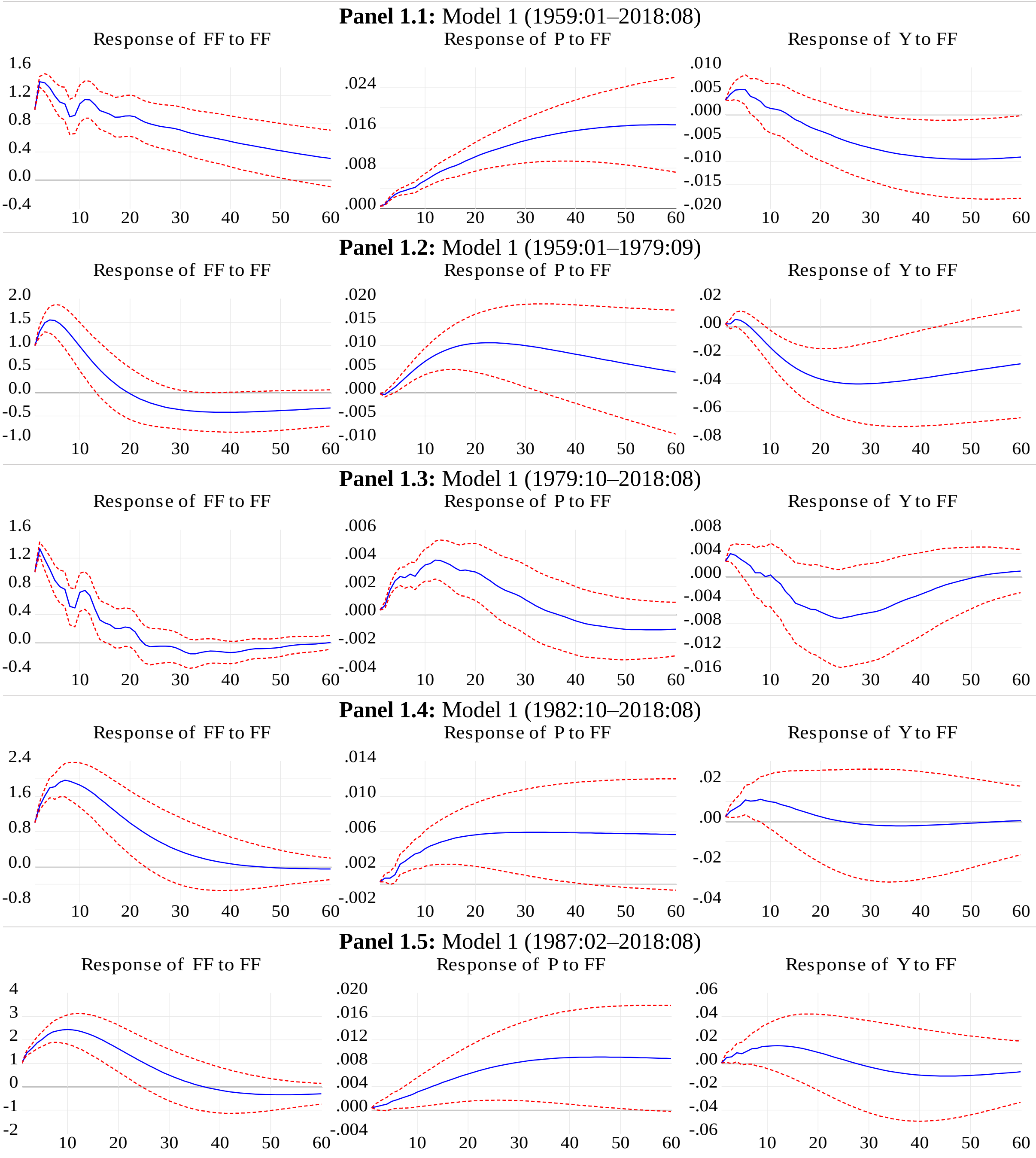

Figure 1. IRFs to a monetary policy shock, Cholesky factorization, Model 1 [$\mathrm{FF_t}$, $\mathrm{P_t}$, $\mathrm{Y_t}$]. Solid lines are point estimates and dotted lines are the computed error bands. 95% confidence interval bands estimated through a Monte Carlo procedure (1000 repetitions).

In Figure 1, the IRFs for Model 1, based on the identification strategy (3) $[FF_t, P_t, Y_t]$,– are reported by displaying the responses of P and Y to a monetary policy shock. Findings suggest that a rise in FF leads to a permanent and significant increase in the level of prices during the period 1959:01–2018:08. Specifically, a one percentage point increase in the rate of interest leads to a significant peak effect on P of 1.66% after 53 months. When the pre-1979 period is analysed in Panel 1.2, the peak effect on P is equal to1.06% after 21 months. Yet, despite the fact that an increase in FF produces the strongest effect on P in the pre-1979 period, the Gibson paradox is confirmed even in the post-1979 period. Specifically, during the period 1979:10–2018:08 (Panel 1.3), the response of P reaches a significant peak of 0.39% after 12 months. However, when Model 1 is estimated by excluding monetary targeting periods, namely in 1982:10–2018:08 and 1987:02–2018:08, monetary policy tightening leads to a permanent increase in the level of prices that is larger than the one estimated for the entire post-1979 period. Specifically, a significant peak effect on P is found to be equal to 0.59% after 26 months during the period 1982:10–2018:08 and to 0.91% after 44 months for the 1987:02–2018:08 sub-sample. The positive response of prices in the pre-1979 period is close to the one estimated in the period 1987:02–2018:08. Additionally, when the post-1979 period is detected, the greatest effect on prices occurs when the era of control over monetary aggregates is excluded, namely when the period 1979:10–1987:01 is omitted (Panel 1.5, Figure 1).

IRFs for Model 2 – based on the identification strategy (4) $[W_t, FF_t, P_t, Y_t]$ – are shown in Figure 2. We report the responses of W, P and Y to monetary policy tightening characterized by one percentage point increase in FF. Findings – reported in the Panel 2.1 for the period 1959:01–2018:08 – show that a rise in FF leads to a permanent and significant increase in P which reaches a peak of 0.82% after 28 months.

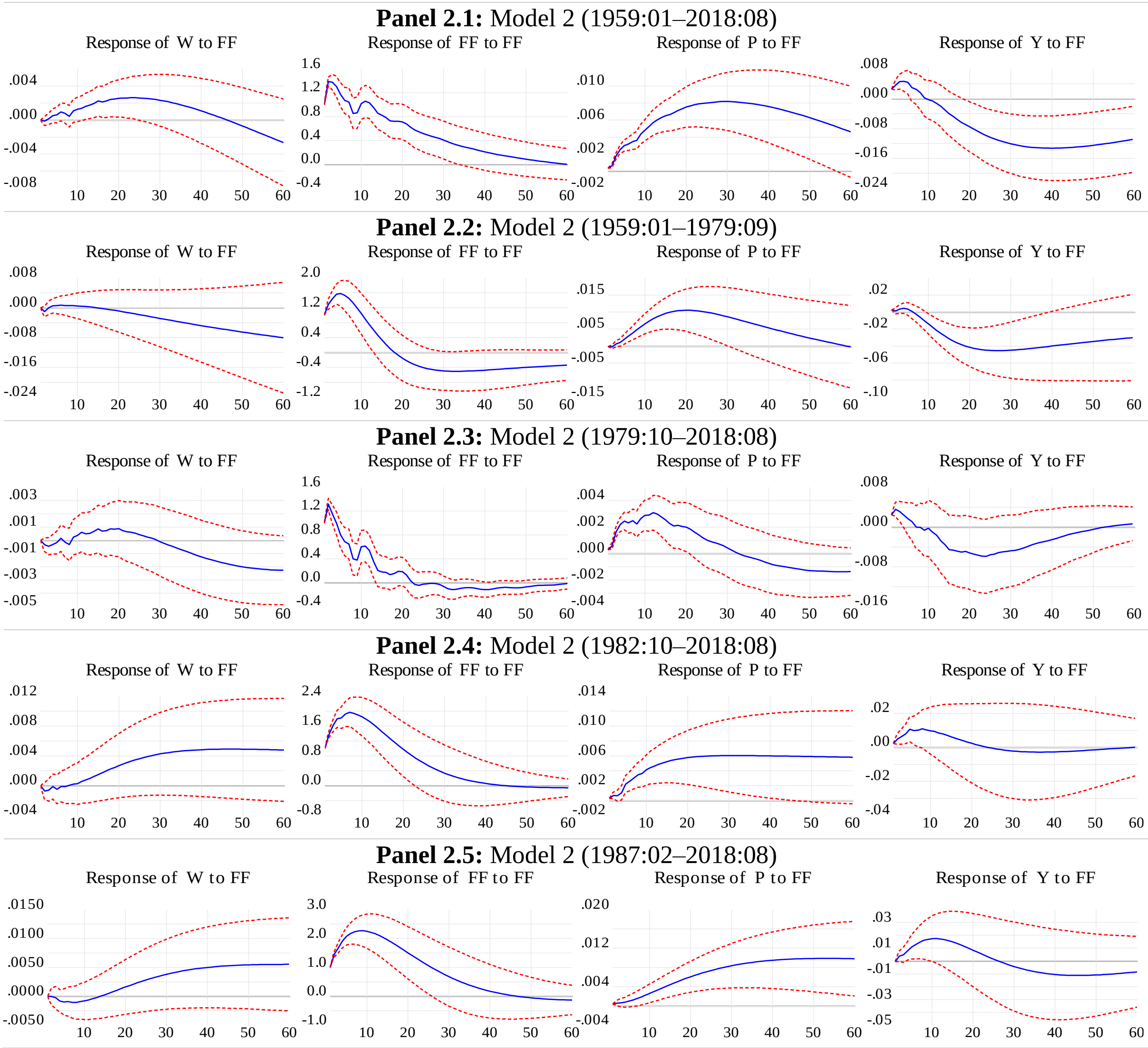

Figure 2. IRFs to a monetary policy shock, Cholesky factorisation, Model 2 [W_t, FF_t, P_t, Y_t]. Solid lines are point estimates and dotted lines are the computed error bands. 95% confidence interval bands estimated through a Monte Carlo procedure (1000 repetitions).

The price puzzle is also found when IRFs are estimated for the different sub-samples. Although an increase in FF produces the strongest positive effect on P in the pre-1979 period, IRFs confirm the Gibson paradox even in the post-1979 period. Specifically, when the pre-1979 period is analysed in Panel 2.2, the response of *P* reaches a significant peak of 1.05% after 19 months. When the post-1979 period is detected, the peak effect on P is equal to: 0.31% after 12 months in the period 1979:10–2018:08 (Panel 2.3, Figure 2); 0.60% after 26 months during the period 1982:10–2018:08 (Panel 2.4, Table 2); and 0.99% after 50 months when the

1987:02–2018:08 (Panel 2.5, Table 2). When Model 2 is estimated in the post-1979 period and excluding the period of control over monetary aggregates, the increase in the level of prices is larger than the one estimated for the period 1979:10–2018:08 and close to the one assessed for the pre-1979 period. Moreover, the inclusion of monetary wages W in Model 2, enables us to draw an additional conclusion: the rise in prices generated by monetary policy tightening leads real wages to fall since the increase in prices P is not compensated for by a rise in monetary wages W. Such results, which are confirmed in all selected periods considered in Figure 2, – are in line with those obtained by Christiano et al. (1997; 1999) according to whom a rise in the rate of interest produces a fall in real wages.

In order to provide a robust analysis of the price puzzle, we make use of additional identification strategies, both for Models 1 and 2, which assume an endogenous rate of interest. IRFs, reported in Appendices C.1 and C.3, are in line with those obtained through the identification strategies (3) and (4). All the peak effects on prices produced by monetary policy tightening and estimated through all the implemented identification strategies are summarized in Table 2. The peak effects are slightly lower when a monetary policy reaction function is imposed, namely when the orderings $[Y_t, P_t, FF_t]$ and $[W_t, Y_t, P_t, FF_t]$ are employed. Nevertheless, our findings show that the price puzzle exists irrespectively of the used recursive ordering. Indeed, our results are in sharp contrast with the ones obtained by Hanson (2004) and Castelnuovo and Surico (2010) according to whom the price puzzle is regarded as a 'regime specific phenomenon', namely dependent on the passive (active) behaviour of the Central Bank in the pre- and post-1979 periods. Yet, although we have found a positive and larger effect on prices in the pre-1979 period, we can affirm that the price puzzle exists even in the post-1979 period. In the post-1979 period, the effect is stronger when the monetary targeting periods are excluded by our sample, namely during the periods 1982:10–2018:08 and 1987:02–2018:08.[23]

Table 2. Peak effect on the level of prices, Models 1 and 2.

	Peak effect on the level of prices				
Identification	1959:01–2018:08	1959:01–1979:09	1979:10–2018:08	1982:10–2018:08	1987:02–2018:08
			Model 1		
FF_t, P_t, Y_t	1.66% (53)	1.06% (21)	0.39% (12)	0.59% (26)	0.91% (44)
Y_t, P_t, FF_t	1.24% (53)	1.07% (21)	0.30% (12)	0.55% (27)	0.82% (39)
			Model 2		
W_t, FF_t, P_t, Y_t	0.82% (28)	1.05% (19)	0.31% (12)	0.60% (26)	0.99% (50)
W_t, Y_t, P_t, FF_t	0.67% (27)	1.06% (19)	0.24% (12)	0.57% (29)	0.96% (51)

In ( ) the month in which the peak effect occurs.

Our results also provide a clear and comprehensive picture of the price puzzle or 'Gibson paradox' in the US economy. Notably, empirical outcomes confirm the price puzzle both for the pre- and post-1979 period: monetary policy tightening leads to a rise in the level of prices. Even when additional firms' costs, that is monetary wages, are added to the model and alternative identification strategies are assumed, the Gibson paradox is confirmed for all the considered sub-samples. Although we have found that an increase in the rate of interest leads to a higher level of prices in the pre-1979 period rather than in the post-1979 one, we show that – when the FED's monetary control over monetary aggregates is excluded by our sample – the positive effect of interest rates on prices is larger than the one experienced in the sub-sample including the 'Volcker era'. Furthermore, when the period 1987:02-2018:08 is compared with the pre-1979 one, estimated IRFs show a similar peak effect on the level of prices.

[23] In the Technical Appendix available under request, Models 1 and 2 are also estimated for the post-1979 period recommended by Castelnuovo and Surico (2010), namely during the 1979:10-2006:12 period. Even when this sub-period is considered, our models reproduce the price puzzle.

5. Inflation expectations and the price puzzle

As anticipated in Section 2, starting with the original contribution of Sims (1992) and arriving at more recent works on the price puzzle (Giordani, 2004; Hanson 2004; Tillmann, 2008; Castelnuovo and Surico, 2010; Tas, 2011), price expectations have played a crucial role in motivating the existence of this paradox. Indeed, the price puzzle would be caused by a spurious correlation in the VAR model generated by the omission of a relevant variable which is supposed to capture price expectations.

To solve or mitigate the puzzle, Sims (1992), Balke and Emery (1994), Leeper et al., (1996) and Christiano et al. (1999) included the commodities price in the VAR because it would capture price expectations. However, this diffuse, conventional wisdom has been criticized by several authors who have raised some doubts regarding the suitability of commodity prices for capturing price expectations (Giordani, 2004; Hanson, 2004). Specifically, Giordani (2004) shows that the puzzle is determined as a consequence of the omission of the output gap which in turn, would produce a misspecification in the VAR. According to Hanson (2004), the commodity prices show feeble forecasting power and lack theoretical underpinning. For these reasons, Hanson (2004) looked in vain for different indicators capable of capturing the forecasts of inflation and solving the puzzle. Tas (2011) maintains that asymmetric information produces frictions in the transmission mechanism of monetary policy by leading to unwarranted effects, namely an increase in the expected and actual inflation when monetary policy tightening occurs. To mitigate the puzzle, Tas (2011) includes the Survey of Consumer Attitudes in the VAR. Finally, Castelnuovo and Surico (2010) reduce the omission problem by including the inflation forecasts provided by the Survey of Professional Forecasters in the VAR. Yet, despite the fact that different measures of inflation expectations have been used, the price puzzle has not been solved, especially when the pre-1979 period is considered.

In order to consider the role played by expectations, we include three alternative measures of expected prices and inflation in our VAR models. We make use of the Future Prices Paid (FPP) released by the Bank of Philadelphia and the Inflation Expectation provided by the University of Michigan (INF_UM).[24]Additionally, in the spirit of Romer and Romer (2004), we reconstruct inflation expectations from the Greenbook where the forward-looking inflation (INF_FED) is released by the Federal Reserve staff before each meeting of the FOMC. We expand the monthly Romer and Romer dataset which can now cover the period 1966:09–2013:12.[25] Since official data correspond to FOMC meetings, variables are converted to monthly observations. To do this, the forecast decided in each meeting will be assigned to the corresponding month. If there are more meetings in one month, we consider the average value. If there are no meetings, we consider no change in the FED expectations and therefore keep the same forecasts as the previous meeting.

The forward-looking variables are alternatively introduced both in Model 1 $[FF_t, P_t, Y_t]$ and Model 2 $[W_t, FF_t, P_t, Y_t]$ as the first ordered variable, namely the most exogenous variable. Expectations are also included as the first ordered variable when the second identification strategy is assumed ($[Y_t, P_t, FF_t]$ for Model 1 and $[W_t, Y_t, P_t, FF_t]$ for Model 2), namely when the FED is supposed to observe Y_t and P_t during the process of setting FF_t. In this section, we will report the IRFs of the first identification and discuss the responses of the price level to monetary policy shocks. The optimal lag selection for the models augmented by expectations is reported in Tables B.2 and B.3, Appendix B. The IRFs of the second identification strategy which includes expectations are reported in Appendices C.2 and

[24] Future Prices Paid forecasts the change in Prices Paid over the next six months for reporting manufacturing firms. As an alternative to inflation expectations released by the University of Michigan, the Consumer Opinion Surveys which contains the Future Tendency of Inflation released by the OECD could be used. The Two variables are correlated at 98%.

[25] We use the inflation expectations which refer to the forecast for the current quarter as a complete series which is traceable from May 1967. However, we estimate the correlation between the forecasts for the actual quarter with the ones estimated for one and two quarters ahead for the 1969:01-2013:12 period. Findings show a high correlation equal to 0.97 and 0.91, respectively.

C.4, whereas a summary of the peak effect on the level of prices estimated through all the implemented identification strategies is reported in Table 3 at the end of this section.

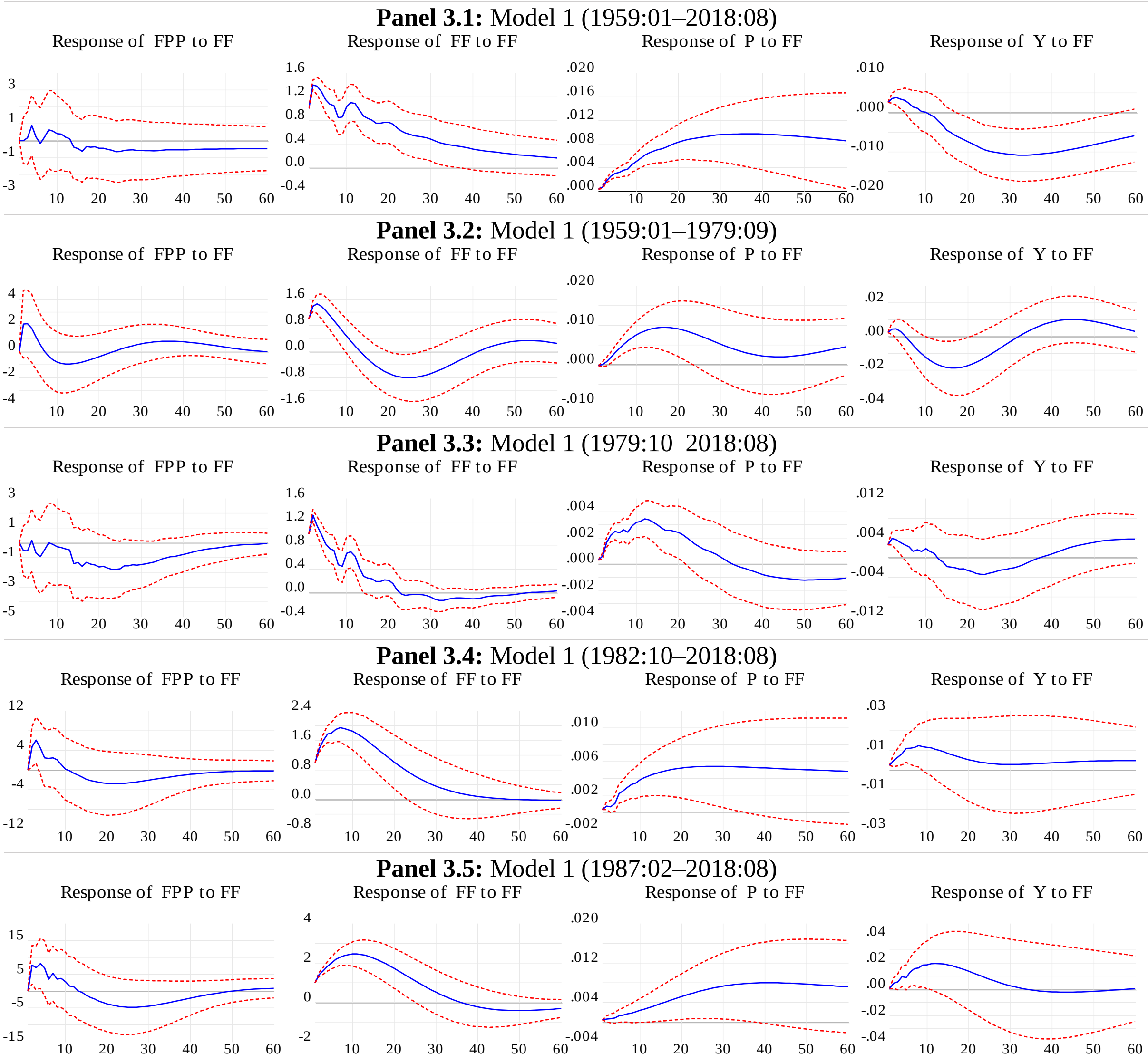

Figure 3. IRFs to a monetary policy shock, Cholesky factorisation, Model 1 [FPP_t, FF_t, P_t, Y_t]. Solid lines are point estimates and dotted lines are the computed error bands. 95% confidence interval bands estimated through a Monte Carlo procedure (1000 repetitions).

As a first step, we start with Model 1 (Figure3), where *FPP* is included. As shown in Panel 3.1, when all the sample is covered, the peak effect on P is equal to 0.97% after 35 months. When the sub-sample1959:01–1979:09 is considered in Panel 3.2, the effect on P reaches a peak of 0.95% 16 months later. When the post-1979 period is analysed in panels

3.3, 3.4 and 3.5, a one percentage point increase in FF leads to a peak effect on P equal to: 0.35% after 12 months in the period 1979:10–2018:08; 0.54% after 23 months during the period 1982:10–2018:08; and 0.80% after 39 months in the period 1987:02–2018:08.

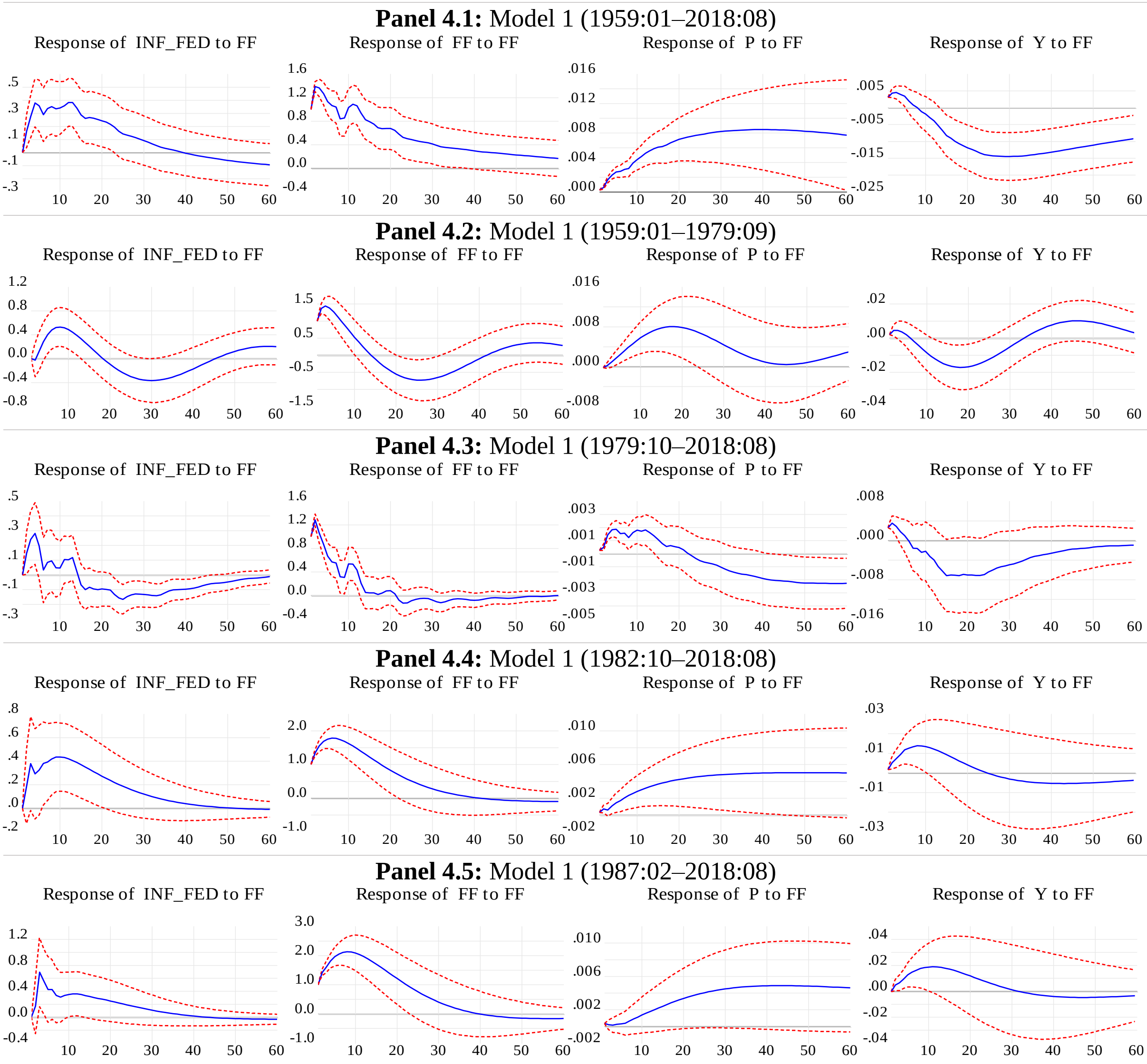

Figure 4. IRFs to a monetary policy shock, Cholesky factorisation, Model 1 [$INF\_FED_t, FF_t, P_t, Y_t$]. Solid lines are point estimates and dotted lines are the computed error bands. 95% confidence interval bands estimated through a Monte Carlo procedure (1000 repetitions).

In Figure 4, we consider Model 1 augmented by the FED's forecasts inflation INF_FED. As reported in Panel 4.1 where the period 1959:01–2018:08 is analysed, the peak effect on P of 0.85% occurs after 37 months. When the sub-sample 1959:01–1979:09 is considered in

Panel 4.2, the peak effect on P is equal to 0.80% after 17 months. During the 1979:10–2018:08 sub-sample, the peak effect on P is equal to 0.18% after 4 months. When the period 1982:10–2018:08 is displayed in panel 4.4, the peak effect on P of 0.50% is reached after 41 months. Similarly, when the 1987:02–2018:08 sub-sample is shown in panel 4.5, a peak effect on P of 0.50% occurs after 40 months.

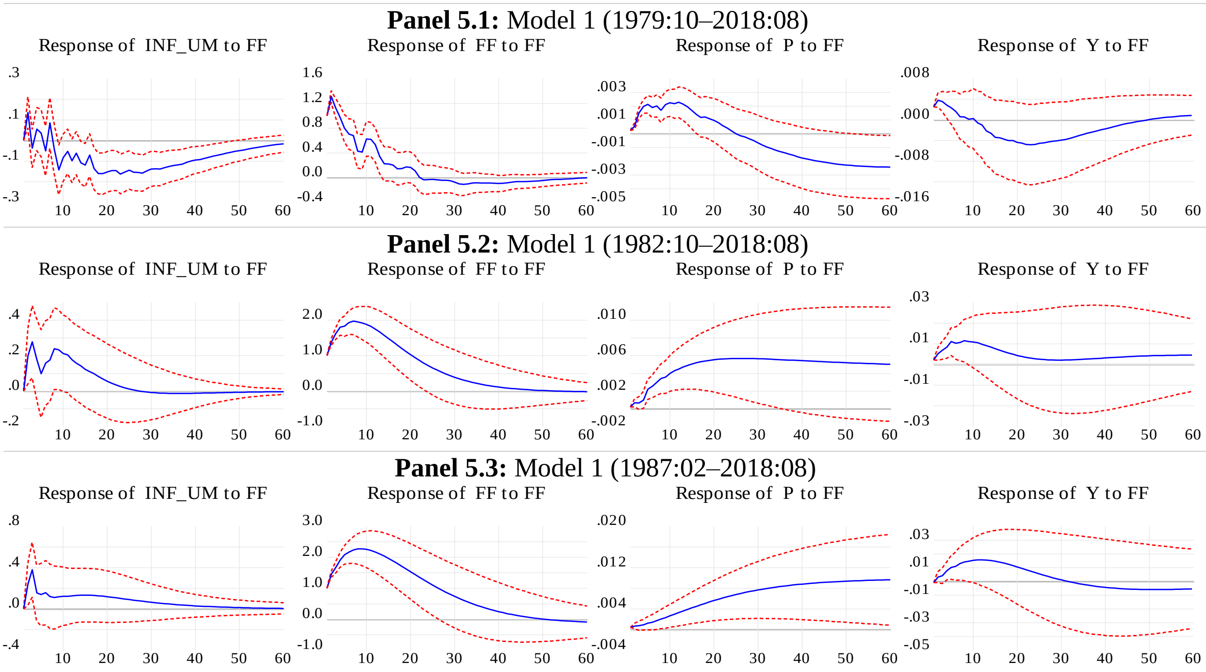

Figure 5. IRFs to a monetary policy shock, Cholesky factorisation, Model 1[INF_UM_t, FF_t, P_t, Y_t]. Solid lines are point estimates and dotted lines are the computed error bands. 95% confidence interval bands estimated through a Monte Carlo procedure (1000 repetitions).

In Figure 5, we display the IRFs estimated for Model 1 which consider the inflation expectations released by the University of Michigan INF_UM. When INF_UM is considered, our estimations are carried out only for the post-1979 period. Specifically, when the period 1979:10–2018:08 is taken into consideration in Panel 5.1, a one-unit increase in FF produces a peak effect on P equal to 0.23% after 12 months. The effect on the level of prices is larger when the control over monetary aggregates is excluded from our samples in Panels 5.2 and 5.3. In particular, during the period 1982:10–2018:08, the level of prices reaches a peak of 0.57%

after 24 months and, when the period 1987:02–2018:08 is analysed, the peak effect on P of 0.96% is reached after 56 months.

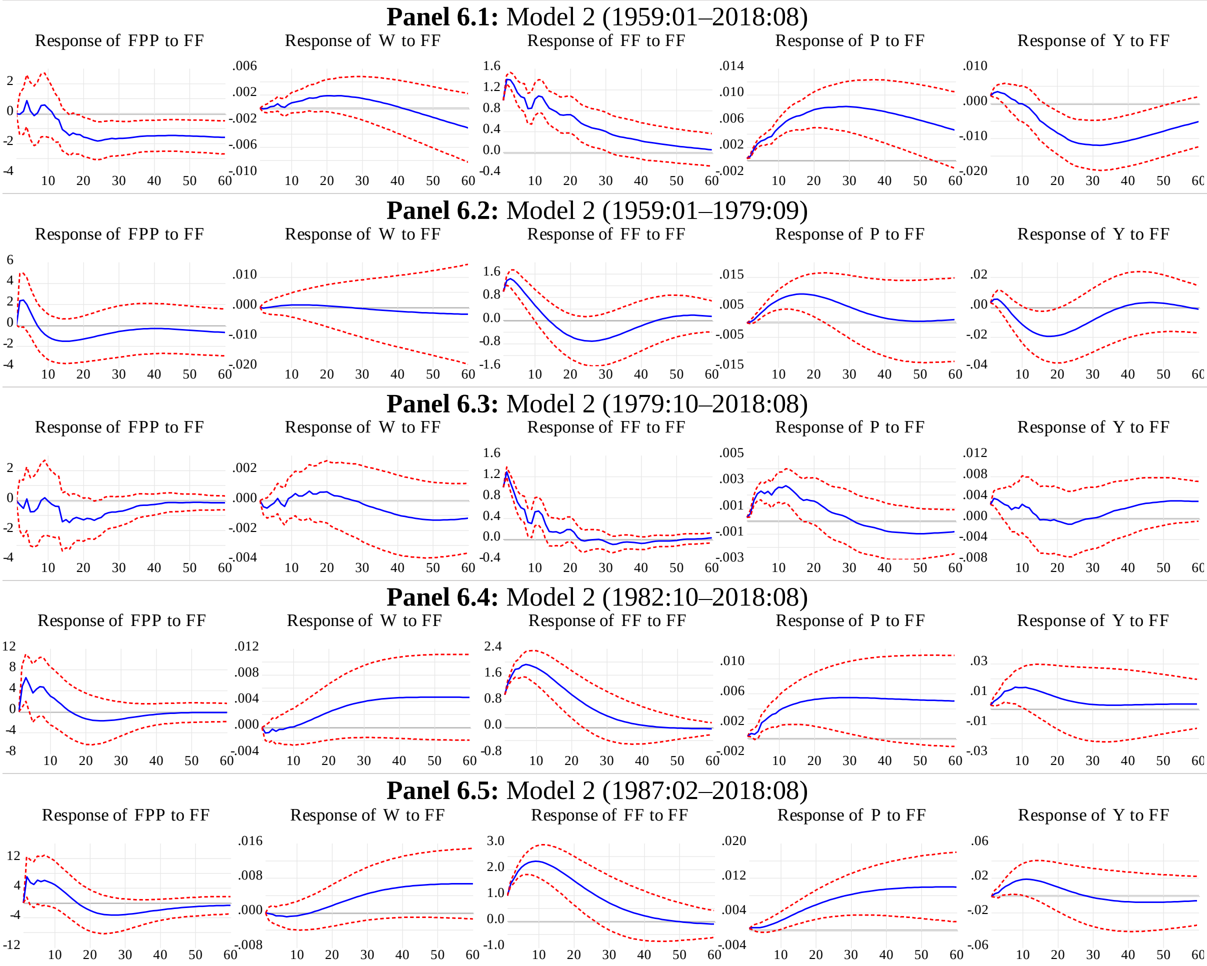

Figure 6. IRFs to a monetary policy shock, Cholesky factorisation, Model 2 [FPP_t, W_t, FF_t, P_t, Y_t]. Solid lines are point estimates and dotted lines are the computed error bands. 95% confidence interval bands estimated through a Monte Carlo procedure (1000 repetitions).

As a second step, we display the IRFs when FPP, INF_FED and INF_UM are introduced in Model 2 as the first ordered variable. In Figure 6, we detect the effect of FF on P when FPP is considered. In Panel 6.1, a unitary monetary policy shock in the period 1959:01–2018:08 leads to a peak effect on P equal to 0.82% after 28 months. During the sub-sample 1959:01–1979:09 in Panel 6.2, the peak effect on P of 0.94% occurs after 16 months. When the post-1979 period is analysed in panels 6.3, 6.4 and 6.5, P reaches a peak equal to: 0.27% after 12 months in the period 1979:10–2018:08; 0.55% after 25 months during the period 1982:10–2018:08; and 1% after 52 months in the period 1987:02–2018:08.

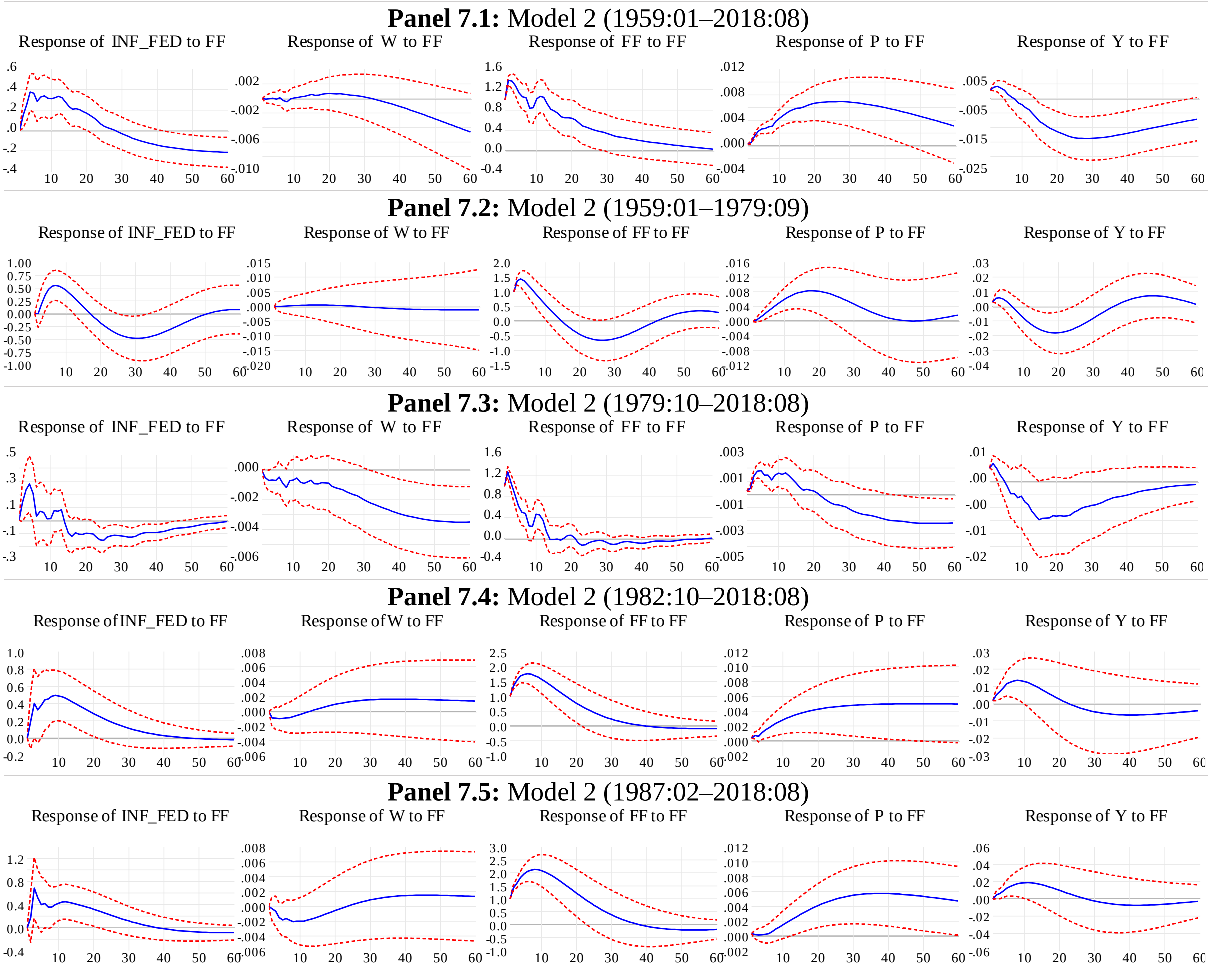

Figure 7. IRFs to a monetary policy shock, Cholesky factorization, Model 2 [$INF\_FED_t, W_t, FF_t, P_t, Y_t$]. Solid lines are point estimates and dotted lines are the computed error bands. 95% confidence interval bands estimated through a Monte Carlo procedure (1000 repetitions).

In Figure 7, we show the IRFs of Model 2 augmented by the Federal Reserve's forecasts INF_FED. As shown in Panel 7.1 where the period 1959:01–2018:08 is considered, a one percentage point increase in FF produces a peak effect on P of 0.69% after 23 months. The sub-sample 1959:01–1979:09 is reported in Panel 7.2 and a peak of 0.83% on *P* occurs after 18 months. When the 1979:10–2018:08 sub-sample is considered in Panel 7.3, the peak effect on *P* equal to 0.18% occurs after 5 months. During the 1982:10–2018:08 sub-sample, a one percentage point increase in FF produces a peak effect on P equal to 0.50% after 41 months. Similarly, during the period 1987:02–2018:08, a peak on P of 0.57% occurs after 34 months.

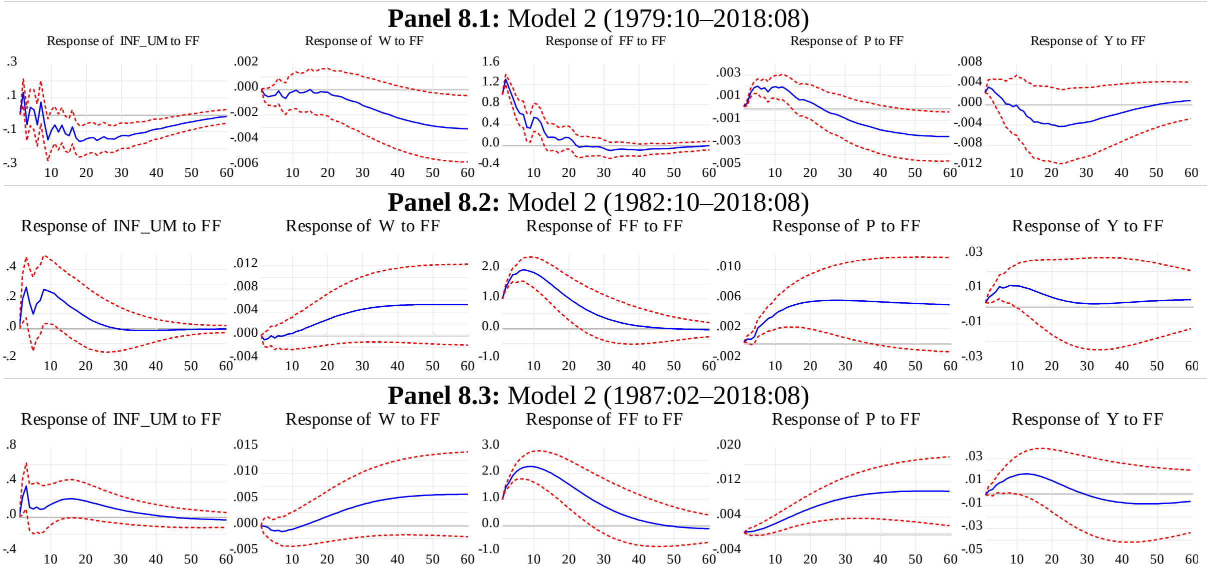

Figure 8. IRFs to a monetary policy shock, Cholesky factorisation, Model 2 $[\mathrm{INF\_UM}_t, \mathrm{W}_t, \mathrm{FF}_t, \mathrm{P}_t, \mathrm{Y}_t]$. Solid lines are point estimates and dotted lines are the computed error bands. 95% confidence interval bands estimated through a Monte Carlo procedure (1000 repetitions).

Finally, Figure 8 shows the IRFs of Model 2 augmented by INF_UM are reported. During the period 1979:10–2018:08 (Panel 8.1), a peak effect on P equal to 0.20% occurs after 5 months. When the monetary targeting periods are not included in the sample, the effect on prices is found to be larger. During the period 1982:10–2018:08, the level of prices reaches a peak of 0.58% after 23 months and, when the period 1987:02–2018:08 is taken into consideration, the peak effect is equal to 1% after 52 months. Furthermore, in line with the models non-augmented by expectations, when expectations are included in Model 2, an increase in the rate of interest produces a fall in real wages. As can be seen in Figures 6, 7 and 8, the increase in the level of prices produced by monetary policy tightening is not compensated for by a proportional increase in the level of monetary wages.

All peak effects on the level of prices estimated for Models 1 and 2 augmented by expectations are summarized in Table 3 and findings are robust to the alternative identification strategies. Although all results confirm the existence of the price puzzle, the estimated peak effects are slightly lower when a monetary policy reaction function is imposed, namely when the FF is ordered as the last variable. Furthermore, if we compare findings of the models estimated with and without expectations (Tables 2 and 3), the inclusion of forward-looking variables marginally mitigates the positive effect of the interest rate on the level of prices. The largest mitigation occurs in the period 1987:02–2018:08 when the variable INF_FED is included in Models 1 and 2.

Table 3. Peak effect on the level of prices, Models 1 and 2.

Identification	Peak effect on level of prices				
	1968:05–2018:08	1968:05–1979:09	1979:10–2018:08	1982:10–2018:08	1987:02–2018:08
FPP_t, FF_t, P_t, Y_t	0.97% (35)	0.95% (16)	0.35% (12)	0.54% (23)	0.80% (39)
FPP_t, Y_t, P_t, FF_t	0.78% (30)	0.94% (15)	0.27% (12)	0.50% (26)	0.72% (38)
$FPP_t, W_t, FF_t, P_t, Y_t$	0.82% (28)	0.94% (16)	0.27% (12)	0.55% (25)	1.00% (52)
$FPP_t, W_t, Y_t, P_t, FF_t$	0.71% (28)	0.93% (15)	0.20% (10)	0.50% (24)	0.97% (57)
	1966:09–2013:12	1966:09–1979:09	1979:10–2013:12	1982:10–2013:12	1987:02–2013:12
$INF\_FED_t, FF_t, P_t, Y_t$	0.85% (37)	0.80% (17)	0.18% (4)	0.50% (41)	0.50% (40)
$INF\_FED_t, Y_t, P_t, FF_t$	0.63% (30)	0.79% (17)	0.14% (4)	0.38% (20)	0.37% (36)
$INF\_FED_t, W_t, FF_t, P_t, Y_t$	0.69% (23)	0.83% (18)	0.18% (5)	0.50% (41)	0.57% (34)
$INF\_FED_t, W_t, Y_t, P_t, FF_t$	0.56% (23)	0.79% (17)	0.13% (4)	0.45% (42)	0.55% (34)
			1979:10–2018:08	1982:10–2018:08	1987:02–2018:08
INF_UM_t, FF_t, P_t, Y_t	-----	-----	0.23% (12)	0.57% (24)	0.96% (56)
INF_UM_t, Y_t, P_t, FF_t	-----	-----	0.18% (10)	0.53% (23)	0.89% (57)
$INF\_UM_t, W_t, FF_t, P_t, Y_t$	-----	-----	0.20% (5)	0.58% (23)	1.00% (52)
$INF\_UM_t, W_t, Y_t, P_t, FF_t$	-----	-----	0.16% (5)	0.55% (24)	0.96% (47)

In ( ) the month in which the peak effect occurs.

6. Discussion of results and theoretical implications

Our findings show a clear and robust picture of the price puzzle estimated for the US economy for the 1959-2018 period. Specifically, our estimates enable us to conclude that the Gibson paradox should be conceived as being specific to the economic theory rather than a ‘regime specific phenomenon’ (Hanson, 2004; Castelnuovo and Surico, 2010). Indeed, irrespective of different model specifications – which include different timespans, expectations and alternative identification strategies and variables – monetary policy tightening is able to produce a positive effect on the level of prices.[26] The empirical findings can be summarized as follows:

(i) Contrary to what has been advocated by Hanson (2004) and Castelnuovo and Surico (2010), the Gibson paradox is confirmed both in the pre- and post-1979 period. Although we have found that an increase in the rate of interest leads to a higher level of prices in the pre-1979 period rather than in the post-1979 one, we show that – when the FED's monetary control over monetary aggregates is excluded by our sample – the magnitude of the effect of interest rates on prices is close to the one obtained in the pre-1979 period. Therefore, the Gibson paradox is not dependent on the passive or active behaviour of the FED in setting the rate of interest.[27]

(ii) In line with the results of Sims (1992), Christiano et al. (1999), Giordani (2004) and Castelnuovo and Surico (2010), the introduction of several measures of price and inflation expectations does not solve the Gibson paradox, but marginally mitigates it. The largest mitigation occurs in the period 1987:02–2018:08 when the inflation projections from the Greenbook (INF_FED) are included in Models 1 and 2.

(iii) Neither the introduction of additional monetary costs of firms in Model 2, namely nominal wages, nor the use of alternative identification strategies modify the empirical regularity prescribed by the Gibson paradox.

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[26] Irrespective of the validity of the way they identify policy shocks, we do not follow Getler and Karadi in rejecting the Cholesky scheme because the estimates confirm the price puzzle when it is used: "as Figure 1 shows, how well a pure monetary policy surprise is identified under the Cholesky scheme is questionable. While the one-year rate increases, both industrial production and the CPI display 'puzzles'" (Getler and Karadi, 2015, pp. 60-61). In our view, on theoretical grounds, there is nothing puzzling about the co-movement of prices and interest rates.

[27] The operating procedures implemented when conducting the monetary policy, namely whether the Central Bank targets monetary aggregates or the interest rate, may have an influence. The attempt in 1979-1982 to control monetary aggregates led to a great variability of interest rates and a strong fall in output that affected the course of money wages and prices.

(iv) In line with Christiano et al. (1999), the upsurge in the level of prices determined by an increase in the rate of interest produces a fall in real wages. Specifically, the increase in the level of prices is not compensated for by a proportional increase in the level of monetary wages.

These empirical findings recall Goodhart's (1986, p. 96) observation that businessmen "tend to regard interest rates as a cost and look to establish a price *rise* in response to increased interest rates". As seen in Section 2, this was already suggested by Tooke (1838) and has recently been revived by the literature on the cost-channel of monetary policy (Ramey, 1992; Barth and Ramey 2002; Christiano and Eichenbaum,1992; Christiano et al., 1997; Ravenna and Walsh, 2006) where the amount of interest to be paid on the working capital or on loans due to a temporal mismatch between factor payments and sales receipts is conceived to affect marginal costs.[28] Even before, however, Kalecki (1971) claimed that the degree of monopoly is likely to increase whenever overhead costs (which can be thought of as including the interest costs associated with debt servicing) rise, and Kaldor (1982, p. 63) alludes to the cost- and price-reducing effect of a reduction in interest rates on the basis that interest costs are passed on prices in much the same way as wage costs (see Lima and Setterfield, 2010). Others considered the mark-ups applied to direct or prime costs of production as affected by changes in the interest rate (Galbraith, 1957; Taylor, 1983; Dutt, 1990). More importantly, it has also been argued that this cost-channel does not necessarily apply only to oligopolistic conditions or to the working capital and short-term loans. Given the money wages, normal profits of enterprise and the methods of production, a permanent increase in the interest rates, namely in the pure cost of capital, would lead to a change in the same direction of commodity prices under the action of free competition that equals prices to the monetary costs of production

[28] Note that in models where output is produced only through labour and the purchase of production factors must be financed through borrowing, the marginal cost of labour is equal to the wage times the gross nominal interest rate.

(Garegnani, 1978-79; Panico, 1988; Pivetti 1991).[29] Workers will thus suffer a loss in their purchasing power unless they are able to resist it by demanding higher money wages and an inflationary process has set in (Levrero, 2021).

The implication for monetary policy is that its tightening may lead to an increase in prices and that the policy response to an adverse shock on prices needs thus to be much more cautious than usually acknowledged. Several factors may have an influence on inflation from the way banks set their lending rates when facing shocks in monetary base rates to the structure of the financial markets (Hülsewig et al., 2009) and the impact of changes in the interest rates on aggregate demand and thus on the course of money wages. For instance, the lower the (negative) sensitiveness of aggregate demand is to the interest rates, the higher the probability there will be "paradoxical" reactions of prices to the decisions of monetary authorities.

[29] The effect also concerns own capital since the interest rate is the opportunity cost of capital. On other post-Keynesian economists who consider the Gibson paradox and interest as a cost which is passed on prices, see Moore (1988), Lavoie (1995) and Wray (2007).

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APPENDICES

Appendix A.

Effective Federal Funds Rate
(https://fred.stlouisfed.org/series/FEDFUNDS)

Consumer Price Index for All Urban Consumers: All Items.
(https://fred.stlouisfed.org/series/CPIAUCNS)

Industrial Production: Total index.
(https://fred.stlouisfed.org/series/IPB50001N)

Hourly Earnings (MEI)
(https://stats.oecd.org/Index.aspx?DataSetCode=EAR_MEI)

Future Prices Paid; Diffusion Index for the Federal Reserve Bank of Philadelphia
(https://fred.stlouisfed.org/series/PPFDFNA066MNFRBPHI)

University of Michigan: Inflation Expectation.
(https://fred.stlouisfed.org/series/MICH)

Inflation expectations, Greenbook projections released by the Board of Governors prior to each meeting of the Federal Open Market Committee
https://www.philadelphiafed.org/research-and-data/real-time-center/greenbook-data/pdf-data-set

Appendix B.

Table B.1. Optimal Lag selection, Akaike Information Criterion. (Models 1 and 2 without expectations).

			Model 1		
Lag	**1959:01–2018:08**	**1959:01–1979:09**	**1979:10–2018:08**	**1982:10–2018:08**	**1987:02–2018:08**
0	5.840384	2.323268	1.793686	0.824009	0.507098
1	-15.30184	-15.54888	-15.71084	-18.50698	-19.06086
2	-15.73363	-15.78599	-16.12245	-18.87925	-19.56345
3	-15.90932	-15.84859*	-16.34616	-18.93551	-19.59233
4	-15.94934	-15.81821	-16.41164	-19.01753	-19.66839
5	-15.98412	-15.79026	-16.44802	-19.02753	-19.64143
6	-15.99875	-15.81174	-16.50005	-19.06534*	-19.68742*
7	-16.01301	-15.80968	-16.50567	-19.05080	-19.67565
8	-16.06206	-15.79269	-16.62057	-19.02226	-19.63974
9	-16.09344*	-15.74387	-16.73853*	-19.02562	-19.66496
10	-16.07271	-15.73329	-16.72194	-19.01339	-19.65188
11	-16.06470	-15.69504	-16.71504	-18.99358	-19.63229
12	-16.05203	-15.63953	-16.72226	-18.97973	-19.61164
			Model 2		
Lag	**1959:01–2018:08**	**1959:01–1979:09**	**1979:10–2018:08**	**1982:10–2018:08**	**1987:02–2018:08**
0	2.556581	-3.871080	-1.922860	-3.035584	-4.136271
1	-24.20533	-23.95927	-24.85562	-27.80442	-28.40272
2	-24.62252	-24.21914	-25.30514	-28.19959	-28.90757
3	-24.78494	-24.26267	-25.50854	-28.26208	-28.94273
4	-24.85450	-24.26957*	-25.59062	-28.35154	-29.03557*
5	-24.89348	-24.19660	-25.63633	-28.34353	-28.98462
6	-24.90868	-24.19758	-25.71030	-28.39093*	-29.01599
7	-24.92462	-24.19453	-25.72063	-28.37980	-28.98784
8	-24.95124	-24.16169	-25.80312	-28.32098	-28.92472
9	-24.96691*	-24.08755	-25.92028*	-28.30992	-28.93925
10	-24.95267	-24.04829	-25.87584	-28.27966	-28.92057
11	-24.93925	-24.00241	-25.86365	-28.26330	-28.89623
12	-24.92860	-23.95601	-25.86885	-28.23546	-28.87282

* is associated to the lowest value assumed by the Akaike Information Criterion.

Table B.2. Optimal Lag selection, Akaike Information Criterion. (Model 1 with expectations)**.**

		Model 1 – FPP			
Lag	**1968:05–2018:08**	**1968:05–1979:09**	**1979:10–2018:08**	**1982:10–2018:08**	**1987:02–2018:08**
0	13.01617	7.632426	10.05510	9.089155	8.702219
1	-8.369271	-8.659127	-8.695537	-11.46188	-12.07747
2	-8.938750	-8.882373*	-9.197095	-11.91348	-12.61179
3	-9.124172	-8.857226	-9.405566	-11.95862	-12.64400
4	-9.137681	-8.825799	-9.450818	-12.02636	-12.70793
5	-9.158503	-8.666500	-9.497916	-12.03647	-12.67497
6	-9.174807	-8.697836	-9.539012	-12.06258*	-12.74349*
7	-9.162711	-8.807262	-9.528778	-12.03814	-12.72791
8	-9.198628	-8.650469	-9.620467	-12.00549	-12.69290
9	-9.240242*	-8.525159	-9.713665*	-11.98164	-12.67717
10	-9.203314	-8.533996	-9.678430	-11.94898	-12.63748
11	-9.179936	-8.382496	-9.653639	-11.90733	-12.59307
12	-9.157344	-8.336566	-9.643325	-11.87366	-12.55483
		Model 1 – INF_FED			
Lag	**1966:09–2013:12**	**1966:09–1979:09**	**1979:10–2013:12**	**1982:10–2013:12**	**1987:02–2013:12**
0	8.619563	3.643028	5.117219	3.289771	2.805389
1	-13.18323	-13.16412	-13.54635	-16.43302	-16.99113
2	-13.58292	-13.42141*	-13.91789	-16.79431	-17.49122
3	-13.75097	-13.34659	-14.17777	-16.85354	-17.54144
4	-13.78833	-13.25114	-14.27044	-16.93226*	-17.64611*
5	-13.82005	-13.09471	-14.38102	-16.91443	-17.58569
6	-13.80938	-13.05966	-14.38171	-16.93101	-17.60619
7	-13.79422	-13.08185	-14.35418	-16.88997	-17.55604
8	-13.85251	-12.99404	-14.42088	-16.85363	-17.50730
9	-13.91158*	-12.85906	-14.56433*	-16.84904	-17.50359
10	-13.88447	-12.83678	-14.52731	-16.81868	-17.47490
11	-13.86196	-12.74536	-14.49737	-16.76892	-17.42435
12	-13.84574	-12.72385	-14.48458	-16.73861	-17.37128
		Model 1 – INF_UM			
Lag	**1959:01–2018:08**	**1959:01–1979:09**	**1979:10–2018:08**	**1982:10–2018:08**	**1987:02–2018:08**
0	-----	-----	4.673423	2.377399	2.090432
1	-----	-----	-15.00602	-17.97366	-18.62341
2	-----	-----	-15.41487	-18.37811	-19.13767
3	-----	-----	-15.65837	-18.43443	-19.16394
4	-----	-----	-15.72098	-18.52817	-19.26242*
5	-----	-----	-15.84213	-18.52281	-19.22881
6	-----	-----	-15.85318	-18.55666*	-19.25419
7	-----	-----	-15.86665	-18.52119	-19.23784
8	-----	-----	-15.95984	-18.47726	-19.17189
9	-----	-----	-16.04632*	-18.44724	-19.16678
10	-----	-----	-16.02578	-18.45181	-19.13347
11	-----	-----	-16.00901	-18.41324	-19.09072
12	-----	-----	-15.99457	-18.38910	-19.05401

* is associated to the lowest value assumed by the Akaike Information Criterion.

Table B.3. Optimal Lag selection, Akaike Information Criterion. (Model 2 with expectations)

		Model 2 – FPP			
Lag	**1968:05–2018:08**	**1968:05–1979:09**	**1979:10–2018:08**	**1982:10–2018:08**	**1987:02–2018:08**
0	9.092580	1.762417	5.982959	4.911581	3.736432
1	-17.32074	-16.96795	-17.86679	-20.82906	-21.45660
2	-17.90160	-17.20548*	-18.40229	-21.26960	-21.96405
3	-18.07638	-17.10549	-18.58935	-21.32015	-22.00264
4	-18.11140	-17.15382	-18.65247	-21.39157	-22.09102*
5	-18.13433	-16.91472	-18.70282	-21.37403	-22.02617
6	-18.14611	-16.94902	-18.76673	-21.40680*	-22.08696
7	-18.13492	-17.08348	-18.76156	-21.38989	-22.06601
8	-18.15166	-17.05708	-18.83365	-21.34736	-22.03158
9	-18.16900*	-16.90663	-18.92050*	-21.29759	-21.99968
10	-18.13184	-16.90933	-18.85982	-21.25117	-21.94847
11	-18.10784	-16.74293	-18.81208	-21.19575	-21.88255
12	-18.09562	-16.76928	-18.80277	-21.15114	-21.83438
		Model 2 – INF_FED			
Lag	**1966:09–2013:12**	**1966:09–1979:09**	**1979:10–2013:12**	**1982:10–2013:12**	**1987:02–2013:12**
0	4.943799	-2.497347	1.274809	-0.600847	-1.786991
1	-22.05431	-21.58495	-22.62267	-25.67689	-26.27411
2	-22.50396	-21.81787*	-23.07705	-26.06011	-26.77339
3	-22.68984	-21.74358	-23.32985	-26.13200	-26.82797
4	-22.71857	-21.66759	-23.40469	-26.19708*	-26.91600*
5	-22.73701	-21.43235	-23.50502	-26.15568	-26.83199
6	-22.71454	-21.33634	-23.53503	-26.17715	-26.83079
7	-22.70912	-21.35390	-23.50325	-26.13305	-26.75910
8	-22.76288	-21.39874	-23.53930	-26.06080	-26.67132
9	-22.77169*	-21.26822	-23.64027*	-26.02308	-26.63917
10	-22.74694	-21.34741	-23.56534	-25.95578	-26.59882
11	-22.73170	-21.23868	-23.51184	-25.89771	-26.52989
12	-22.72276	-21.33225	-23.50893	-25.84232	-26.46367
		Model 2 – INF_UM			
Lag	**1959:01–2018:08**	**1959:01–1979:09**	**1979:10–2018:08**	**1982:10–2018:08**	**1987:02–2018:08**
0	-----	-----	0.799158	-1.519913	-2.712255
1	-----	-----	-24.12025	-27.26538	-27.95884
2	-----	-----	-24.58878	-27.68667	-28.46591
3	-----	-----	-24.81211	-27.74473	-28.49728
4	-----	-----	-24.89544	-27.84233	-28.61776*
5	-----	-----	-25.00658	-27.81448	-28.56214
6	-----	-----	-25.05201	-27.85492*	-28.57445
7	-----	-----	-25.04497	-27.81917	-28.54715
8	-----	-----	-25.10982	-27.74028	-28.44439
9	-----	-----	-25.17260*	-27.69027	-28.42913
10	-----	-----	-25.13243	-27.66887	-28.38082
11	-----	-----	-25.10409	-27.63175	-28.33839
12	-----	-----	-25.08779	-27.57991	-28.27941

* is associated to the lowest value assumed by the Akaike Information Criterion.

Appendix C.

Appendix C.1.

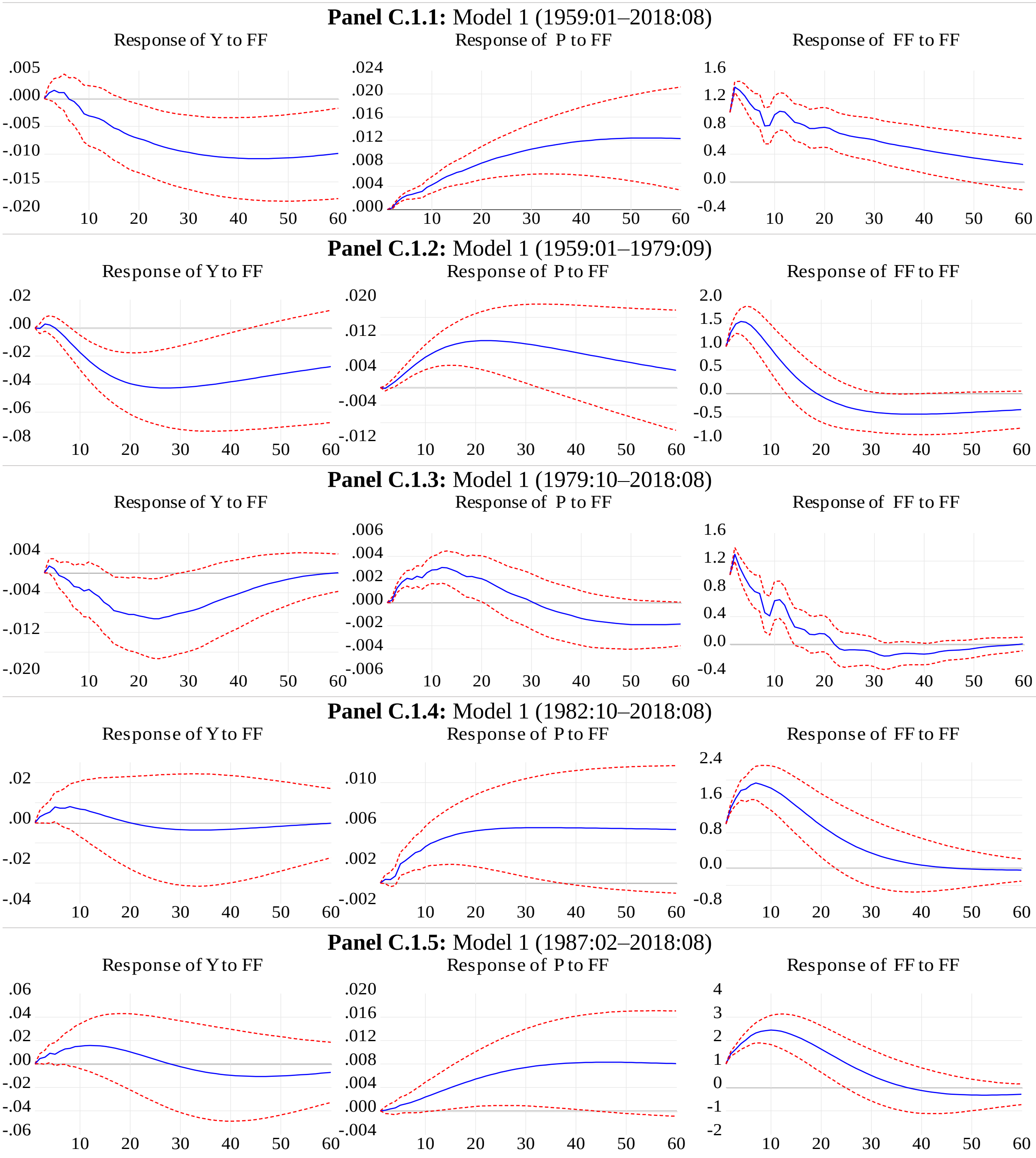


Figure C.1. IRFs to a monetary policy shock, Cholesky factorisation, Model 1 [Y, P, FF]. Solid lines are point estimates and dotted lines are the computed error bands. 95% confidence interval bands estimated through a Monte Carlo procedure (1000 repetitions).

The alternative identification strategies imposed at variables included in Model 1 are based on the following recursive ordering: $[Y_t, P_t, FF_t]$. Responses of Y and P to monetary policy tightening are summarized in Figure C.1.

Appendix C.2.

In Figures C.2.A, C.2.B and C.2.C, we report the IRFs estimated for Model 1 augmented by price and inflation expectations based on the following identification strategies: (i) $[FPP_t, Y_t, P_t, FF_t]$; (ii) $[INF\_FED_t, Y_t, P_t, FF_t]$; and (iii) $[INF\_UM_t, Y_t, P_t, FF_t]$. IRFs which include FPP, INF_FED and INF_{UM} are displayed in Figures C.2.A, C.2.B and C.2.C, respectively.

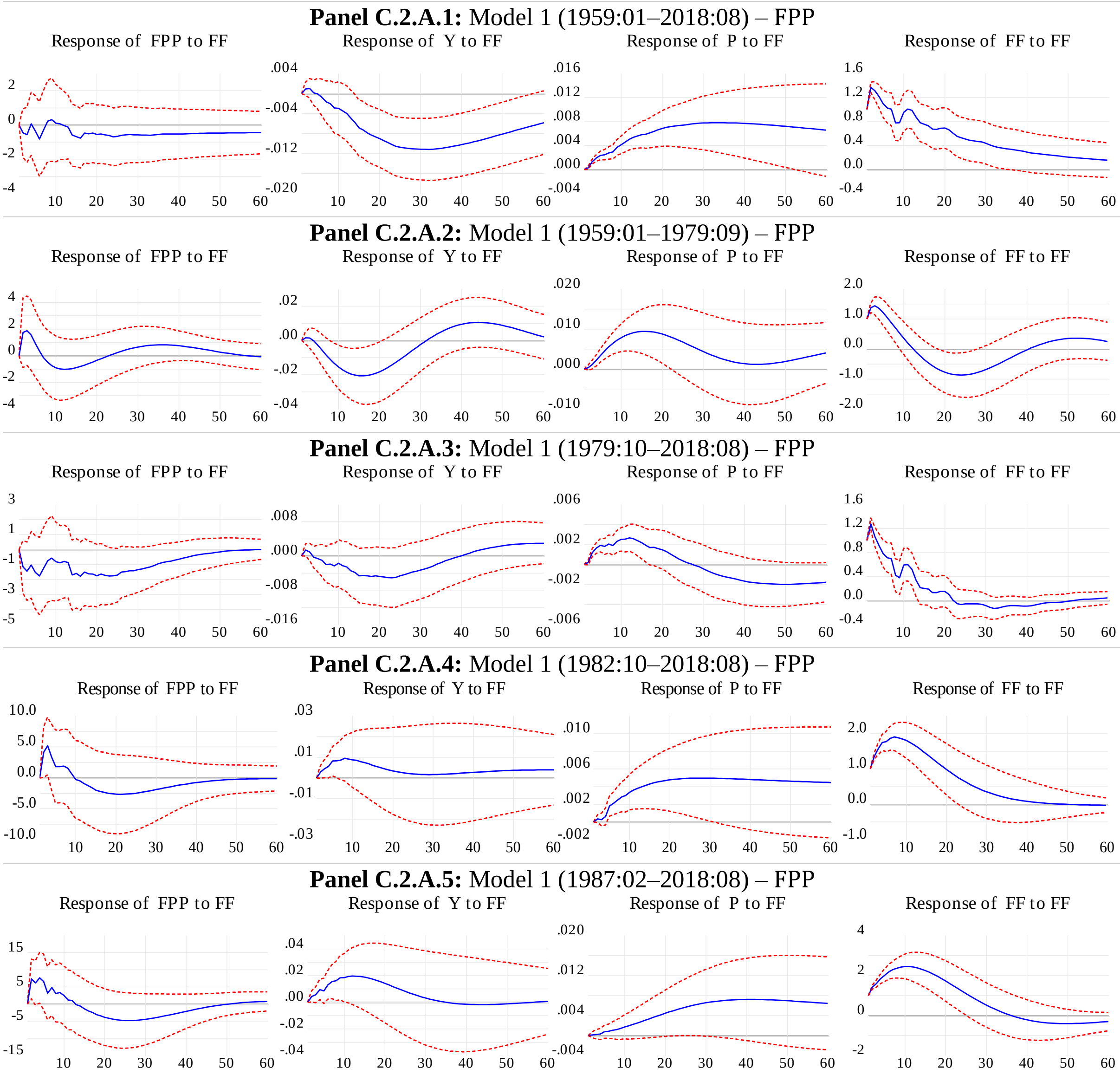


Figure C.2.A. IRFs to a monetary policy shock, Cholesky factorisation, Model 1 $[FPP_t, Y_t, P_t, FF_t]$. Solid lines are point estimates and dotted lines are the computed error bands. 95% confidence interval bands estimated through a Monte Carlo procedure (1000 repetitions).

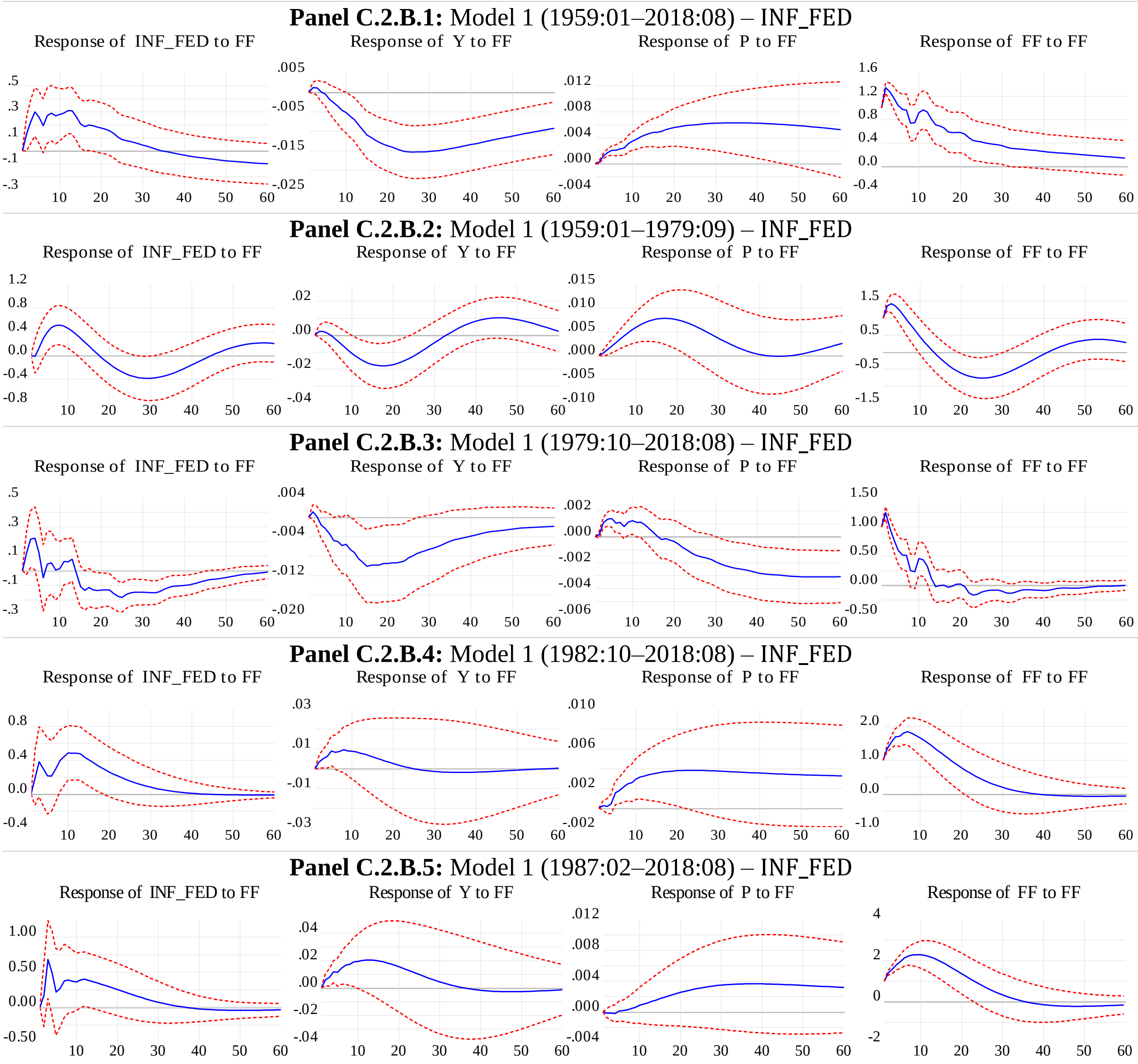
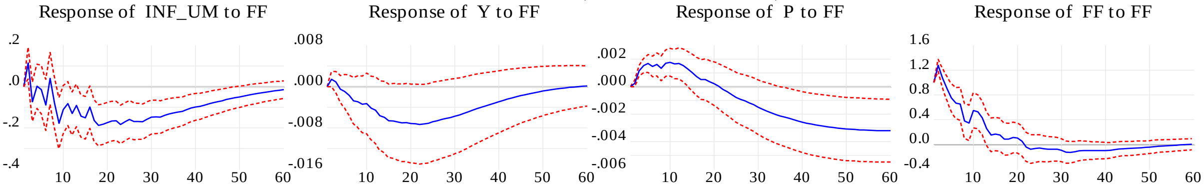
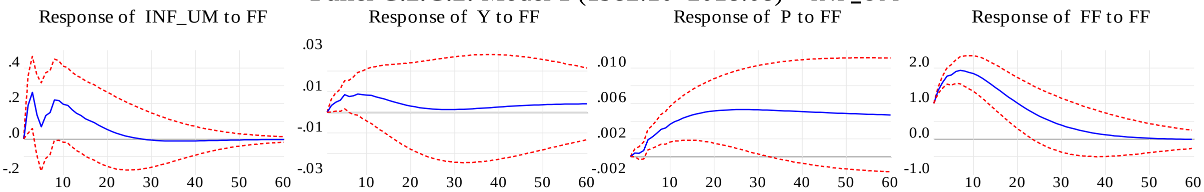


Figure C.2.B. IRFs to a monetary policy shock, Cholesky factorisation, Model 1 [INF_FED_t, Y_t, P_t, FF_t]. Solid lines are point estimates and dotted lines are the computed error bands. 95% confidence interval bands estimated through a Monte Carlo procedure (1000 repetitions).

Panel C.2.C.1: Model 1 (1979:10–2018:08) – INF_UM



Panel C.2.C.2: Model 1 (1982:10–2018:08) – INF_UM



Panel C.2.C.3: Model 1 (1987:02–2018:08) – INF_UM

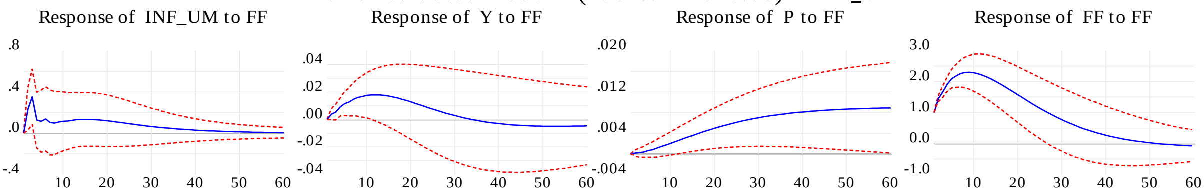


Figure C.2.C. IRFs to a monetary policy shock, Cholesky factorisation, Model 1 [INF_UM_t, Y_t, P_t, FF_t]. Solid lines are point estimates and dotted lines are the computed error bands. 95% confidence interval bands estimated through a Monte Carlo procedure (1000 repetitions).

Appendix C.3.

The alternative identification strategies imposed at variables included in Model 2 are based on the following recursive ordering: $[W_t, Y_t, P_t, FF_t]$. Responses of W, Y and P to monetary policy tightening are summarised in Figure C.3.

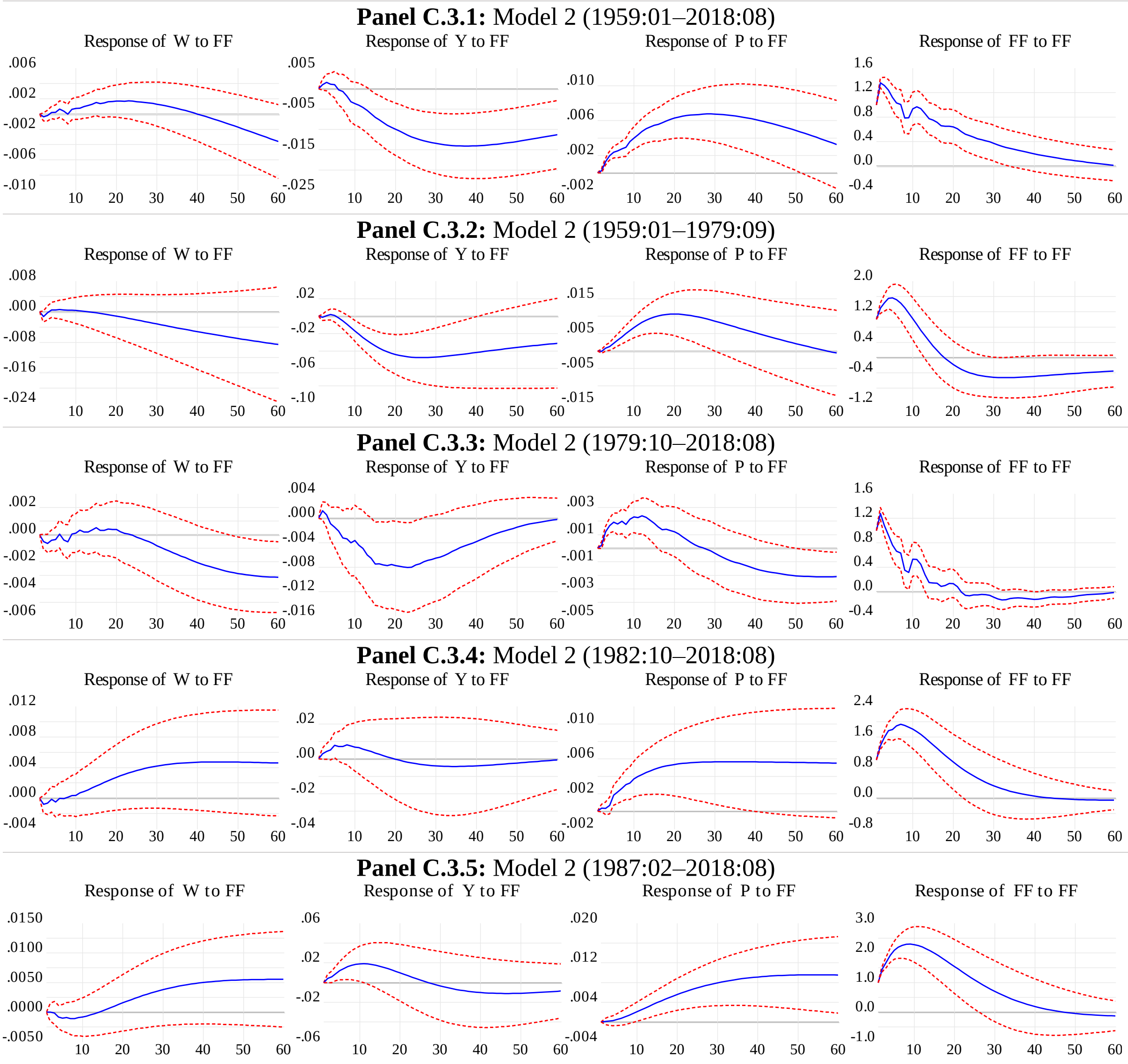


Figure C.3. IRFs to a monetary policy shock, Cholesky factorization, Model 1 [W, Y, P, FF]. Solid lines are point estimates and dotted lines are the computed error bands. 95% confidence interval bands estimated through a Monte Carlo procedure (1000 repetitions).

Appendix C.4.

In Figures C.4.A, C.4.B and C.4.C, we report the IRFs estimated for Model 2 augmented by price and inflation expectations based on the following identification strategies: (i) $[FPP_t, W_t, Y_t, P_t, FF_t]$; (ii) $[INF\_FED_t, W_t, Y_t, P_t, FF_t]$; and (iii) $[INF\_UM_t, W_t, Y_t, P_t, FF_t]$. IRFs which include FPP, INF_FED, and INF_UM are displayed in Figures C.4.A, C.4.B and C.4.C, respectively.

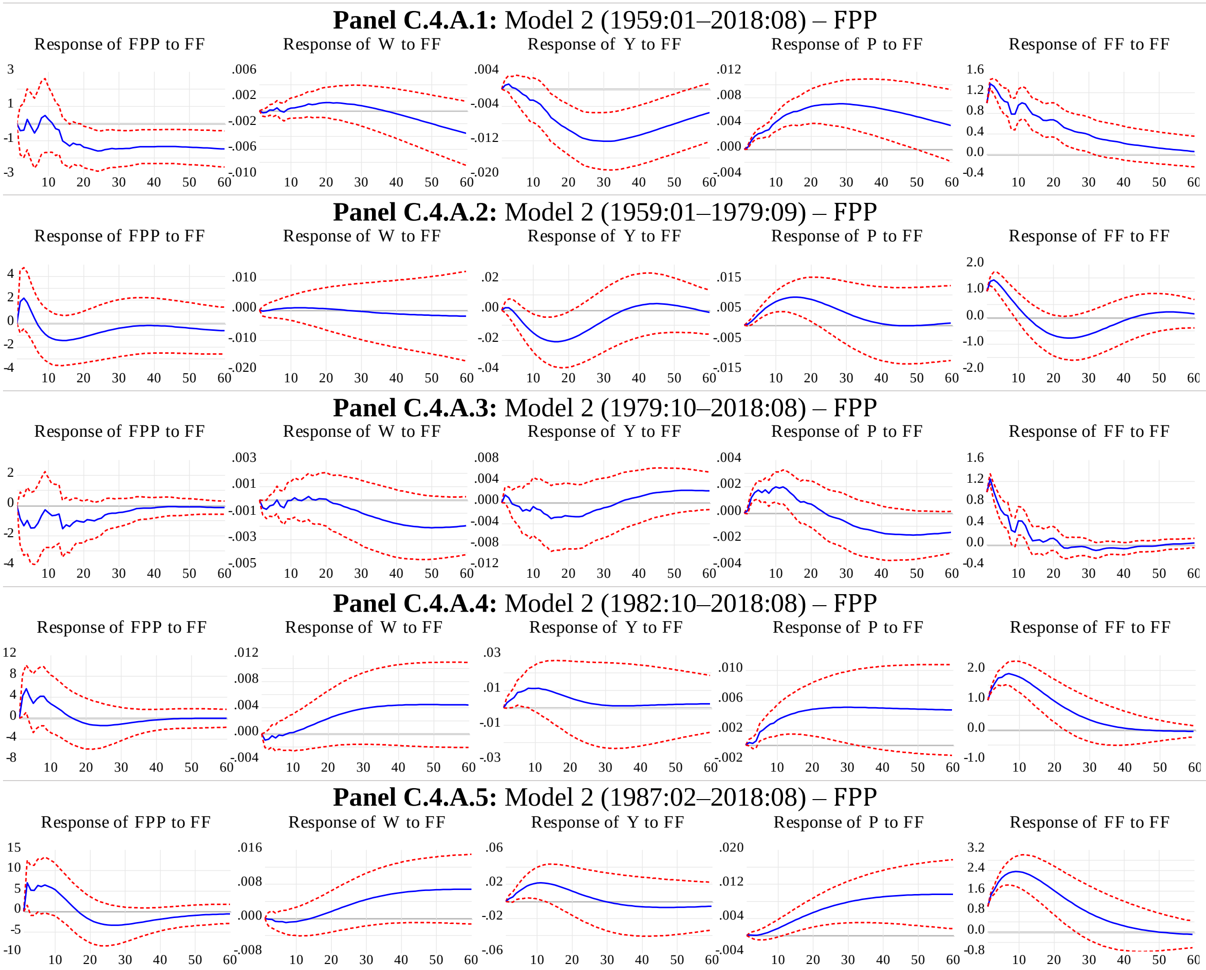


Figure C.4.A. IRFs to a monetary policy shock, Cholesky factorisation, Model 1 $[FPP_t, W_t, Y_t, P_t, FF_t]$. Solid lines are point estimates and dotted lines are the computed error bands. 95% confidence interval bands estimated through a Monte Carlo procedure (1000 repetitions).

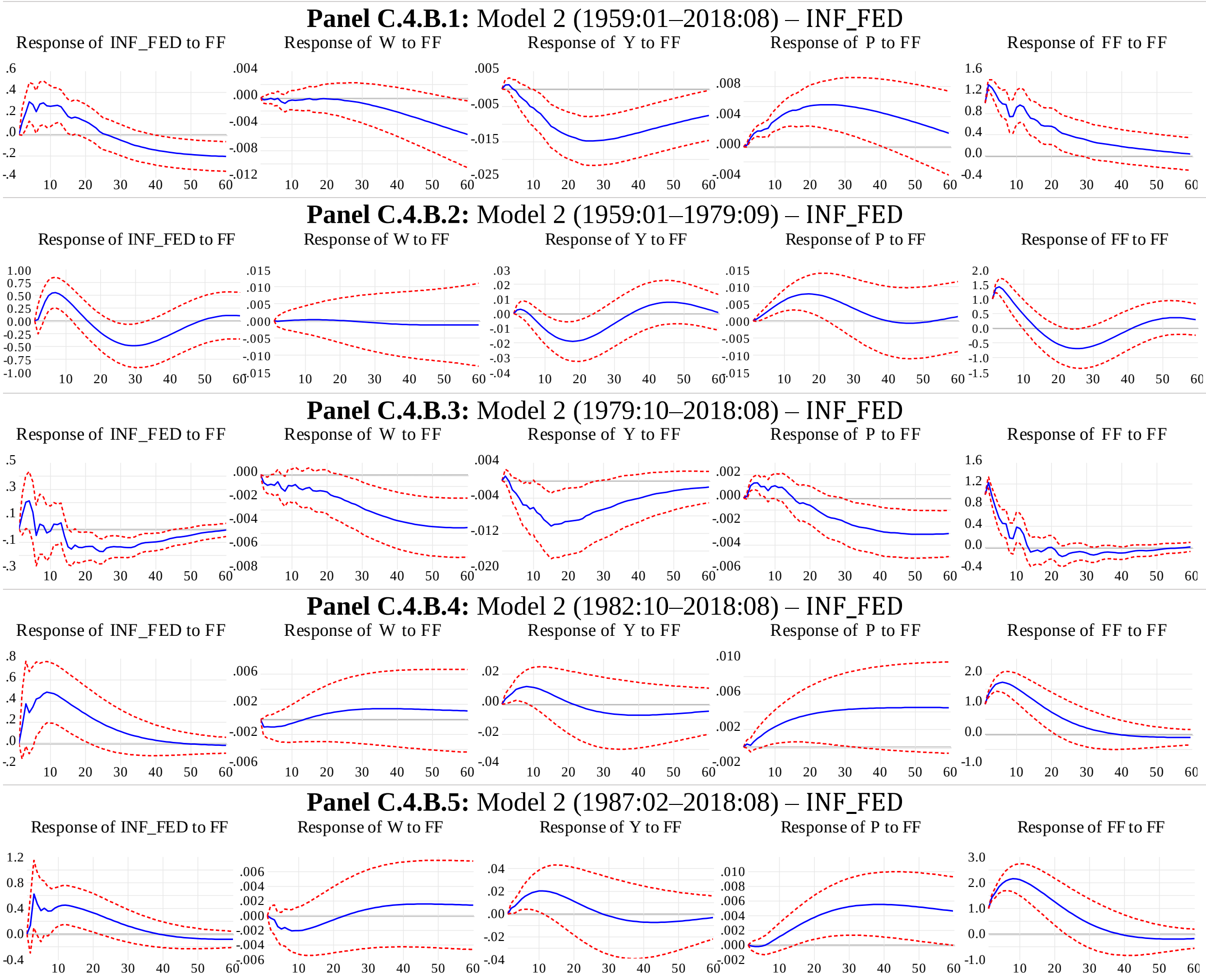


Figure C.4.B. IRFs to a monetary policy shock, Cholesky factorisation, Model 1 [INF_FED_t, W_t, Y_t, P_t, FF_t]. Solid lines are point estimates and dotted lines are the computed error bands. 95% confidence interval bands estimated through a Monte Carlo procedure (1000 repetitions).

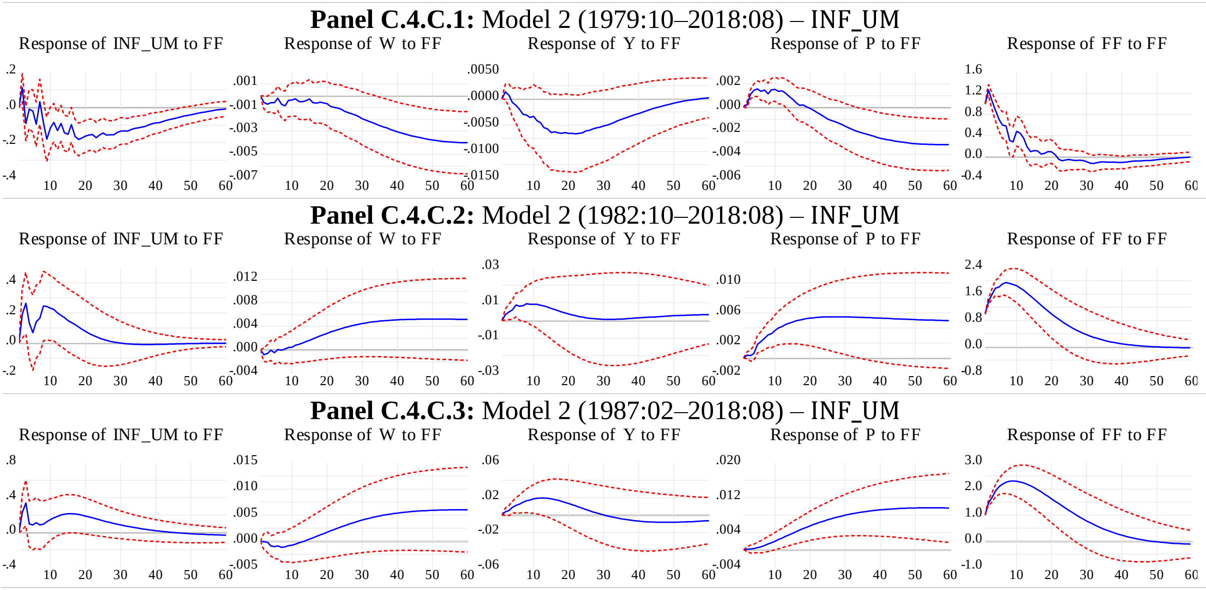


Figure C.4.C. IRFs to a monetary policy shock, Cholesky factorisation, Model 1 [$INF\_UM_t, W_t, Y_t, P_t, FF_t$]. Solid lines are point estimates and dotted lines are the computed error bands. 95% confidence interval bands estimated through a Monte Carlo procedure (1000 repetitions).