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News Shocks and the Slope of the Term Structure of Interest Rates*

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Abstract

We adopt a statistical approach to identify the shocks that explain most of the fluctuations of the slope of the term structure of interest rates. We find that one single shock can explain the majority of all unpredictable movements in the slope over a 10-year forecast horizon. Impulse response functions lead us to interpret this shock as news about future total factor productivity (TFP). We confirm this interpretation formally by identifying a TFP news shock following recent work by Barsky and Sims (2011). By showing that the 'slope shock' and the 'TFP news shock' are closely related, we provide a new explanation for the relationship between the slope of the term structure and macroeconomic fundamentals and for why the yield curve is one of the most reliable predictors of future economic growth. Our results also provide a new empirical benchmark for structural models at the intersection of macroeconomics and finance.

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1 Introduction

The slope of the term structure – commonly defined as the spread between the yield on a long-term treasury bond and a short-term bill rate – has drawn the attention of many separate literatures. In forecasting, it is well established that the slope provides valuable predictive content for future economic activity (e.g. Estrella and Hardouvelis, 1991).[1] In finance, latent factor no-arbitrage models identify the slope as an important explanatory variable for the entire cross-section of bond yields (e.g. Duffie and Kan, 1996). In macroeconomics, the slope of the term structure plays a central role for the transmission of monetary policy (e.g. Clarida, Gali and Gertler 1999). A number of recent studies attempt to bridge the gap between these literatures, either by incorporating macro determinants into multi-factor yield models (e.g. Ang and Piazzesi, 2003; Diebold, Rudebusch and Aruoba, 2006) or by building consumption-based asset pricing models that establish a structural relationship between the term structure, consumption and inflation (e.g. Piazzesi and Schneider, 2006; Rudebusch and Swanson, 2012). The lesson from these studies is that there are strong linkages between the slope and macroeconomic dynamics. However, important questions remain unanswered. In particular, what are the fundamental sources of movements in the slope? Do these fundamentals look like macroeconomic shocks or should we associate them with shocks arising independently in the financial sector? Can the identified shock explain the well-documented linkages between the slope and macroeconomic variables?

This paper provides answers to these questions. We apply a novel statistical identification strategy to show that 50% or more of all unpredictable movements in the slope over a 10-year forecast horizon are due to news shocks about future total factor productivity (TFP). A key driver of this result is the *endogenous* response of monetary policy. After a positive news shock, the Federal Funds rate, and with it the short-end of the term structure, falls. Since the reaction of the long-end of the term structure is small, the slope increases and only gradually returns to its initial value. The shock we identify therefore provides a unified explanation for a number of stylized facts: (i) variations in the slope are primarily due to fluctuations in the short-end of the term structure; (ii) steep yield curves (i.e. large slopes) generally predict future economic growth; and (iii) *systematic* monetary policy plays an important role for the linkage between macroeconomic and term structure dynamics.

The starting point of our analysis is, as in existing macro-finance papers, a vector autoregression (VAR) that combines term structure variables with prominent macro aggregates. But instead of imposing zero restrictions implied by particular types of shocks and then ana-

[1] In earlier work Harvey (1988) documents that the term structure predicts consumption growth. See Ang, Piazzesi and Wei (2006) for a recent application and an extensive review of the literature.

lyzing their effects on the term structure, our identification strategy proceeds in reverse. We first uncover (in a statistical sense) the mutually orthogonal shocks that are quantitatively the most important for the slope of the term structure and then provide an economic interpretation of these shocks. To do so, we apply a methodology developed by Uhlig (2003) to extract the exogenous shocks that explain as much as possible of the Forecast Error Variance (FEV) of a target variable in the VAR, which in our case is the slope. We then interpret these shocks by analyzing the impulse response functions (IRFs) of the different variables in the VAR and contrasting them with the theoretical implications of typical macroeconomic shocks.

Nothing in our approach requires that a small number of shocks accounts for a large fraction of slope variations or that these shocks have an appealing interpretation. Yet, when applying our empirical strategy to the 1959-2005 period, we find that one single shock can account for 70% to 90% of all unpredictable fluctuations in the term structure slope over a 10-year horizon. On impact of the shock, the slope jumps up significantly and returns to its average value only after 3 years. On the macro side, TFP and consumption barely move on impact of the shock but then gradually increase to a new permanent level. Inflation and the Federal Funds rate, in turn, drop sharply and remain below their initial level for more than 2 years. Since the drop of the Federal Funds rate is larger than the drop in inflation, the real short rate falls as well, implying that monetary policy responds aggressively to inflation.

The observed dynamics of consumption and TFP with respect to the slope shock closely resemble the responses to a news shock about future innovations in TFP as reported in Beaudry and Portier (2006) or more recently Barsky and Sims (2011). In contrast, the gradual but permanent long-run reaction of TFP and consumption together with the inverse reaction of *both* inflation and the Federal Funds rate rules out alternative interpretations of the slope shock such as exogenous monetary policy shocks, fiscal policy shocks, labor supply shocks or contemporaneous TFP shocks. Likewise, the permanent response of TFP and consumption eliminate independently arising disturbances in the financial sector as a possible source of the identified slope shock.[2]

To investigate the TFP news shock interpretation more formally, we follow Barsky and Sims (2011) and identify a TFP news shock directly as the innovation that accounts for most

[2]Our results do not rule out that any of these alternative shocks can play a significant role for slope movements during particular episodes. For example, financial shocks in the recent crisis are likely to have influenced the term structure. Our results simply imply that *temporary* financial shocks would have to exert a sizable permanent effect on real macro variables for them to be the source behind the identified slope shock. This seems implausible. While it is conceivable that financial innovations lead to permanent changes in the term structure and thus the macroeconomy, the stationary behavior of the slope rules out this possibility in the present case.

of the FEV of TFP over the same 10-year horizon but has no contemporaneous effect on TFP. Even though this identification procedure is completely different from our slope shock identification, we find that the extracted TFP news shock is highly correlated with the slope shock and generates almost identical IRFs. These results remain unchanged for a battery of robustness checks. We conclude that the main driver of fluctuations in the slope of the term structure is *news about future TFP*.

Our main empirical result is important for the term structure literature because it provides a novel insight into why the slope moves. Two studies in the term structure literature by Piazzesi (2005) and Evans and Marshall (2007) highlight how the economic source of movements in the slope has eluded the literature. Piazzesi (2005) shows how to use high frequency data to trace the effect of exogenous monetary shocks onto yield data. Evans and Marshall (2007) combine term structure and macroeconomic variables in a VAR and identify fundamental innovations from empirical measures of standard macroeconomic shocks. While the identified shocks in both papers have important effects on the level of the term structure, neither of them can account for the majority of slope movements. This motivates our strategy of first finding the shocks that are quantitatively important for the slope, and then interpreting them.

Our empirical results also provide valuable insights for the recent literature on Dynamic Stochastic General Equilibrium (DSGE) models with news shocks. Jaimovich and Rebelo (2009) introduce preferences with limited wealth effect on labor supply in order to generate comovement of real aggregates in response to news shock in a real business cycle context. Schmitt-Grohe and Uribe (2010) confirm the importance of this type of preferences in an estimated real business cycle model and find that news shocks account for a substantial part of economic fluctuations. Our VAR results indicate that news shocks are also an important determinant of nominal variables such as inflation and interest rates; and that these same preferences will be useful in explaining the responses of nominal variables to a news shock. Furthermore, as we discuss at the end of the paper, the sharp drop in inflation and interest rates on impact of a TFP news shock has strong implications for the specification of nominal and real rigidities and monetary policy in New Keynesian models.

The documented drop in real interest rates after a TFP news shock also suggests that nominal frictions and monetary policy play a major role for the propagation of TFP news shocks. Indeed, Christiano, Ilut, Motto and Rostagno (2008, 2010) make the theoretical point that it is hard to generate a drop in real interest rates in response to news shocks in a purely real business cycle model. By contrast, they show that in a world with nominal frictions, a sufficiently aggressive response of the Federal Reserve to a slowdown in inflation in the wake of a positive TFP news shock leads to a drop in real interest rates, thus fueling an inefficient boom in real activity and the stock market. Our VAR results provide empirical support for this theoretical point.

The remainder of the paper proceeds as follows. Section 2 explains our empirical approach. Section 3 provides information about the data and VAR specification. Section 4 presents our empirical results. Section 5 reports several robustness checks. Section 6 concludes.

2 Empirical Approach

This section explains the two VAR identification approaches we use in the paper. The first approach, proposed by Faust (1998) and extended by Uhlig (2003)[3], is purely statistical and extracts the largest 1 or 2 (or 3 or 4) shocks that explain the maximal amount of the FEV over some forecast horizon for a given target variable, which in our case is the slope of the term structure. The second approach identifies a TFP news shock following Barsky and Sims (2011). They extend the FEV maximization approach of Uhlig (2003) by using TFP as the target variable and imposing the extra restriction that the identified news shock is orthogonal to contemporaneous movements in TFP. Since both approaches already exist in the literature, we only describe the basics and relegate the details to the appendix.

Start by considering the vector moving average representation of a reduced-form VAR

$$Y_t = C(L)u_t, \tag{1}$$

where Y_t is a $m \times 1$ vector of variables observed at time t; $C(L) \equiv I + C_1 L + C_2 L^2 + ...$ is a lag polynomial; and u_t is a $m \times 1$ vector of one-step-ahead prediction errors with variance-covariance matrix $E[u_t u_t'] = \Sigma$. Identification of the structural shocks amounts to finding a mapping A between the prediction errors u_t and a vector of mutually orthogonal shocks ε_t; i.e. $u_t = A\varepsilon_t$. The key restriction on A is that it needs to satisfy $\Sigma = E[A\varepsilon_t\varepsilon_t' A'] = AA'$. This restriction is, however, not sufficient to identify A because for any matrix A, there exists some alternative matrix $\tilde{A}$ such that $\tilde{A}Q = A$, where Q is an orthonormal matrix, that also satisfies $\Sigma = \tilde{A}\tilde{A}'$. This alternative matrix maps u_t into another vector of mutually orthogonal shocks $\tilde{\varepsilon}_t$; i.e. $u_t = \tilde{A}\tilde{\varepsilon}_t$. For some arbitrary matrix $\tilde{A}$ satisfying $\Sigma = \tilde{A}\tilde{A}'$(e.g. the Cholesky decomposition of Σ), identification therefore reduces to choosing an orthonormal

[3]Faust (1998) proposed the methodology based on finding the minimal explanatory power of a shock while Uhlig (2003) extended the approach to search maximal explanatory power. Hereafter we refer only to Uhlig (2003) as we also use the maximal approach.

matrix Q.

Uhlig's (2003) statistical approach consists of finding the $n < m$ columns of Q defining the n mutually orthogonal shocks that explain most of the FEV of some variable in Y_t over forecast horizon $\underline{k}$ to $\bar{k}$. Formally, denote the k-step ahead forecast error of the i-th variable $y_{i,t}$ in Y_t by

$$y_{i,t+k} - E_t y_{i,t+k} = e_i' \left[\sum_{l=0}^{k-1} C_l \tilde{A} Q \varepsilon_{t+k-l} \right], \tag{2}$$

where e_i is a column vector with 1 in the i-th position and zeros elsewhere. Then Uhlig's (2003) approach solves

$$Q_n^* = \arg\max_{Q_n} e_i' \left[\sum_{k=\underline{k}}^{\bar{k}} \sum_{l=0}^{k-1} C_l \tilde{A} Q_n Q_n' \tilde{A}' C_l' \right] e_i \tag{3}$$

subject to $Q_n' Q_n = I$, where Q_n contains the columns of Q defining the n most important shocks. Uhlig (2003) shows that (**??**) can be formulated as a principal components problem with the columns of Q_n^* corresponding to the eigenvectors associated with the n largest eigenvalues of the appropriately transformed objective. Details are provided in the appendix.

Once Q_n^* identified, one tries to provide an economic interpretation of the shocks by studying the IRFs of the different variables in Y_t with respect to each column of Q_n^*. As part of this procedure one learns how many shocks are needed to explain a given variable. That is, does one need many shocks to explain movements in a given variable – in our case the slope of the term structure – or can one focus on one, possibly two key shocks?

In the second part of our empirical analysis, we identify a news shock about future innovations to TFP as in Barsky and Sims (2011). To gain intuition for their approach, assume that TFP evolves according to the following exogenous moving average process

$$\log TFP_t = v(L)\varepsilon_t^{current} + d(L)\varepsilon_t^{news}, \tag{4}$$

where $\varepsilon_t^{current}$ and ε_t^{news} are uncorrelated innovations; and $v(L)$ and $d(L)$ are lag polynomials with the only restriction that $d(0) = 0$. This restriction defines $\varepsilon_t^{current}$ as a traditional contemporaneous TFP shock and ε_t^{news} as a TFP news shock; i.e. while $\varepsilon_t^{current}$ is revealed and affects TFP in t, ε_t^{news} is revealed in t but affects TFP only in $t + 1$ or later.[4]

[4]At a given point in time, TFP can therefore move for three possible reasons. First, a contemporaneous shock hits. Second, past news shocks realize. Third, past changes in productivity innovations propagate forward to affect current TFP. In a univariate context, it would be impossible to separately identify the two shocks. In a VAR context, however, identification is possible through the presence of forward-looking variables such as the slope of the term structure that react immediately to TFP news.

The exogeneity assumption of TFP together with $d(0) = 0$ implies that in a VAR with TFP ordered first, the contemporaneous TFP shock $\varepsilon_t^{current}$ is identified as the shock associated with the first column of the matrix $\tilde{A}$ obtained from a Cholesky decomposition.[5] The news shock ε_t^{news} then corresponds to the innovation that explains all remaining variation in TFP conditional on being orthogonal to $\varepsilon_t^{current}$. While it is generally not possible to simultaneously satisfy both of these conditions, a slightly restricted version of Uhlig's (2003) approach offers a natural way to come as close as possible; i.e. based on a VAR with TFP ordered first and Cholesky decomposition $\tilde{A}$, choose the column q of Q that maximizes the FEV of TFP over forecast horizon $\underline{k}$ to $\bar{k}$ subject to $q'q = 1$ and $q(1) = 0$.

The crucial assumptions for Barsky and Sims' (2011) approach to be valid are that TFP is well-described by an exogenous process in two orthogonal innovations. The assumption that TFP is exogenous is a basic tenent of business cycle modeling. The assumption that two orthogonal innovations account for most variations in TFP may seem more arbitrary but is consistent with the general model criteria of parsimony – indeed, TFP in modern business cycle models is usually assumed to be driven by one contemporaneous shock only. Furthermore, we show that for our data, a contemporaneous shock and a news shock as identified above explain the vast majority of all TFP movements.

Aside from the two assumptions, Barsky and Sims' (2011) approach has several desirable features. First, the approach allows but does not require that either the contemporaneous TFP shock or the TFP news shock or both have a permanent impact on TFP (i.e. $v(1) = 1$ and/or $d(1) = 1$ in the above notation). Second, the approach does not make any restriction about common trends in the different VAR variables. Third, because it is a partial identification method, the approach can be applied to VARs in many variables without imposing additional and potentially invalid assumptions about other shocks.

3 Data and VAR specification

The VAR we estimate combines term structure and macroeconomic variables. For the term structure data we use two time series. The first is the Federal Funds rate. The second is the term spread which is measured as the difference between the 60-month Fama-Bliss unsmoothed zero-coupon yield from the CRSP government bonds files and the Federal Funds rate. We choose the 60-month yield as our long rate because it is available back to 1959:2, whereas longer-term yields such as the 120-month yield become available only in the early

[5] To see this, recall that $\tilde{A}$ obtained from the Cholesky decomposition is a lower-triangular matrix. Hence, the only shock in $\tilde{\varepsilon}_t$ associated with $\tilde{A}$ that can have an immediate effect on the first variable in Y_t (i.e. TFP) is the first element in $\tilde{\varepsilon}_t$.

1970s. We use the Federal Funds rate as the short rate because we want to investigate about the role of monetary policy for our results. To check for robustness, we ran our estimations with alternative measures of the slope and the short rate and found all of the main results to be unchanged.[6]

For the macroeconomic data we use two datasets. The first is a small set of macroeconomic variables consisting of TFP, consumption and inflation. TFP is Fernald's (2012) quarterly measure of TFP that has been adjusted for factor utilization. The series is constructed using the Basu, Fernald and Kimball (2006) methodology which exploits first-order conditions from a firm optimization problem to correct for unobserved factor utilization and is thus preferable to a simple Solow residual measure for exogenous TFP.[7] Consumption is measured as the log of real chain-weighted total personal consumption expenditures. Inflation is measured as the growth rate of the GDP deflator. We checked for robustness of results with alternatives measures of consumption and inflation and found very similar results.[8]

The second dataset is a larger dataset that adds three variables to our smaller dataset. These variables are real chain-weighted GDP, real chain-weighted gross private domestic investment, the S&P 500 composite index deflated by the consumer price index.

All of the macroeconomic series are obtained in quarterly frequency from the FRED II database of the St. Louis Fed. The term structure and stock market data are available in daily and monthly frequency. We convert them to quarterly frequency by computing arithmetic averages over the appropriate time intervals. Inflation and term structure data are reported in annualized percent. All remaining variables are reported in natural logs. The sample period is 1959:2-2005:2. Both the baseline VAR and the extended VAR are estimated in levels with 4 lags of each variable, an intercept term, but no time trend. To improve precision, we impose a Minnesota prior (see Hamilton 1994, page 360) on the estimation and compute error bands by drawing from the posterior. None of the results change, however, if we estimate the VAR with OLS instead and compute error bands by bootstrapping from the estimated VAR (see appendix).

[6]First, we replaced the 60-month yield with the 120-month zero-coupon yield as computed by Gurkaynak, Sack and Wright (2007) and the Federal Funds rate by the 3-month bill rate. Second, we used a Nelson-Siegel style slope factor as computed in Diebold and Li (2006). See the appendix for robustness of our results with respect to these alternative measures.

[7]Basu, Fernald and Kimball (2006) also make use of industry level data to correct for differences in returns to scale. Since this industry level data is available only on an annual basis, our quarterly TFP measure does not include this returns to scale correction. See Barsky and Sims (2011) for details.

[8]Specifically, we alternatively measured consumption as the sum of non-durables and service expenditures; and inflation as the growth rate of personal consumption expenditures or the growth rate of the consumer price index. See the appendix for details. We also performed a battery of robustness checks with respect to other macroeconomic variables and found our results to be very robust.

4 What Moves the Slope of the Term Structure?

In this section we answer the main question of the paper. We do so by first extracting the shocks that explain most of the movements in the slope of the term structure, our target variable in the VAR. Second, we look for different possible interpretations of this shock. In particular, we pursue the hypothesis that this shock captures news about future innovations to TFP.

4.1 Slope Shocks

As described in Section 2, we extract the shocks that maximize the fraction of the FEV of the slope explained by these shocks over some forecast horizon. We set the forecast horizon to $0 \leq k \leq 40$ quarters, weighing the importance of each of the forecasts equally. This choice is motivated by the fact that we want to capture short- and medium-run movements in the term structure slope while providing at the same time reliable estimates at the long end of the forecasting horizon. We limit our analysis to two shocks ($n = 2$) because we find that two shocks explain virtually all the movements in the slope. The following results refer to the VAR based on the small set of macro variables described above. Robustness with respect to the larger set of macro variables is provided in the next section.

Figure 1 displays the fraction of the FEV of the different variables explained by the first shock. The solid lines correspond to the posterior median estimates, while the grey bands display the 16%-84% posterior coverage intervals. As the top left panel shows, this first shock explains more than 85% of all slope movements over the entire 0 to 40 quarter forecast horizon. The second shock (not shown) accounts for virtually all of the remaining fraction of the FEV of the slope. This result is robust across many different VAR specifications. For example, in the large VAR that we examine at the end of this section, one shock explains about 75% of all slope movements and the second shock accounts for almost all of the remaining 25%. In other words, two shocks are sufficient to understand all movements in the slope and to an approximation, the first shock is by far the most relevant. We thus focus on the properties of this first shock only.

The other panels in Figure 1 show that the slope shock accounts for less than 20% of variations in the long-end of the term structure but accounts for a surprising 50% to 70% of all Federal Funds rate variations.[9] This result indicates that slope movements are to a large part driven by monetary policy interventions that influence the short end of the

[9] The long bond rate is not part of our estimated VAR. However, its FEV and IRF to different shocks can be constructed from the spread and the Federal Funds rate.

term structure.[10] For the macroeconomic variables the slope shock explains very little of variations in TFP, consumption and inflation at short horizons. As the forecast horizon increases, however, the slope shock gradually accounts for a larger fraction of the movements in these variables. In particular, the shock explains more than 40% of the consumption variation at a 20 quarter horizon and about 30% of TFP variations 40 quarters ahead (with this latter fraction increasing towards 50% for forecast horizons beyond 40 quarters). This confirms earlier findings by Ang and Piazzesi (2003), Diebold, Rudebusch and Aruoba (2006) and Evans and Marshall (2007) that there are important linkages between slope movements and macroeconomic fluctuations. Our analysis adds the qualification that these linkages are mostly present for medium- and longer-term macroeconomic fluctuations whereas high-frequency variations in macroeconomic variables are almost completely orthogonal to slope innovations.

The second step in our approach is to provide an economic interpretation of the slope shock. We do this by examining the IRFs of the different variables to a 1% innovation in the slope shock.[11] Figure 2 displays the results. The slope jumps up about 70 basis points on impact of the shock, while the long end of the term structure remains roughly constant on impact before becoming slightly negative. The strong reaction of the slope is therefore largely driven by the marked and persistent drop in the Federal Funds rate. Interestingly, the slope shock has no significant impact on either TFP or consumption on impact, but within 2 quarters of the shock, both of these variables start to increase significantly to a permanently higher level. Finally, inflation drops significantly on impact of the slope shock and remains below its initial rate for more than two years. This drop in inflation is smaller than the drop in the Federal Funds rate, implying that the *real* Federal Funds rate and with it the real term structure reacts negatively to the slope shock.

The insignificant reaction of TFP on impact and its gradual increase to a permanently higher level thereafter suggests that the slope shock captures a slow, permanent diffusion process of technology that is anticipated by economic actors. Such a supply-side interpretation also rationalizes why, despite the loosening of monetary policy, inflation decreases and remains persistently lower for more than two years. The slow TFP diffusion interpretation fits well with recent views about technological adoption by Rotemberg (2003) or Comin and Gertler (2006). Both of these papers argue, based on numerous pieces of empirical evidence,

[10]Indeed, the Federal Funds rate and short-term bill rates move very closely together. For our sample, the correlation coefficient of the Federal Funds rate and the 3-month bill rate is 0.984.

[11]The impulse responses are computed by administering a one-time 1% innovation to the slope shock which feeds through the impulse vector to the different variables of the VAR. Since the first element of the impulse vector is less than one the slope (ordered first in the VAR) increases by less than 1 percent.

that it takes on average several years for new technologies to be adopted even though these innovations are known to exist and be commercially valuable.[12] A very similar idea lies behind the literature on news shocks as originally proposed by Pigou (1927) and reconsidered in recent empirical work by Beaudry and Portier (2006) and Barsky and Sims (2011). Indeed, the dynamics of TFP and consumption in Figure 2 look very much like the responses to a news shock about future TFP as identified in Barsky and Sims (2011). They report that TFP news shocks lead to a delayed but permanent increase in TFP and consumption and a sharp drop in inflation. Furthermore, they find that TFP news shocks explain almost none of high-frequency variations in TFP and consumption but account for 40% or more of the two variables at horizons of 20 quarters or more.

Before confirming this TFP news interpretation formally, it is important to check whether other prominent macroeconomic shocks can be consistent with the IRFs in Figure 2. Consider first monetary policy shocks, which are often considered in both macroeconomic and term structure studies. Such an alternative interpretation appears clearly inconsistent. If the drop in the Federal Funds rate was related to an *exogenous* monetary policy intervention, then inflation should increase rather than decrease and there should be no permanent effect on either consumption or TFP (e.g. Christiano, Eichenbaum and Evans, 2005). Our technology news hypothesis, by contrast, implies that monetary policy reacts *endogenously* to the drop in inflation and is thus only indirectly the main driver of the slope.

A second type of shock considered in the macroeconomics literature are demand shocks, either in the form of exogenous changes in government deficits (Evans and Marshall, 2007; Dai and Phillippon, 2008) or exogenous changes to the effective interest rate that applies to savings and investment decisions (De Graeve, Emiris and Wouters, 2008). Similar to exogenous monetary policy shocks, such demand shocks should not have a permanent positive effect on either consumption or TFP. Likewise, we know of no theory of demand shocks that produces a prolonged decline in both inflation and the Federal Funds rate in response to a positive demand shock.

A third type of shock from the macro-labor literature is a shock to the marginal rate of substitution (MRS) between consumption and leisure, which is commonly interpreted as a labor supply shock. Evans and Marshall (2007) study the impact of this shock on the term structure and find that this shock has a statistically insignificant affect on the slope

[12]See Rotemberg (2003) for many examples about slow diffusion of technological innovations and references. Among others, Rotemberg (2003) cites evidence by Mansfield (1989) to conclude that technological innovations can be classified according to three speeds of adoption. "In the fastest [of three] brackets, half of the innovation's adopters do so within 5 years, while in the slowest [bracket], it takes them 15 years (page 1544)."

and inflation while increasing both real activity and the Federal Funds rate. Again, these predictions are inconsistent with the IRFs in Figure 2. We conclude that labor supply shocks cannot be an interpretation of our slope shock either.[13]

A fourth type of macroeconomic shock is a contemporaneous innovation to TFP as traditionally assumed in the business cycle literature. But a shock to contemporaneous TFP has an immediate impact on TFP, not a delayed impact. Additionally, as shown in the appendix, a contemporaneous TFP shock in our VAR makes consumption jump up on impact, has no significant effect on the term spread and only a delayed but negligible effect on the Federal Funds rate. Hence, the extracted slope shock is not a contemporaneous technology shock. All of these results suggest that it is indeed *news about future productivity* innovations that are a main driver of the slope of the term structure.

4.2 Slope Shocks are TFP News Shocks

We pursue the TFP news interpretation of the slope shock formally by identifying a news shock about future innovations to productivity as in Barsky and Sims (2011). As described in Section 2, their approach is a restricted version of our statistical extraction of the slope shock and consists of identifying the shock that explains accounts for most of the FEV of TFP over a given forecast horizon but is orthogonal to contemporaneous movements in TFP.

Figure 3 displays the fraction of the FEV of the variables in our baseline VAR explained by a TFP news shock. As we found for the slope shock, the TFP news shock explains almost none of the movements in macroeconomic variables on impact but up to 50% of consumption variations after 20 quarters and about 40% of TFP variations after 40 quarters. Together with the contemporary TFP shock (discussed above, with results reported in the appendix), this news shock explains over 90% of the FEV of TFP at all horizons, which implies that two shocks are sufficient to describe the majority of TFP movements. The shock also explains over 60% of term spread movements at all horizons and between 60% and 80% of Federal Funds rate movements. As before, however, the TFP news shocks accounts for only a relatively small fraction of variations in the long end of the term structure. In other words, the TFP news shock seems to be a major determinant of movements in the slope through its influence on monetary policy at the short end of the term structure.

Figure 4 reports the IRFs of the different variables to the TFP news shock (solid blue lines), with 16%-84% posterior coverage intervals in grey. For comparison, the figure also reproduces the IRFs to the slope shock from Figure 2 (dashed red lines). The similarity

[13]Evans and Marshall (2007) find that labor supply shocks are primarily important for variations in the level of the term structure but have no significant impact on the slope.

in results is striking. In particular, the slope jumps up significantly on impact and then returns back to its pre-shock value after 10 to 15 quarters; TFP increases gradually from zero (by construction for the news shock identification) to a permanently higher level (even though no constraint on long-run effects is imposed); consumption increases slightly (but insignificantly) on impact and then gradually increases to a permanently higher level; and both inflation and the Federal Funds rate drop markedly on impact, remaining below their initial value for more than 15 quarters. As with the slope shock, the drop in the Federal Funds rate is larger than the drop in inflation, implying a decline in the real Federal Funds rate.[14]

To further illustrate the correspondence between the TFP news shock and our slope shock, we extract the time series of each of the two shocks and plot them together. As Figure 5 shows, the slope shock is slightly more volatile than the TFP news shock but overall, the two shocks move closely together, with a correlation coefficient between the two of 0.86. This close correspondence is surprising because the identification criteria behind the two shocks are completely different from each other. The slope shock is extracted by maximizing the FEV of the *slope* while the TFP news shock is extracted by maximizing the FEV of *TFP* subject to the additional constraint that the shock is orthogonal to contemporaneous TFP movements. Hence, there is no a priori reason to believe that the two innovations capture the same economic shock. To confirm that our results are not a statistical artefact we applied the Uhlig (2003) identification to other variables in our VAR. The shock that we extracted was very weakly correlated with our slope shock in all cases, even when the target was the long bond yield, which is part of the slope. See the appendix for details.

5 Robustness

In this section we show that our empirical results are robust to a number of potential issues. The first potential issue concerns mismeasurement of technological progress. In particular, advances in technology may not come through increases in TFP but rather through technological progress that is embodied in new capital. Hence, if capital services are not appropri-

[14] This result for the impulse response of inflation is different from Barsky and Sims (2011) who use the CPI deflator to compute inflation and report a substantially larger drop in inflation to a TFP news shock. As a result, the real short rate *increases*. We confirm Barsky and Sims' (2011) finding in our VAR. The difference to our main results is due to the fact that the CPI deflator is considerably more volatile than the GDP deflator. We prefer the latter because it represents a broader measure of aggregate prices, does not suffer from substitution bias, and is less affected by large temporary swings in food and energy prices. Also, if we use the PCE deflator to compute inflation, the inflation response to a TFP news shock remains smaller than the Federal Funds response, implying a drop in the real short rate, as in our baseline results.

ately measured, our identification may mistake embodied (i.e. capital-specific) technological progress for TFP improvements. This concern is motivated by recent empirical evidence from Fisher (2006) who reports that embodied technological shocks are a main driver of business cycle fluctuations. To address this issue, we add Fisher's (2006) relative price deflator series for investment and equipment goods to our VAR and rerun both the slope shock identification and the TFP news shock identification.[15] In response to the slope shock, both relative price deflators increase slightly on impact and then decrease significantly after about 10 quarters to a permanently lower level. In response to the TFP news shock, by contrast, neither of the relative price deflators reacts significantly. All of the other results remain unaffected. This suggests, on the one hand, that TFP news shocks are not erroneously capturing capital-specific embodied technological progress. On the other hand, the slope shock seems to pick up not only news about future TFP increases, but also news about future embodied technological progress. This could be one of the reasons why the extracted slope shock is slightly more volatile than the TFP news shock.

A second issue is the extent to which our results are robust to alternative VAR specifications. We estimated many different VAR specifications and found our results to be very robust. For space reasons, we report here only one of these alternative specifications, which extends the baseline VAR with output, investment and the real S&P 500 composite index. We choose this particular extension because it allows us draw comparisons with the recent empirical literature on news shocks. Figure 6 reports the IRFs to the TFP news shock (solid black line) and the slope shock (dotted red line) for this larger VAR along with the 16%-84% posterior coverage interval for the TFP news shock in grey. The coverage intervals for the slope shock are very similar (see appendix)[16] As in the smaller VAR, the TFP news shock has a gradual but permanent effect on real variables. Consumption now increases significantly on impact of the shock. Output declines slightly on impact, but the change is not very significant. Investment, by contrast, contracts significantly over the first two periods. The real stock market index increases on impact and remains significantly higher for about four years before slowly returning back to its initial value. Finally, both inflation and the Federal Funds rate drop markedly on impact and remain persistently below their

[15] The relative price series we use are updated by DiCecio (2008).

[16] In the interest of conciseness, while we do not plot the fraction of FEVs explained by the shocks for the different variables of this larger VAR, the results are quite interesting. The TFP news shock accounts for an even larger fraction of TFP and consumption movements at the 20-40 quarter horizon. Similarly, the shock explains almost nothing of output and investment fluctuations on impact but about 50% of both variables after 20 quarters and more. For the term structure, in turn, the shock explains between 40% and 50% of movements in the slope and the Federal Funds rate over the entire horizon. This is somewhat less than in the baseline VAR but still very sizable. Finally, the TFP news shock explains roughly 20% of inflation and stock market movements over the entire horizon.

initial value for 15 to 20 quarters. As before, the drop in the Federal Funds rate is larger than the drop in inflation and thus, the real short rate drops as well. Since the long rate barely moves, the spread increases on impact of the shock and then gradually returns to its average value. Overall, these results look very similar to the results obtained above with the baseline VAR. Moreover, the IRFs from the two identification schemes retain their close correspondence; and the extracted slope and TFP news shock series remain highly correlated (with a correlation coefficient of 0.84).[17]

The small inverse reaction of output and investment relative to consumption on impact of the TFP news shock matches closely the findings in Barsky and Sims (2011) but contradicts earlier results by Beaudry and Portier (2006) who find that consumption and real activity (measured by either hours or investment) *both* display sizable positive reactions immediately after a TFP news shock.[18] Barsky and Sims (2011) argue that this difference in results is due to the different identification approach employed by Beaudry and Portier (2006). Furthermore, Barsky and Sims (2011) argue that their identification approach encompasses the conditions under which Beaudry and Portier's (2006) identification is valid; is less restrictive on a number of important dimensions; and explains a sizable fraction of medium and longer-run movements in TFP whereas Beaudry and Portier's identification does not. For all these reasons, we prefer the Barsky-Sims identification of TFP news shocks over the Beaudry-Portier identification. Nevertheless, we performed robustness checks using a bivariate VAR in TFP and the slope and found that our results for the slope are robust to Beaudry and Portier's (2006) orthogonality restriction on current TFP.

6 Implications

We began this paper with an exploration into the sources of movements in the slope of the term structure and uncovered a robust statistical link between the main shock affecting the slope and news about future TFP. In the process of documenting this result we also found sharp predictions for the joint dynamics of real and nominal variables in response to a TFP news shock. We now explore the implications of these results for structural models at the

[17]Interestingly, moving in the direction of a smaller VAR in TFP, consumption and inflation results in a significant decline in the correspondence between the news shock and the slope shock (from the baseline 5-variable VAR). This illustrates an important implication of our results: if term spread movements reflect to large part TFP news and are thus a good predictor of subsequent TFP growth, then including the term spread and the Federal Funds rate in the VAR is important to identify TFP news shocks. Of course, other forward-looking variables with predictive power about future TFP growth could help identify news shocks. Our point is that yield curve information is particularly useful in this respect.

[18]Barsky and Sims (2011) also report that hours worked decline for the first few quarters after the TFP news shock. We find the same result if we include hours worked as an additional variable in the VAR.

intersection of macroeconomics and finance.

The first implication is with respect to monetary policy. Our VAR evidence shows that both inflation and the Federal Funds rate drop sharply on impact of the TFP news shock and then gradually return to their average levels. Since the drop of the Federal Funds rate is larger than the drop in inflation, the real short rate falls as well, implying that monetary policy responds aggressively to inflation. This is consistent with Taylor's (1993) principle of systematic monetary policy. In fact, we experimented with a conventional interest rate rule in which the Federal Funds rate responds to inflation and output. We found that the Federal Funds rate response implied by the VAR and the response implied by the interest rate rule fit closely.[19] The one caveat is that according to our VAR, the drop in the Federal Funds rate is largest on impact of the shock, implying at best a limited role for interest rate smoothing. Given that modeling such inertia in the policy rule is somewhat controversial (e.g. Rudebusch, 2006), we view this as additional evidence against imposing persistence in interest rates through a very high smoothing coefficient.

An important question related to monetary policy is how the dynamics of the Federal Funds rate contribute to the response of the slope to a TFP news shock. To assess this question, we decompose the slope's response into changes in expected future short rates as implied by our VAR evidence – i.e. the Expectation Hypothesis – and changes in term premia.[20] We find that the Expectations Hypothesis accounts for two thirds of the slope response to the TFP news shock. Systematic monetary policy, through its effect on expected future short rates, is therefore a key driver of the response of the slope to TFP news shocks. The result also implies that a linearized DSGE model with homoscedastic innovations, which by definition makes term premia constant, should at least in principle be able to capture a large part of the movements in the slope. Time-variations in term premia, and the potential

[19] The interest rate rule that we used is

$$i_t = .5i_{t-1} + 0.5(2\pi_t + 0.5\Delta y_t) + e_t,$$

where i_t denotes the Federal Funds rate; π_t inflation; Δy_t real output growth; and e_t a residual. See appendix for details.

[20] The spread between the nominal yield i_t^T on a T-period zero-coupon bond (in our case the 5-year treasury bond) and nominal yield i_t on a 1-period bill (in our case, the Federal Funds rate) can be decomposed as follows

$$i_t^T - i_t = \frac{1}{T}\sum_{i=0}^{T-1}\left[\left(1 - \frac{i}{T}\right) E\left[\Delta i_{t+i}|Y_t\right]\right] + tp_t,$$

where the $E[\Delta i_{t+i}|Y_t]$ denote expectations of future short rates as implied by the VAR based on information Y_t; and tp_t denotes term premia. See the appendix for details. This type of decomposition has been used widely in the term structure literature. Notable examples are the seminal paper by Cambpell and Shiller (1991) or more recently Diebold, Rudebusch and Aruoba (2006) and Evans and Marshall (2007).

role that monetary policy plays for these variations, remain of course important to analyze. In fact, the very small response of the long rate implies that term premia increase on impact of the TFP news shock. We come back to this result below.

We now turn to the implications of our results for the remaining macroeconomic aggregates. We adopt a New Keynesian perspective to do so, based on two considerations. First, the main object of interest of our paper is the nominal term structure. We therefore need a model that makes joint predictions about quantities and prices.[21] A New Keynesian DSGE model is a natural choice in this regard since medium-scale versions of this model have been shown to successfully fit important dimensions of U.S. business cycles (e.g. Christiano, Eichenbaum and Evans, 2005; or Smets and Wouters, 2007). Second, two recent studies by Christiano, Ilut, Motto and Rostagno (2008, 2010) make the theoretical point that it is hard to generate a drop in the real short rate in response to a TFP news shock with a purely real business cycle model. By contrast, in a model with wage and price stickiness, a monetary policy that follows the Taylor principle will generate a drop in the real short rate in response to a decline in inflation caused by TFP news. Our VAR results for monetary policy discussed above provide empirical support for this theoretical argument.

In New Keynesian models, inflation is a function of the expected path of real marginal cost and lagged inflation, depending on the degree of price stickiness and the extent to which non-reoptimized prices are indexed to lagged inflation. The sharp decline of inflation on impact of the TFP news shock has strong implications for this theory. First, inflation must be forward-looking (i.e. little indexation to lagged inflation) and responsive to changes in real marginal cost (i.e. relatively little price stickiness). Second, the present value of expected real marginal cost must be negative. Broadly speaking, this requires that real factor prices, and in particular labor costs, react minimally or even negatively on impact of the TFP news shock. One way to achieve this is if nominal wage contracts are very rigid in the short run. A second way is if firms borrow the wage bill short-term (since short rates fall in response to the TFP news shock). A third way is if firms can cheaply adjust factor utilization. A fourth way is if workers have preferences that imply a limited short-term wealth effect on labor supply (e.g. Jaimovich and Rebelo, 2009). Each of these elements has been included in some variant of modern DSGE models. The first open question is

[21]The nominal spread $i_t^T - i_t$ is related to the real spread $r_t^T - r_t$ by

$$i_t^T - i_t = (r_t^T - r_t) + (E_t\bar{\pi}_{t:t+T} - E_t\pi_{t:t+1}),$$

where $E_t\bar{\pi}_{t:t+T} - E_t\pi_{t:t+1}$ denotes the difference in expected average inflation from t to $t+T$ and expected average inflation from t to $t+1$. To understand movements in the nominal spread, we therefore need to understand movements in quantities and prices, which jointly drive inflation expectations.

whether there exists a parameterization of these elements that is able to replicate the sharp fall in inflation to a TFP news shock documented in our VAR evidence. If the answer to the first question is positive, then a second open question is whether that parameterization is also able to replicate the responses to other shocks, such as monetary policy shocks. We investigate this formally in current work (Kurmann and Otrok, 2012).

Turning to quantities, the observed gradual increase of consumption towards a new permanently higher level suggests strong habit persistence in consumption preferences. Furthermore, the initial drop of output and investment on impact of the TFP news shock is consistent with a basic real business cycle model, as emphasized by Barro and King (1984) and more recently Barsky and Sims (2011). Similar inverse impact responses of consumption and investment and output obtain in a New Keynesian model as long as monetary policy is not too accommodative. As discussed at the end of the previous section, this implication comes with the caveat that the alternative news shock identifications by Beaudry and Portier (2006) results in positive impact responses of real aggregates. While we prefer the Barsky-Sims identification, we note that the question of whether consumption, investment and output comove directly on impact or only a few periods after a TFP news shock is not central to our main results.

Finally, we return to the issue of time-varying term premia. Several recent papers examine whether relatively simple, nonlinear DSGE models with recursive utility preferences can generate large term premia variations (e.g. Rudebusch and Swanson, 2012; or Binsbergen, Fernandez-Villaverde, Koijen and Rubio-Ramirez, 2010). It would be interesting to investigate how term premia behave with respect to a TFP news shock in these models and in particular to what extent the opposite movement of consumption growth and inflation generates 'inflation risk' (e.g. Piazzesi and Schneider, 2006).[22] Second, the TFP news shock we identify causes persistent changes in consumption growth that the consumption-based asset pricing literature has associated with 'long-run risk' to explain a variety of asset pricing puzzles (e.g. Bansal and Yaron, 2004). An additional important ingredient in this long-run risk story is time-varying volatility of consumption. A promising avenue of future research would be to examine whether TFP news shocks are associated with episodes of high conditional volatility and to what extent the combination of the two helps generate time-variations in term premia consistent with our VAR evidence.

[22] Rudebusch and Swanson (2012) go in that direction at the end of their paper when they introduce a shock that leads to a slow-moving increase in trend productivity. However, this does not generate more variable term premia because their macro model fails to generate opposite movements in consumption growth and inflation.

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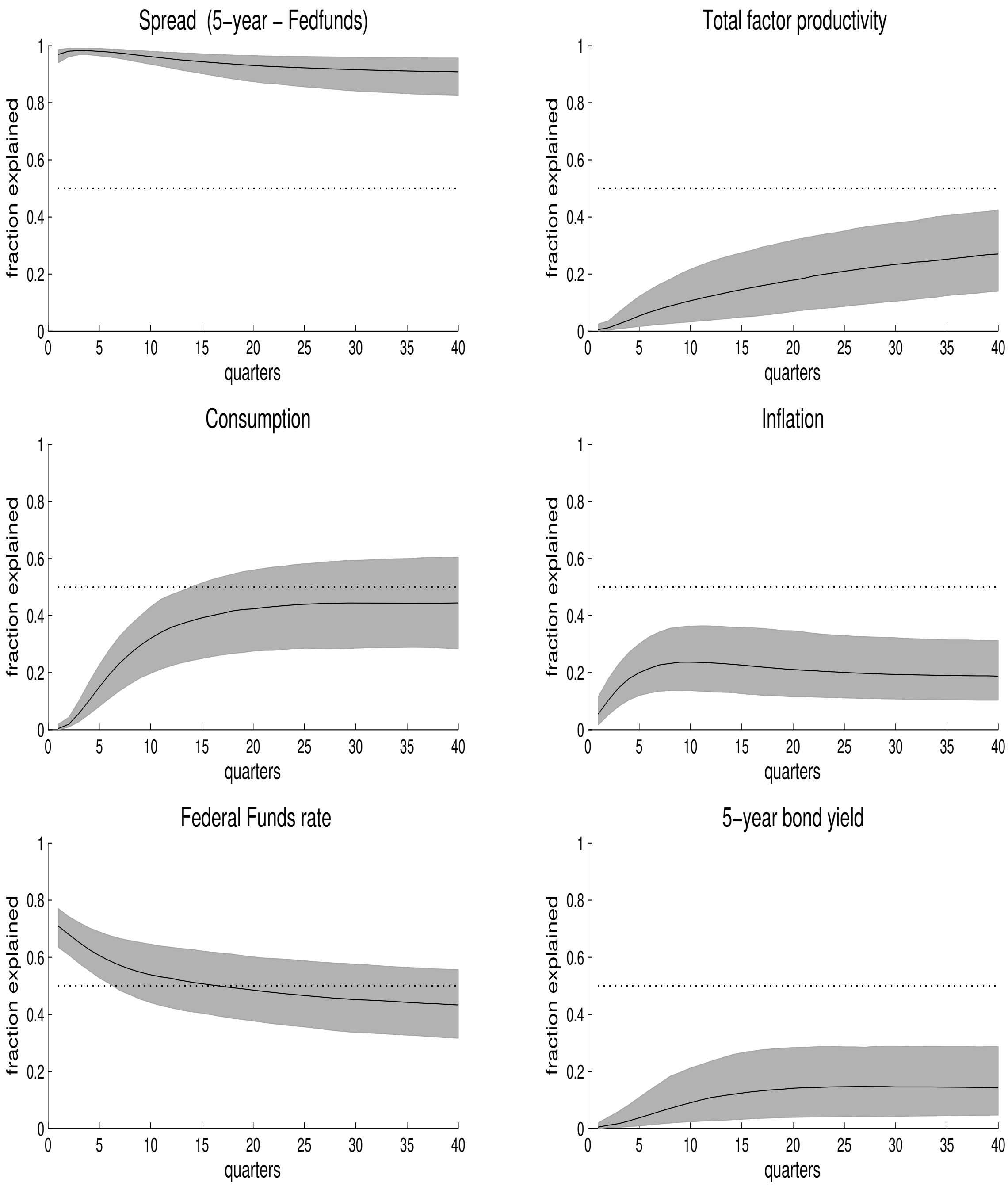

Figure 1 : Fraction of Forecast Error Variance (FEV) explained by slope shock

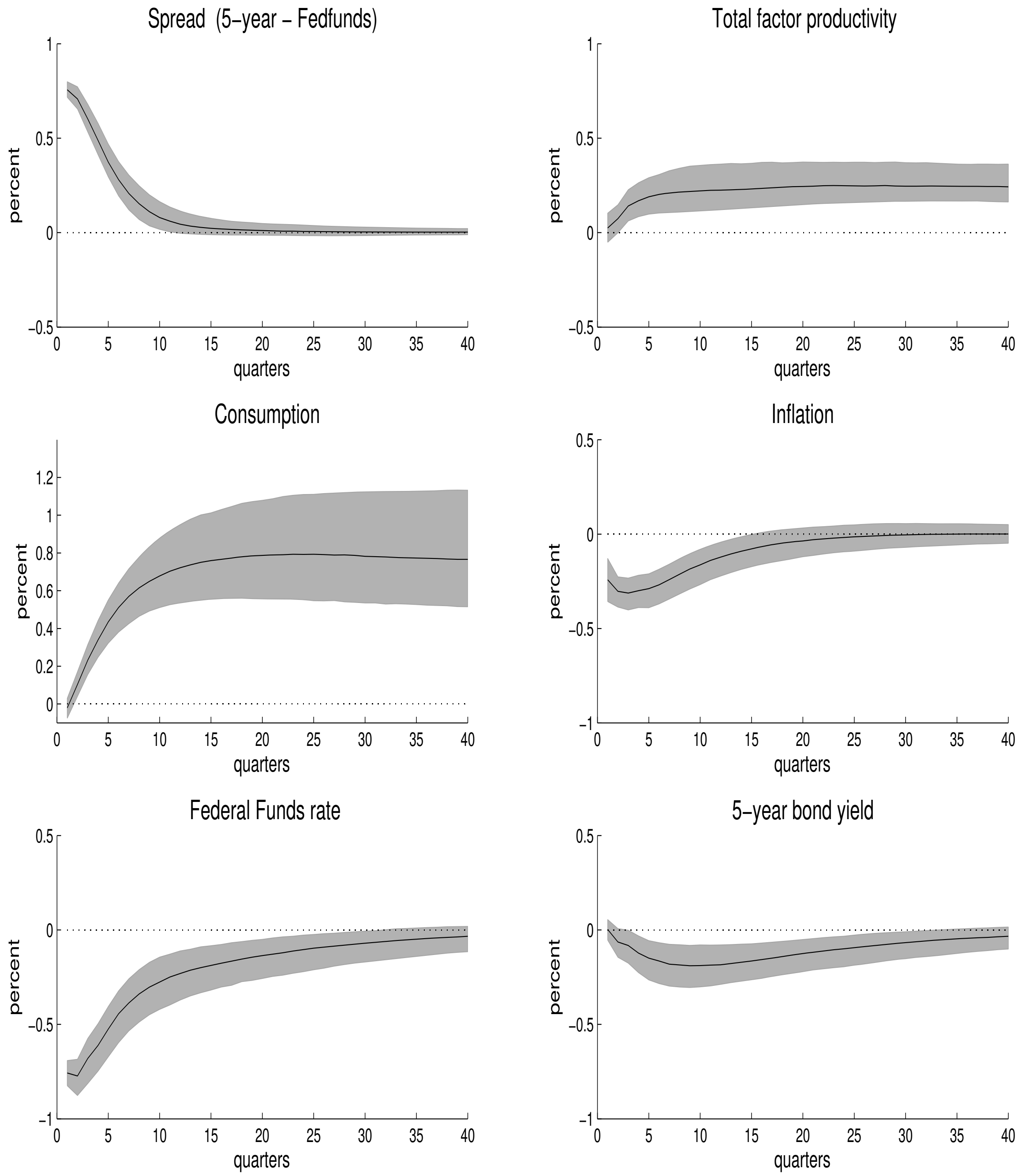

Figure 2 : Impulse responses to a 1% innovation in the slope shock

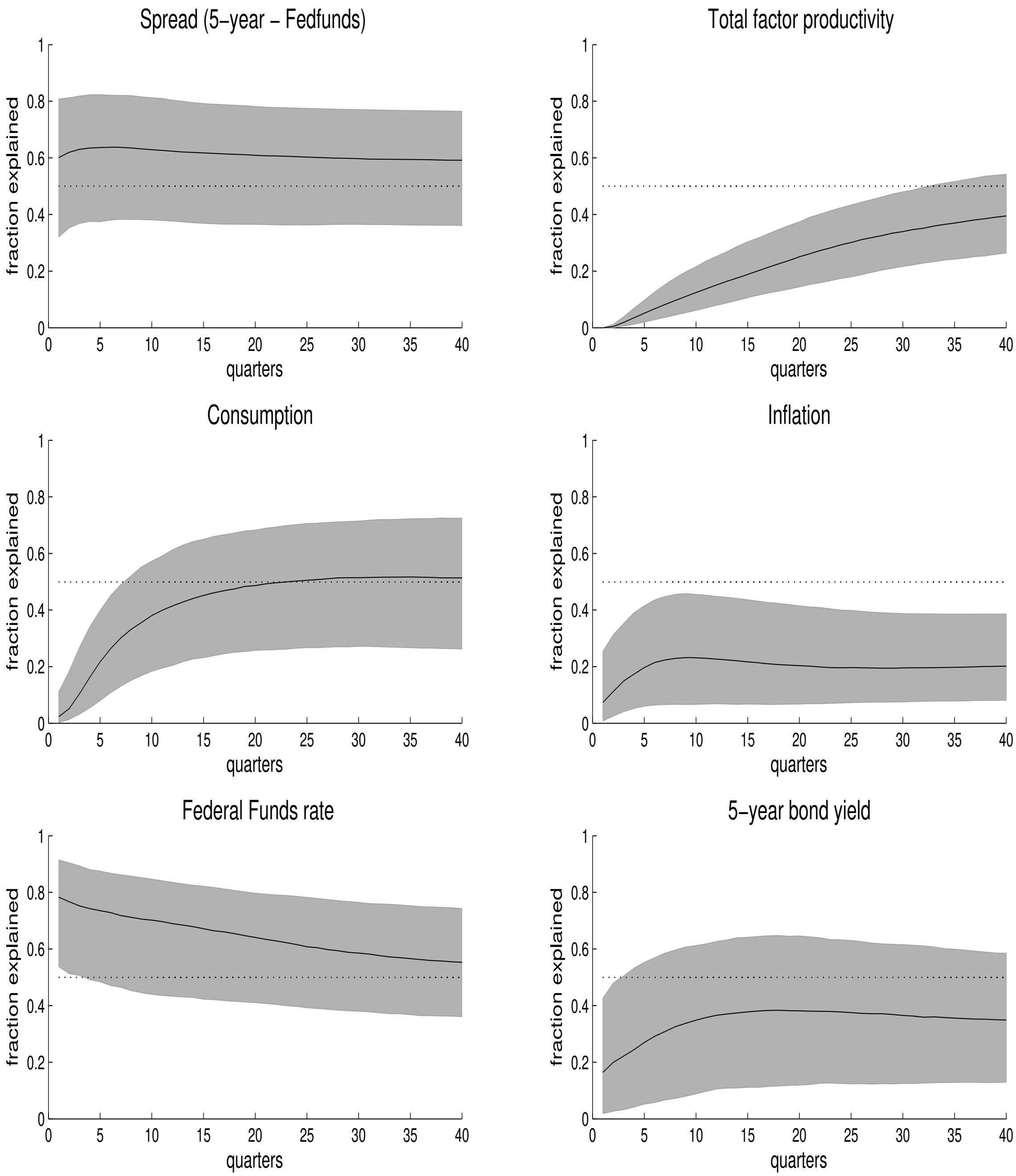

Figure 3 : Fraction of Forecast Error Variance (FEV) explained by TFP news shock

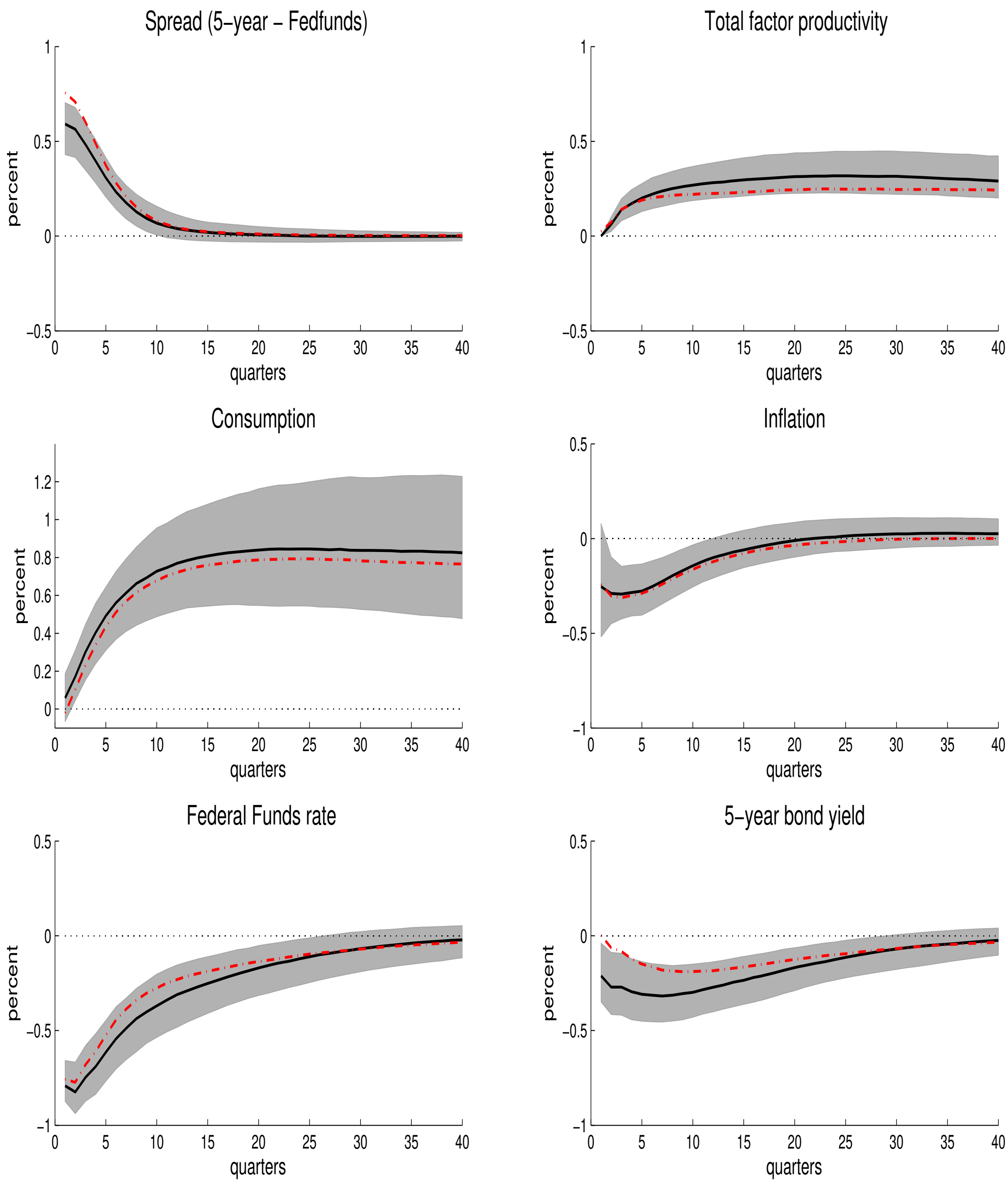

Figure 4 : Impulse responses to 1% innovation in the TFP news shock (black solid lines) and 1% innovation in the slope shock (red dashed lines); gray coverage intervals pertain to TFP news shock

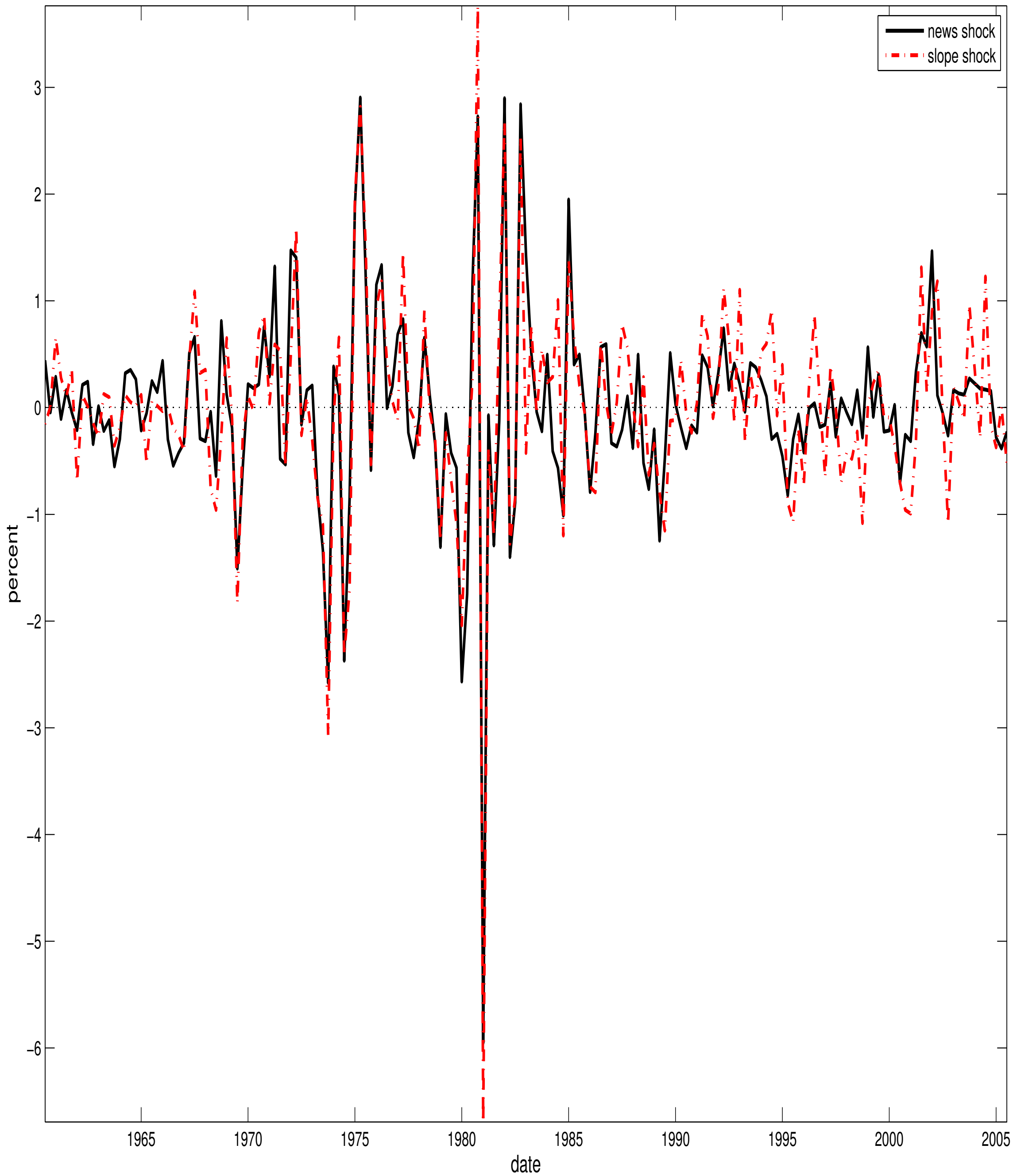

Figure 5 : Comparison of TFP news shock (black solid line) and slope shock (red dashed line)

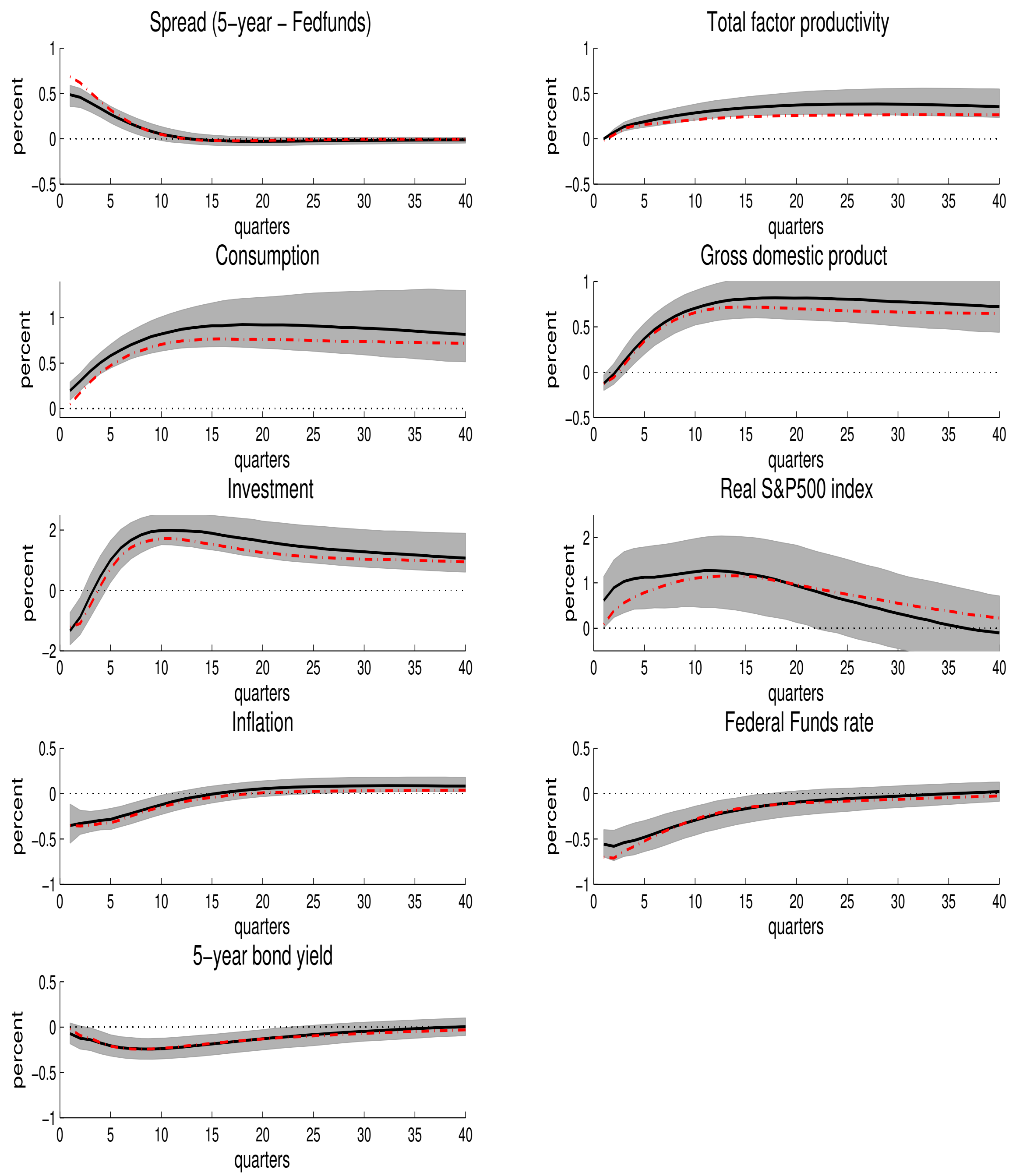

Figure 6 : Impulse responses to 1% innovation in the TFP news shock (black solid lines) and 1% innovation in the slope shock (red dashed lines) for extended VAR; gray coverage intervals pertain to TFP news shock