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Abstract

We assess whether the effects of fiscal policy depend on the extent of uncertainty in the economy. Specifically, focusing on tax shocks, identified by the narrative series by Romer and Romer (2010), and various measures of uncertainty, we use a Threshold VAR model to allow for dependence of the effects of the tax shocks both on the level of uncertainty and on the sign of the shock. Our two main empirical results are that the economy responds more positively to tax cuts during periods of low uncertainty, while, in response to tax increases, monetary policy contributes significantly in making the reaction of the economy neutral during more uncertain times. We also show that existing theoretical models can explain, to a good extent, this empirical evidence.

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Tax shocks with high and low uncertainty*

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September 2017

Abstract We assess whether the effects of fiscal policy depend on the extent of uncertainty in the economy. Specifically, focusing on tax shocks, identified by the narrative series by Romer and Romer (2010), and various measures of uncertainty, we use a Threshold VAR model to allow for dependence of the effects of the tax shocks both on the level of uncertainty and on the sign of the shock. Our two main empirical results are that the economy responds more positively to tax cuts during periods of low uncertainty, while, in response to tax increases, monetary policy contributes significantly in making the reaction of the economy neutral during more uncertain times. We also show that existing theoretical models can explain, to a good extent, this empirical evidence.

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1 Introduction

The debate on the effects of fiscal policy has been revamped by the financial crisis and subsequent global recession, with a number of papers suggesting that the size of fiscal multipliers can be dependent on economic conditions. The recession has also stimulated interest in the study of uncertainty, which is increasingly looked at as a fundamental factor in shaping economic agents' behavior, with an increasing body of literature trying to estimate the impact of uncertainty shocks on the economy, as well as to theoretically explain why changes in uncertainty may be a driver of the business cycle. Naturally, economic policy and uncertainty interact and this paper focuses on this interaction. Specifically, we assess whether and to what extent the effects of tax shocks depend on the amount of uncertainty in the economy, whether this relationship is the same for expansionary and contractionary tax shocks, and whether monetary policy has an impact on the fiscal policy - uncertainty interaction.

The literature on fiscal policy and on uncertainty is vast, and the main relevant references for our paper are examined in Section 2. Here we would like to mention a few papers that are closest to our analysis. Aastveit, Nativik, and Sola (2013) explore whether uncertainty influences the transmission and the effects of monetary policy. They find that monetary policy is much less effective in periods of high uncertainty, consistently with real-options models, such as McDonald and Siegel (1986). Pellegrino (2015), using a different econometric methodology, arrives to similar results: monetary policy shocks are less effective during uncertain times. Callegari, Cimadomo, and Ricco (2016) focus on the fiscal side, investigating the time-varying effects of government spending shocks on aggregate variables. They find that the strongest effects of government spending shocks on GDP occur during less uncertain times and that the main channel through which this happens is the increase of private investments, consistent, e.g., with the option value theory by Bernanke (1983). No papers, to our knowledge, consider the tax policy - uncertainty relationships, on which we focus.

A key issue is the definition of the tax policy and of uncertainty. Following studies such as Mertens and Ravn (2010), Favero and Giavazzi (2012), and Mertens and Ravn (2013), we use tax shocks identified by the narrative series of Romer and Romer (2010). By examining the documents on the decisions of the US Congress about fiscal issues, Romer and Romer (2010) are able to break down overall changes in government revenues into four components, including spending-driven tax changes, countercyclical tax changes, deficit-driven tax changes, long-run growth tax changes. The first two categories are endogenous to the current situation of the economy, while the last two categories can be considered as exogenous tax changes. These exogenous tax changes can be treated as orthogonal structural shocks in VARs, and used to identify the impulse response of output to tax shocks. Other studies, reviewed in Section 2, adopt different definitions of tax shocks, generally based on structural VAR models identified with various methodologies (e.g., external instruments in Blanchard and Perotti (2002) or sign restrictions in Mountford and Uhlig (2009)).

As for tax policy, there is no unique definition of uncertainty, though there is consensus that uncertainty shocks are related to an increase in the volatility of one or a set of economic variables. Following Jurado, Ludvigson and Ng (2015, JLN), we measure uncertainty as the common component in the volatilities of forecast errors for a large set of macroeconomic indicators. We think this is the concept of uncertainty that matters most in our context, as it relates to the difficulty in predicting the future broad macroeconomic conditions. Other measures based on the dispersion of the SPF forecasts (see e.g. Rossi and Sekhposyan (2015) - results of robustness checks in Appendix - and Callegari, Cimadomo and Ricco (2016)) or of firms' characteristics (see e.g. Bloom et al. (2012)) are narrower, though typically they tend to provide a similar assessment of the uncertainty conditions.[1] Yet other uncertainty mea-

[1] Callegari, Cimadomo, and Ricco (2016) use the Survey of Professional Forecasters for both the identification of unanticipated government spending shocks and for the creation of a new, very specific, measure of uncertainty. The extension of their analysis to tax shocks has the main difficulty that the SPF is not available for government revenues, so that both the identification scheme and the uncertainty measure they propose are not replicable.

sures are based on the appearance of specific terms in newspapers articles (see e.g. Baker et al. (2016)). These measures try to capture the agents' perception of future developments of the economy, with particular reference to lack of clarity, for example, on government fiscal and trade policy or to increased ambiguity about the monetary policy changes. As such they can be also relevant in our context, and indeed we assess (results in the Appendix) the robustness of our results to the use of the Baker et al (2016) Economic Policy Uncertainty index, finding only few differences. A third class of measures focuses on financial uncertainty. The VIX is a well-known example, but forecast based measures similar to those proposed by JLN for macroeconomic uncertainty can be also constructed, see, e.g. Ludvigson, Ma, Ng (2016, LMN). We think financial uncertainty is too narrow and too volatile to be the best measure in our context, but we also check its performance.

Another key choice concerns the econometric methodology to be used to study the fiscal policy - uncertainty interaction. A linear specification is clearly not sufficient in our context. In the set of non-linear models, we need to find one that allows for uncertainty dependent parameter time variation and, possibly, sign asymmetries in the effects of tax shocks, while remaining computationally doable and economically interpretable. In line with the literature studying nonlinear policy effects over the business cycle or under different credit conditions, see e.g. Auerbach and Gorodnichenko (2012), we use a Threshold VAR (TVAR) model, with the uncertainty measure as transition variable. Following the specification and identification strategy designed by Favero and Giavazzi (2012), in the TVAR we insert the narrative shocks isolated by Romer and Romer (2010) as exogenous structural shocks to tax revenues. According to Favero and Giavazzi (2012), the resulting model reconciles the evidence coming from the narrative approach, which typically found large effects of tax shocks, with that from the Structural VAR literature, in particular from Blanchard and Perotti (2002), where the magnitude of the impact of a tax shock on output was much weaker.

Empirically, we find that our uncertainty TVAR model with sign nonlinearity has a better fit than a model using the business cycle conditions as a conditioning variable, as in Auerbach and Gorodnichenko (2012). Quantitative assessment of nonlinearity via Olivei and Tenreyro (2010) tests confirms that, in the model with sign nonlinearity, the reaction of the economy is statistically different across uncertainty regimes, considering either expansionary or contractionary tax shocks, and that relevant sign nonlinearity exists also when considering shocks occurring in periods of high macroeconomic uncertainty. In particular, we find that the economy reacts more negatively to a tax increase when ex-ante macroeconomic uncertainty is high and, on the contrary, tax expansions are more effective in stimulating the economy in periods of low uncertainty. Also, we find that monetary policy effectively counteracts contractionary tax shocks in the high-uncertainty regime, making the impact of shocks more similar across regimes. As a further check, we find that, even though macroeconomic uncertainty is related to business cycle conditions, our results are not driven by business cycle movements, since previous findings are fully robust to the use, as threshold variable, of the residuals of the regression of macroeconomic uncertainty on Auerbach and Gorodnichenko (2012) business cycle proxy.

Our findings fit very well, especially in the case of expansionary shocks, with theoretical models linking uncertainty to investment and hiring decisions by firms (Bernanke (1983), McDonald and Siegel (1986), Bloom (2009), Bloom et al. (2012)) and to precautionary savings on the consumers side (Basu and Bundick (2017), Fernandez-Villaverde, Guerron-Quintana, Rubio-Ramirez and Uribe (2011)): agents respond more mildly to positive policy stimuli because they adopt a wait-and-see or precautionary behavior. In the case of tax increases in periods of low macroeconomic uncertainty, agents may be willing (tax increases seem temporary in this regime) and able (limited financial frictions) to smooth consumption and maintain investment, while they may not be able to do so in the high-uncertainty regime, typically associated with tightening of the credit conditions to households and firms (Arellano, Bai and Kehoe (2016), Gilchrist, Sim, and Zakrajsek (2014)).

The remainder of the paper is structured as follows. In Section 2 we review the main related literature. In section 3, we introduce the econometric framework, the identification strategy, and the model's specifications. In Section 4 we present the empirical results and relate them to economic theory. In Section 5 we present the results of the robustness analyses studying the effects of the inclusion of a monetary policy variable in the specification, the degree with which business cycle movements affect our results, the role of the uncertainty measure, the estimaton with an adaptation of the 3SLS estimator by Judge et al. (1980), to also allow for changes in the variance-covariance matrix of the shocks, and supplementary results including GIRFs. In Section 6 we summarize and conclude. An appendix contains additional results and robustness checks.

2 Literature Review

Our paper is at the crossing of at least three different strands of literature. The first one refers to the impact of fiscal policy, and in particular of tax shocks, on the main economic aggregates. The second one studies the nonlinear propagation of shocks across regimes identified by a specific driving variable. The third strand, instead, focuses on the impact of uncertainty shocks on economic aggregates and on the implications for policy transmission. In the following subsections we briefly review the main contributions related to our analysis in each area.

2.1 Fiscal Policy

As to the literature on the impact of fiscal policy on macroeconomic aggregates, one of the most influential papers is by Blanchard and Perotti (2002), who exploit the characteristics of the U.S. institutions in order to impose a recursive identification structure to their fiscal VAR.

A second very influential paper in the field of fiscal policy, and in particular of tax shocks, is Romer and Romer (2010), who employ the so-called narrative approach. By examining the documents on the decisions of the Congress about fiscal issues, they are able to break down overall changes in government revenues into four components, including spending-driven tax changes, countercyclical tax changes, deficit-driven tax changes, long-run growth tax changes. The first two categories are defined as endogenous to the current situation of the economy, while the last two categories are considered as exogenous tax changes. Then they use, in a single equation framework or in a small scale VAR, the exogenous tax changes as orthogonal shocks to identify the impulse response of output to tax shocks [2].

A third identification approach for fiscal VARs is the one proposed by Mountford and Uhlig (2009), who use sign restrictions to identify both tax and government spending shocks.

Favero and Giavazzi (2012) aim at reconciling evidence from different identification strategies. They show that, by using the narrative shocks by Romer and Romer (2010) as orthogonal tax shocks in a VAR framework and including as endogenous variables also inflation, cost of debt and an equation tracking debt dynamics, the results obtained via the narrative method are in line with those found from the SVAR approach by Blanchard and Perotti (2002).

2.2 Nonlinear Effects of Fiscal Policy

As to the second strand of literature, the most important paper is the one by Auerbach and Gorodnichenko (2012), where they study the nonlinear effects of government spending shocks with a Smooth Transition Threshold VAR, with transition between regimes governed by the 7 quarters moving average of GDP growth, which is used as a proxy for the business cycle. They find that the response of GDP is typically stronger in periods of recession than in periods of expansion, when the effect of an increase in public spending is even negative after few quarters. Christiano, Eichenbaum and Rebelo (2011) show empirically that the size of the government spending multiplier is larger when

[2] Mertens and Ravn (2010) use as a starting point the narrative shocks identified by Romer and Romer (2010) and distinguish between unanticipated and anticipated fiscal shocks, where the latter are defined as shocks announced at time t and implemented after 90 days (1 quarter). Typically, the effect of an unanticipated tax increase is negative right from the start, while, in response to an anticipated tax increase, the effect on output is positive until the effective implementation of the policy measure occurs, and thereafter it becomes negative. Mertens and Ravn (2013) distinguish between tax changes to personal and corporate income. Extending the Stock and Watson (2012) external instrument identification strategy for the use of two external instruments, they find that, while personal income tax cuts lower significantly tax revenues, increase employment, investment and consumption, corporate income tax cuts have a negligible effect on tax revenues, boost investments, but have no effect on consumption and employment.

the economy hits the zero lower bound on nominal interest rates.

Perotti (1999) studies the nonlinear effect of deficit cuts (via government spending reduction) in periods of "fiscal stress", as defined by periods when government debt is high. He finds that, during these periods, deficit reduction increases private consumption and the reaction of macroeconomic aggregates is significantly different depending on the state of the economy at the moment in which government spending reduction is carried out. Ferraresi, Roventini, and Fagiolo (2014) use a TVAR model to study the effect of fiscal policy in periods when the economy is credit constrained. They proxy the tightness of the credit situation with the spread between the BAA-rating corporate bonds and the 10-years Treasury constant maturity rate and they find that the fiscal multiplier is significantly above one in the constrained credit regime. Roeger and in 't Veld (2009) find similar results using a DSGE model. Afonso, Baxa, and Slavik (2011) study the nonlinear impact of fiscal policy in a TVAR framework, using as a conditioning variable the Financial Stress Index, which is a proxy for the state of the financial markets.

More recently, Alesina et al. (2016) study the effect of fiscal consolidations introducing a double nonlinearity in the state of the economy and in the composition of the fiscal consolidation, i.e. tax-based versus expenditure-based. In practice, they use a Smooth Transition TVAR as in Auerbach and Gorodnichenko (2012) with the addition of a dummy variable distinguishing between expenditure and tax-based fiscal contractions and they estimate this panel TVAR model on a dataset by De Vries et al. (2011), updated to 2014, providing a narrative account of fiscal episdoes in 16 OECD countries from 1981 to 2014. They find that the strongest source of nonlinearity deals with "how" the fiscal consolidation is carried out, with tax-based contractions being more harmful to output than expenditure-based ones. The state of the economy generates some nonlinearity in the response of GDP, but empirically this is less relevant than the one introduced by the composition. Finally, Auerbach and Gorodnichenko (2017) find that the level of public debt shows modest interaction with the effectiveness of fiscal measures and the impact of the latter on interest rates and CDS spreads.

2.3 Uncertainty

The literature on uncertainty strongly expanded in recent years and it touches on several aspects. Bloom (2014) provides a review of the uncertainty literature.

A first group of papers deals with how to properly measure uncertainty. A description of the uncertainty measure proposed by Rossi and Sekhposyan (2015) is provided in the Introduction. In addition, Rossi, Sekhposyan, and Soupre (2016) provide a decomposition of uncertainty, based on the SPF density forecasts. They distinguish between ambiguity, i.e. the uncertainty about the probability distribution generating the data, and risk, i.e. uncertainty about the odds of two outcomes in the case the DGP is known. Jurado, Ludvigson, and Ng (2015) propose another uncertainty measure also based on the concept of forecast errors, whose detailed description is available in Section 3. The analysis is extended in Ma, Ludvigson and Ng (2016) to allow also for financial uncertainty and a possible endogeneity of uncertainty with respect to the business cycle. Carriero, Clark and Marcellino (2016) extend the JLN and MLN approach by estimating in a single model (a large BVAR with common and idiosyncratic volatilities) both macro and financial uncertainty measures and their effects on the economy. The results of the robustness checks made using the latter two measures of financial uncertainty can be found in the Appendix. Casarin, Foroni, Marcellino and Ravazzolo (2016) measure uncertainty as the disperiosn in SPF and assess its effects in a panel MS model, finding important asymmetries over the business cycle. Instead, Baker, Bloom and Davis (2016) develop the Economic Policy Uncertainty Index, which is a news-based measure of uncertainty. The measure is based on textual analysis (the relative frequency of specific keywords) webscraped on newspapers articles.

A related literature develops theoretical models to justify the impact of uncertainty on the usual macroeconomic aggregates. A first set of models claims that uncertainty is a cause of slower economic growth. These models encompass the so-called real option effect of uncertainty, according to which there is a value in waiting before taking a decision (for example, there is an extra value in waiting before investing as in the model of McDonald and Siegel (1986)) and uncertainty increases this value. Another identified mechanism through which uncertainty may cause a recession is via financial constraints. Papers in this category are, for example, Gilchirst, Sim, and Zakrajsek (2010) and Arellano, Bai, and Kehoe (2016). On the demand side, precautionary savings have been proposed as a possible transmission mechanism, both empirically and theoretically. Papers that suggest this channel are Basu and Bundick (2017), Leduc and Liu (2016) and Fernandez-Villaverde, Guerron-Quintana, Rubio-Ramirez and Uribe (2011). Other models, instead, assume that higher uncertainty influences the process of technological innovation, which is the ultimate cause of declines in economic activity. In Bloom (2009) uncertainty shocks cause firms to pause hiring and investing, which causes productivity to drop because of the stop in the reallocation of resources towards most productive units. Bloom et al. (2012) argue that uncertainty shocks are one of the main drivers of the business cycle and that, importantly, policies like wage subsidies are temporarily less effective due to wait-and-see behavior of firms.

A second set of models presents higher uncertainty as a consequence, and not as a cause, of lower economic activity. In this set there are papers by Bachmann and Moscarini (2011),Van Nieuwerburgh and Veldkamp (2006) and Pastor and Veronesi (2013).

A third set of papers even argues that some types of uncertainty can actually increase output: these are the so-called growth option theories. Pastor and Veronesi (2006) and Segal, Shaliastovich, and Yaron (2015) are examples in this category.

The third strand of uncertainty literature focuses on estimating the impact of various types of uncertainty shocks on macroeconomic variables. There are several papers on this topic, among others: Bloom (2009), Bloom et al. (2012), Gilchrist, Sim, and Zakrajsek (2014), Basu and Bundick (2017), Bachmann and Moscarini (2011), Bachmann, Esltner, and Sims (2013), Alessandri and Mumtaz (2014), Jones and Enders (2016), Caggiano, Castelnuovo and Nodari (2017). All these papers investigate the response of economic aggregates to uncertainty shocks without considering the contemporaneous feedback effect of shocks to real macroeconomic variables on uncertainty. Instead, Ludvigson, Ma, and Ng (2016) propose a small scale VAR (with a measure of real economic activity, a measure of macroeconomic uncertainty, and a measure of financial uncertainty) identified via an Iterative Projection Instrumental Variable strategy and moments' restrictions. They find that both macro and financial uncertainty shocks cause drops in output and other real variables, but only macroeconomic uncertainty responds, falling, to positive shocks to real aggregates. On the contrary, financial uncertainty seems to be very mildly responding to real economy shocks.

2.4 Uncertainty and economic shocks

The fourth strand of uncertainty literature tries to understand how different uncertainty situations influence the transmission of other shocks, usually fiscal and monetary policy shocks, to the economy. Van Robays (2016) uses a TVAR model in order to investigate the different effects of an oil shock during periods of high and low macroeconomic uncertainty. Aastveit, Nativik, and Sola (2013) explore whether uncertainty influences the transmission and the effects of monetary policy. They find that monetary policy is much less effective in periods of high uncertainty, consistently with real-options models. Pellegrino (2015) uses an Interacted VAR to answer a similar empirical question and he arrives to similar results: monetary policy shocks are less effective during uncertain times. The work of Callegari, Cimadomo, and Ricco (2016) is focused instead on the fiscal side, investigating the effects of government spending shock on aggregate variables with a TVAR model. They find that the strongest effects of government spending shocks on GDP occur during less uncertain times and that the main channel through which this happens is the increase of private investments, consistent with the option value theory by Bernanke (1983). However, the extension of their analysis to tax shocks is not possible because the SPF, which they use for both identification and definition of uncertainty, is not available for government revenues.

3 Econometric Framework and Identification

3.1 Econometric Framework

In this section we briefly explain the working of the Threshold Vector Autoregression (TVAR), the econometric model that we use in the empirical section. The TVAR model is an extension of standard VAR models introduced by Sims (1980) and it can capture possible nonlinearities, like asymmetric reactions to shocks, driven by the level of an external threshold variable. As a consequence of this property, impulse responses are nonlinear in the general model, but linear within regimes. Following Afonso, Baxa, and Slavik (2011), who also use a TVAR in the context of fiscal policy, the TVAR model can be written as follows:

$$Y_t = c^1 + B^1(L)Y_{t-1} + \delta^1 e_t + (c^2 + B^2(L)Y_{t-1} + \delta^2 e_t)I_{[s_{t-d}>\gamma]} + U_t \qquad (1)$$

where Y_t is the vector of endogenous variables, I is an indicator function that takes value 1 if the conditioning variable is above the fixed threshold and 0 otherwise, and U_t is a multivariate white noise error. In our paper, the indicator function will take value 1 in the high uncertainty regime. d is the number of lags imposed on the switching variable to define the regimes: in the empirical part this value will be set to one, in order to minimize feedback effects of the economic aggregates on the definition of the regime via their possible contemporaneous impact on the uncertainty measure and to take into account that changes in the macroeconomic dynamics require some time. The threshold γ is determined by grid search and it is chosen as the value which minimizes the sum of squared residuals of the estimated model. $B^1(L)$ and $B^2(L)$ are the lag polynomials that regulate the dynamics of the system and c^1 and c^2 are vectors of intercepts. e_t are the structural shocks to taxes identified by Romer and Romer. In this case the coefficients that indicate the on-impact effect of tax shocks are δ^1 and δ^2 and they are allowed to differ across regimes. To allow for the possibility of asymmetries in the effects of shocks of different sign, we consider a specification where e_t is split into two variables: one with all the positive elements of e_t and zero otherwise, another with all the negative tax shocks and zero otherwise.

3.2 Identification Strategy

Following the specification and the identification strategy designed by Favero and Giavazzi (2012), we use the exogenous narrative shocks isolated by Romer and Romer (2010) as true structural shocks to tax revenues. By structural we mean that these shocks really identify changes in tax revenues that are orthogonal to innovations to other endogenous variables in the VAR. However, instead of using these shocks in a single equation framework or in a 2 variables-VAR as in Romer and Romer (2010), we embed them as exogenous regressors in a larger VAR framework, where the dynamics of inflation, cost of debt, government spending, monetary policy and uncertainty itself are made endogenous. This identification strategy has been designed by Favero and Giavazzi (2012) in order to reconcile the evidence coming from the narrative approach, which typically found that the effect of tax shocks was very large, with the evidence from the Structural VAR literature, in particular from Blanchard and Perotti (2002), where the magnitude of the impact of a tax shock on output was found to be much weaker. Favero and Giavazzi (2012) show that, when using the narrative shocks in a VAR framework, the estimated multipliers are much lower than in Romer and Romer (2010) and in line with the evidence by Blanchard and Perotti (2002), because using a truncated MA representation, as in the original use of the narrative shocks, delivers biased estimates because it fails to take into account the correlation between distant lags of government revenues and GDP and the narratives.

A potentially critical issue with this identification strategy could come from the narrative shocks identified by Romer and Romer (2010) not being really orthogonal to the other endogenous variables of the system, and therefore not allowing a structural interpretation. An alternative identification strategy would be, instead of including the narrative shocks directly in the VAR, to use the narratives as external instruments and use the identification strategy proposed by Stock and Watson (2012) and then extended by Mertens and Ravn (2013). However, Favero and Giavazzi (2012) bring evidence in order to show that the narrative shocks can actually be interpreted as structural innovations. Indeed, they test the hypothesis of orthogonality and find that they cannot reject it, i.e., the narratives are indeed orthogonal to the endogenous variables of the system[3]. In addition, this strategy also takes care of the fiscal foresight issue, because, with the use of narrative shocks, which are built using information outside of the statistical model, identification does not require the invertibility of the MA representation.

Since we use a slightly different information set, which adds uncertainty in the main specification and also the FFR in one of the robustness checks, we repeat the Favero and Giavazzi (2012) orthogonality test and find similar results. After regressing the narrative shocks on the first 4 lags of the model's endogenous variables and taking residuals, we find that the latter are only a noisy version of the original narrative shocks and that, also, the adjusted R^2 of the regression is virtually 0.

3.3 Model Specification

Our first specification is a TVAR with 6 endogenous variables, an additional exogenous regressor, and an external uncertainty measure which defines regimes. In particular, we follow the specification by Favero and Giavazzi (2012), but we add in the last position of the VAR the chosen uncertainty measure, so that the model specification is:

$$X_t = c^1 + B^1(L)X_{t-1} + \delta^1 e_t + (c^2 + B^2(L)X_{t-1} + \delta^2 e_t)I_{[u_{t-d}>\gamma]} + U_t \qquad (2)$$

where $X_t = [i_t \; y_t \; \Delta p_t \; t_t \; g_t \; u_t]'$. i_t is the average cost of servicing debt and it is computed by dividing net interest payments at time t by the federal government debt held by the public (FYGFDPUN in the Fred database) at

[3]In their empirical analysis, Favero and Giavazzi (2012) include, in addition to the endogenous variables that we will specify at the beginning of the empirical section, another equation accounting for the dynamics of the debt to GDP ratio in response to tax shocks. This additional equation in the VAR, which has not to be estimated since it is an identity, should check that the response of the macroeconomic aggregates is not computed along "unsustainable debt paths". They report the results for both the VAR tracking the debt-to-GDP ratio dynamics and for the VAR without the additional equation, where the results from the second are better comparable with the existing SVAR literature on tax shocks. Favero and Giavazzi (2012) find that the estimation of the system including the debt dynamics on U.S. data never delivers unsustainable debt paths. Since we use the same Romer and Romer narrative shocks and we focus on the U.S. economy over the same period too, we estimate a VAR without keeping track of the debt dynamics, feeling confident that the results will not be biased by tax shocks leading the public finance on an unsustainable path.

time $t-1$. In the empirical section, we omit IRFs to i_t because they bring no relevant contribution to the analysis and because recent literature, e.g. Auerbach and Gorodnichenko (2017), shows that the effect of fiscal changes on cost of debt is modest- These IRFs are anyway available upon request. y_t is the log of GDP expressed in real per capita terms, i.e. by dividing the overall nominal figure by the GDP deflator and by population. [4] Δp_t is a proxy for inflation and it is obtained as the log difference of the GDP price deflator. t_t is a measure of tax revenues and it is obtained as the log of federal government receipts expressed in real per capita terms. g_t is government spending and it is computed as the log of real per capita primary government expenditure, which is Total Federal Government Current Expenditure minus net interest payments at annual rates. u_t is the uncertainty measure, which affects all variables and can also lead to a switch in regime. Finally, e_t is the vector of Romer and Romer (2010) tax shocks and it is expressed in percentage of previous quarter GDP.

An alternative specification presented in the robustness section adds, just before the uncertainty measure, the Federal Funds Rate, which is included in order to account for the behavior of monetary policy during episodes of fiscal expansion or contraction. As we will see, this is particularly relevant when we distinguish between tax shocks of different nature.

In all specifications the sample goes from 1960Q3, the quarters where the uncertainty series starts, to 2007Q4, when the Romer and Romer (2010) narrative shocks series ends.

The chosen uncertainty variable is the macroeconomic uncertainty measure provided by Jurado, Ludvigson, and Ng (2015). They start from a dataset of 132 macroeconomic variables and 147 financial variables - mainly constituted by portfolio returns from the Fama and French (1992) factors - and they estimate, in this data-rich environment, a factor augmented model in order to

[4]In the section reporting the empirical evidence, we also present results from different specifications substituting to GDP, as a second variable in the VAR, either log real per capita aggregate consumption, log real per capita investments or private savings as a percentage of disposable income. Unofrtunately, the variables cannot be jointly included in the VAR due to the nonlinearity and the relatively short sample size.

produce forecasts for each of the 132 macroeconomic variable included. These series include variables relative to output and income, labor market, consumption, housing, money supply, exchange rates, prices, bond spreads, stock market valuations, and credit. With these forecasts at different time horizons - 1, 3, and 12 months ahead - squared forecast errors are computed and aggregate uncertainty is obtained as the simple average of the square root of the squared forecast errors of the 132 series. In the present work, we use the 12-month-ahead measure of macroeconomic uncertainty, since we think this is the most appropriate horizon in this context. In addition, while the uncertainty variable is included in the VAR specifications without further transformation, when it is used for the definition of regimes it is smoothed by taking the 6-quarters moving average, so that the definition of regimes is not too volatile and it really captures medium term trends in uncertainty.

3.4 Computation of the IRFs

Given our specific identification strategy, we provide here a brief description on how IRFs are computed. As described in section 3.1, we identify separate parameters for different uncertainty regimes both for the dynamics of the systems (matrices $B^1(L)$ and $B^2L)$) and for the structural on-impact effect of narrative tax shocks (vectors - or matrices in the case of the TVAR with sign nonlinearity - δ_1 and δ_2). To compute IRFs first we build the parameters for the high-uncertainty regime by summing, respectively, $B^1(L)$ and $B^2L)$ and δ_1 and δ_2. We take as the structural response of the endogenous variables at $t = 0$ to a structural shock at $t = 0$ the vectors (or matrices) δ_1 and $(\delta_1+\delta_2)$. Then, for each t from 1 to the chosen horizon, we multiply the vector of responses at $t - 1$ by the companion-form matrix governing the dynamics of the model in each of the two regimes.

Apart from the technical details, computing IRFs in the way just described implies that we consider linear IRFs within regimes. In principle the tax shocks we study may trigger regime shifts over the time horizon under study and our method for computing IRFs would not take into account these evolutions. This could be accomplished by using Generalized IRFs, however our main interest is to observe the reaction of the aggregates depending on levels of ex-ante uncertainty, which can be well-accomplished by using the within-regime-linear IRFs just described. For the main specification, however, we also compute GIRFs following, e.g., Ferraresi, Roventini and Fagiolo (2014) and we show that results are robust. In particular, this implies that the implicit assumption of no regime shift induced by tax shocks seems to hold.

Finally, confidence bands for the impulse responses are compute by bootstrapping the residuals from the nonlinear model, maintaining the identified definition of regimes.

3.5 Assessing the relevance of the nonlinearity

We implement two statistical tests suggested by Olivei and Tenreyro (2010) in order to assess whether the impulse responses found for the nonlinear model are statistically different from those of the linear model. The two tests are based on statistics obtained from the comparison of the impulse responses of the linear and nonlinear models with bootstrapped critical values. The first test considers the maximum difference in absolute value between the impulse responses relative to different regimes. In particular, the first statistic is:

$$S_1 = \sup_t \left| y_{j,t}^1 - y_{j,t}^0 \right| \tag{3}$$

where the arguments of the absolute value are the response of variable y_j in the high and low regimes and the sup is taken over the time horizon over which impulse responses are computed (20 quarters).

The second test statistic considers the cumulated difference between the impulse responses of a given variable in the two different linear and nonlinear specifications. The sum of the impulse response is made over the whole time horizon considered (20 quarters). In formulas, the statistic is:

$$S_2 = \left| \sum_{t=1}^{20} \left(y_{j,t}^1 - y_{j,t}^0 \right) \right| \tag{4}$$

For both statistics, empirical distributions are obtained by bootstrapping the residuals generated from model estimation, re-estimating the model and the impulse responses on the simulated data, and computing the value of the test statistic for that draw. 1,000 repetitions are used, as in Olivei and Tenreyro

(2010). Bootstrapped p-values are the percentage of simulated test statistics with a value exceeding the one estimated from the original data.

4 Empirical Evidence

4.1 Correlation between Uncertainty and the Business Cycle

One important starting question is whether the possibly nonlinear response of aggregates to tax shocks, which we ascribe to different levels of macroeconomic uncertainty, is in fact driven by other factors. One obvious variable within this set is an indicator of the business cycle. Hence, we compare the macroeconomic uncertainty index with the 7-quarters moving average of GDP growth employed by Auerbach and Gorodnichenko (2012) as switching variable. From a graphical inspection of the two standardized time series (Figure 1), there appears to be some co-movement between the two variables, but also discrepancies. In general, correlation is negative (-0.6), so that periods where economic growth is slower tend to be correlated with periods of higher macroeconomic uncertainty, which is reasonable. This suggests that some of the results might be influenced not only by macroeconomic uncertainty, but also by the conditions of the economy. However, the estimated level of correlation confirms that the uncertainty measure also carries a significant amount of information which is not linked to the cycle and, from a graphical inspection of Figure 1, one can also see that significant periods of negative growth are included in the low-uncertainty regime sub-sample. In order to additionally examine this issue, in Section 5 we carry out a robustness check where we use, as a threshold variable in our specification, the residuals from the regression of macroeconomic uncertainty on the business cycle proxy by Auerbach and Gorodnichenko (2012), which are orthogonal to the business cycle itself.

As to the exogenous tax changes narratives, there are essentially two periods of strong concentration of tax shocks, both positive and negative. The first spans from 1964Q2 to 1967Q4 and the second from 1976Q4 to 1988Q1. Also, it seems, from a graphical inspection of the series, that large tax cuts are often followed by significant tax increases in the following quarters.

Another issue may be that the results we find are driven by the fact that, for example, tax cuts occur only in periods of low macroeconomic uncertainty or that all shocks occur in a specific range of uncertainty quantiles. However, we find that the average percentile where exogenous tax increases occur is the 50th, while for tax cuts it is the 44th. Overall, the average percentile where any of the tax shocks occurs is the 47th. This confirms that there is no relevant issue about systematic relations between the type and size of shocks and the uncertainty level.

4.2 Linear VAR

The impulse responses are always generated by a tax shock equivalent to 1% of previous quarter GDP. The linear VAR (Figure 2) delivers expected results: GDP, consumption, investments and saving rate respond positively to a tax cut. Instead, inflation seems to be unaffected by the fiscal change and government spending shows an increase over the considered horizon, signaling that possibly episodes of fiscal contraction and fiscal expansion occur in a coordinated manner. As expected, government revenues initially fall and then get back to the initial level as time goes. Finally, macroeconomic uncertainty falls quite evidently after the shock.

4.3 Threshold VAR with sign nonlinearity

It is worth checking how the model identifies regimes. We find that the low-uncertainty regime is observed during the periods 1962Q2:1973Q3, 1976Q4:1979Q2, 1988Q3:1990Q3, 1992Q2:2000Q2, 2003Q2:2005Q4 and the high-uncertainty regime during periods 1973Q4:1976Q3, 1979Q3:1988Q2, 1990Q2:1992Q1, 2000Q3:2003Q1, 2006Q1:2007Q4. If we compare this regime-definition with recession dates by the NBER, we see that the recession occuring in the period 1969Q4:1970Q4 falls in the low-uncertainty regime, while other NBER recession identified in the periods 1973Q4:1975Q1, 1980Q1:1980Q3, 1981Q3:1982Q4, 1990Q3:1991Q1, and 2001Q1:2001Q4 instead are all included in the high-uncertainty regime. However, it is also worth noticing that, despite this disproportion, the high-uncertainty regime periods are in general considerably wider than actual recession periods. [5]

4.3.1 Contractionary Tax Shock

Figure 3 shows that, for GDP, consumption and investments, the impulse response to a 1% tax increase is null when ex-ante uncertainty about the macroeconomic situation 12 months ahead is low, while the picture is very different when the high-uncertainty regime is considered. Indeed, for GDP and consumption, the impulse responses are negative, with a high level of statistical significance. This seems to suggest that contractionary tax shocks have a worse effect when uncertainty about the future conditions of the economy is high. As to investments, we observe an atypical behavior. They first rise on impact in the high-uncertainty regime and then revert to zero, with confidence bands being particularly wide. This behavior of investments on impact might be explained by the fact that, in the high-uncertainty regime, we see macroeconomic uncertainty falling after a tax increase. This decrease in uncertainty might explain why we see investments rising slightly at first.

Nonlinearity is quite evident also for other variables. Saving rate increases in the high-uncertainty regime and decreases in the low one. Government revenues increase in both regimes, but the decline of this variable is more rapid in periods of high uncertainty than in those of low uncertainty, when it takes more time for this aggregate to revert back to pre-shock levels. The fact that government spending also falls in this regime (while the same variable is unchanged in the other regime) might partly contribute to the worse reaction of GDP in the high-uncertainty regime. Likely as a consequence of the bad performance of the economy, inflation is reduced in the high-uncertainty regime. Finally, macroeconomic uncertainty seems to be reduced when tax increases are adopted in periods of high ex-ante uncertainty, while it is weakly increased when uncertainty is low before the shock.

[5] Also, when we try to remove the business cycle component from the macro uncertainty measure used (results of this robustness check are presented later) the definition of regimes is in general quite similar to the one just presented. The major differences are that a period of high-uncertainty is identified over 1970Q2:1971Q4 and that, instead, the long high-uncertainty period originally observed during 1979Q2:1988Q2 is halved, with quarters from 1984Q1 to 1988Q2 now falling in the low-uncertainty regime.

4.3.2 Expansionary Tax Shock

Figure 4 shows that, on the one hand, the response to a tax cut shown by the economy, either in terms of GDP, consumption or investments, is strong and positive in the low-uncertainty regime. On the other hand, the opposite is true for tax cuts occurring when ex-ante macroeconomic uncertainty is high: in this case the impulse responses are slightly negative or not statistically different from zero. This has the obvious implication that, while fiscal stimuli carried out via tax cuts are effective when the future developments of the economy are subject to low uncertainty, the same policies, carried out when the economic outlook is more uncertain, are ineffective or perhaps even harmful. Two factors can contribute to explain the worse reaction: the first is that, while the saving rate is unaffected in the low-uncertainty regime, it increases strongly in the high-uncertainty regime. This means that uncertainty, as theoretically suggested, induces people to save the tax cut rather than consume it, likely adopting a wait-and-see behavior. The second relevant factor is that government spending, which does not react in the low-uncertainty regime, shows a fall on impact in the high-uncertainty regime. In addition, government revenues are quite stable in the high-uncertainty regime, while they tend to increase as quarters go in the low-uncertainty one, possibly due to the very positive response of GDP and, as a consequence, of the tax base to the expansive fiscal measure. If we specifically focus on investments and extending the line of reasoning previously presented in the case of a tax increase, we see that, when uncertainty is low, the tax cut is followed by a further drop in uncertainty and by a growth of investments, while, in the high-uncertainty regime, the quite strong jump of uncertainty might contribute to mute the effects of the fiscal expansion.

4.3.3 Quantitative assessment of nonlinearity

In the specification with GDP and in response to a contractionary shock, the tests for the difference between the IRFs referred to the two alternative uncertainty regimes deliver p-values of 0.22 (maximum absolute difference) and 0.13 (cumulative distance). For consumption, the p-values are 0.07 (maximum distance) and 0.05 (cumulative distance). Instead, empirical assessment of nonlinearity in the response of investments to contractionary tax shock fails to deliver p-values below the 32% level.

The comparison of IRFs of different uncertainty regimes to an expansionary tax shock delivers remarkably low p-values in the specification with GDP: 0.08 in the maximum distance test and 0.05 in the cumulative distance test. For consumption, p-values are 0.06 (maximum distance) and 0.05 (cumulative distance) and, in the case of investments, these are 0.37 (maximum distance) and 0.08 (cumulative distance). Therefore, once we allow IRFs to differ depending also on the direction of the tax shock, the presence of nonlinearity generated by macroeconomic uncertainty is suggested, in addition to a graphical inspection, by a more quantitative assessment.

Finally, we compute p-values for the two tests in the case we compare IRFs to a contractionary and to an expansionary tax shock within the same uncertainty regime. In the specification with GDP, p-values for IRFs in the low-uncertainty regime are high in both tests (around 68%), but these are much lower in the case of the high-uncertainty regime (10%). Therefore, it seems that sign nonlinearity is more relevant in the high-uncertainty regime, while the asymmetry of the response is less relevant in periods of low macroeconomic uncertainty.

5 Possible Interpretations of empirical evidence

The evidence provided by the previous analysis can be summarized into two main points. In general, we see different responsiveness across different uncertainty regimes once controlling for the sign of the shock. In particular, it emerges that, following tax increases, GDP responds more negatively in the high-uncertainty regime than in the low one. Similarly, aggregate consumption reacts very negatively to tax increases in the high-uncertainty regime and it is virtually unchanged during less uncertain times. Instead, aggregates respond positively to expansionary tax shocks in periods of low uncertainty, while the response is negligible, or even negative, in the high-uncertainty regime.

Let us now interpret this evidence using the theoretical framework developed in the literature to investigate the impact of uncertainty on aggregates and on policy transmission.

In particular, the main proposed channels through which uncertainty can affect real variables are: 1) the real option value of waiting before taking investment decisions on the firm side (Bernanke (1983), McDonald and Siegel (1986)), 2) precautionary savings on the consumer side (Basu and Bundick (2017), Fernandez-Villaverde, Guerron-Quintana, Rubio-Ramirez and Uribe (2011)), 3) pausing of hiring and capital investment decisions (Leduc and Liu (2016), Bloom (2009), Bloom et al. (2012)), and 4) financial frictions constraining firms' decisions (Arellano, Bai, and Kehoe (2016), Gilchrist, Sim, and Zakrajsek (2014)).

We consider first the models by Bloom: idiosyncratic uncertainty shocks induce movements in aggregate output and productivity because firms pause hiring and capital investment decisions, thereby stopping reallocation of resources from less productive firms to more productive ones. This framework implies a S-s type mechanism in the decision of firms. When examining the effects of policy under different uncertainty regimes, Bloom et al. (2012) argue that, under high uncertainty, policy is less effective because the productivity thresholds outside which firms actually make decisions instead of waiting shift outside, so that the transmission from the policy stimulus to the real economy is jammed. Despite starting from different premises, the bottom line implications of real option theories is similar. In the presence of uncertainty, the value of waiting increases and fewer firms translate policy incentives into actions. Models focusing on financial frictions as a propagation mechanism for uncertainty shocks also end up predicting that firms hire less input and this reduces output.

On the consumer side, models pointing at precautionary savings are more specific and have contrasting implications. In Basu and Bundick (2017), an uncertainty shock induces consumers to increase savings, but, since in their model output is unaffected, investments must rise. Instead, the model by Fernandez-Villaverde, Guerron-Quintana, Rubio-Ramirez and Uribe (2011) implies a fall in all the aggregates after an uncertainty shock. In this case, the type of uncertainty they consider is about the interest rate at which a small open economy can borrow, which captures only one specific aspect of the broader concept of macroeconomic uncertainty represented by the variable used in our work. Finally, Leduc and Liu (2016) develop a model in which uncertainty shocks have aggregate demand effects as in the two models just described, but there are, in addition, job search frictions. So, during uncertain times, fewer matches between workers and firms are made, households' income and demand decrease even further, inducing firms to less job posting and eventually increasing unemployment, which amplifies the fall in demand.

Back to our empirical evidence, the fact that the response of aggregates to fiscal stimuli is weaker during periods of high uncertainty is perfectly in line with the theoretical literature presented above. Instead, the interpretation of the evidence emerging from the model with sign nonlinearity calls for a deeper analysis, with particular reference to tax increases.

As to the case of tax cuts, interpretation is less problematic: existing models are in general suitable to explain observed responses. In particular, on the firm side, all proposed mechanisms go in the direction of weaker response during more uncertain times: wait-and-see behavior, presence of worse financial frictions in high uncertainty, shift outwards of the S-s threshold for the decisions. Also, we observe a further drop of uncertainty in the low-uncertainty regime, which helps investments growth, and, instead, a rise in uncertainty in the high-uncertainty regime. As well, on the consumer side, the precautionary savings mechanism works properly: much of the tax cut is saved during more uncertain times and this weakens the effect of the policy measure on the aggregates, which is otherwise strong during less uncertain periods. Moreover, evidence shows that tax cuts are accompanied by government spending reduction during high-uncertainty periods, which might contribute to generate a worse response of the economy in this regime. More specifically, given the very strong nonlinearity observed in the responses of consumption across regimes and by the very high spike in the saving rate when ex-ante macroeconomic uncertainty is high, the most important mechanism underlying the evidence presented seems to be the precautionary savings one. This is consistent with the fact that agents give particular importance to keeping consumption smooth over time so that, even though their disposable income increases following the tax cut, the uncertainty about the future conditions of the economy, including the conditions of the labor market, wages, inflation rate and, as a consequence, real income, and credit conditions, implies that they prefer to save large part of additional income in order to avoid the risk of being forced to reduce back consumption within a 12-months horizon, when macro conditions may become worse.

In the case of a tax increase, we should be cautious about interpretation of the results because, as we will see, evidence changes quite substantially when we consider the interplay between tax shocks and the reaction of monetary policy to these shocks. However, we can sketch possible explanations for our findings. In particular, one should notice that the increase in tax revenues in both regimes is mainly temporary, with the variable increasing in the quarters after the shocks and then decreasing. The reversion of the initial spike is more rapid and down to negative levels in the high-uncertainty regime, while it is smoother in the low regime. In this context, high uncertainty about future macroeconomic conditions may trigger a tightening of the credit conditions to households. Hence, while in periods where the future economic outlook is less uncertain agents may be willing - due to the fact that tax increase seems to be temporary - and able - due to limited financial frictions - to smooth consumption, as testified by the falling saving rate, agents may not be able to do so in the high-uncertainty regime[6]. In addition to the financial frictions

[6] We checked, at a very preliminary level, whether we observe any evidence in the data of tighter credit conditions when our measure of macroeconomic uncertainty is high. For firms, we check the correlation between the measure of macroeconomic uncertainty by JLN and two variables from the Senior Loan Officer Survey done by the Federal Reserve. The first is a measure of credit tightening to large and medium firms and the second to small firms: Higher values imply a tightening of credit conditions applied by banks and lower values suggest an easing. The correlation between macroeconomic uncertainty and the first proxy of credit to firms is 0.58 and with the second proxy 0.59. This suggests that when macro uncertainty is high also credit conditions become tighter. In particular, if we consider the definition of uncertainty regimes as identified by our main specification, we find that the mean of the two proxies in the two uncertainty regimes differs: It is -1.9 and -1.5 in the low-uncertainty regime, suggesting credit easing, and it is 21.3 and 17.0, indicating substantial tightening. As to households, the series of the Senior Loan Officer Survey starts in 1996Q1

explanation, the precautionary savings narrative may find application also in the context of tax increase. Indeed, in the high-uncertainty regime, the saving rate increases slightly, even if confidence bands generally include the zero level. Agents, even if they see their disposable income reduced as a consequence of the increase in taxes, tend to increase the saving rate because future conditions of the economy as a whole are hardly foreseeable. Furthermore, an additional explanation for the stronger fall in GDP in the high-uncertainty regime may be found in that government spending is cut in periods of high uncertainty. This possible explanation would weaken the role played by uncertainty, but notice that, while it may be valid for GDP, it cannot explain the observed pattern of consumption, so that, overall, the narrative presented above remains well-grounded. As to firms, instead, we already pointed out before that the reaction of macro uncertainty itself to the tax increase might contribute to seeing investments rising on impact in the high-uncertainty regime (macro uncertainty falls in this regime).

6 Robustness checks

6.1 Adding Monetary Policy

An interesting aspect of the analysis would be to understand whether previous evidence changes if we add a monetary policy variable to our specification, taking into account the endogenous response of the monetary policy authority to tax shocks. This allows us to understand whether excluding a potentially relevant variable may bias the results and, in addition, to have a picture of the possible interplay of the two main economic policy instruments. Specifically, we add the Federal Funds Rate as an endogenous variable in our specification, positioned penultimate just before the uncertainty variable.

and, given that our analysis stops at 2007Q4, the overlapping period is too short even for a preliminary analysis. Instead, we focus on the series reporting the Net Change in Consumer Credit Outstanding, also produced by the FED. In this case we find that the correlation with macro uncertainty is near zero and the mean of the variable over the two regimes does not change much. This makes the interpretation of evidence regarding tax increases in high uncertainty in light of more credit constrained households a bit weaker, but alternative mechanisms may be in place as well.

6.1.1 TVAR with sign nonlinearity

Contractionary shock Evidence coming from our main specification changes significantly when we take into account the reaction of monetary policy (Figure 5). While the impulse responses for the low-uncertainty regime remain fully comparable to those obtained from the more parsimonious specification, those relative to the high-uncertainty regime are very different. Point estimates are in general around zero, with levels similar to those of the low-uncertainty regime, and confidence bands are quite wide. We argue that the difference with previous evidence is attributable to the heterogeneous response of the Federal Funds Rate in the two regimes. While when ex-ante macroeconomic uncertainty is low the stance of monetary policy remains neutral after a contractionary tax shock, monetary policy becomes strongly accommodative in the high-uncertainty regime, perhaps in order to counteract the fall in inflation observed also in the previous specification. The major effect of the monetary stimulus is to counteract the contractionary shock coming from the fiscal side, so that the response of GDP, above all, turns neutral from the otherwise strongly negative behavior. This, rather than undermining previous evidence, adds an interesting piece of information to the analysis. Our interpretation is that, in general, uncertainty about future economic developments worsens the reaction of GDP and consumption to a tax increase, but an accommodative monetary police plays a relevant and effective role in mitigating this negative effect. Notice in particular that the saving rate, previously higher in the high-uncertainty regime, now falls in both regimes, so that, consistently, consumption reacts less negatively also when ex-ante macro uncertainty is high.

Expansionary shock Contrary to the case of contractionary shocks, evidence presented in our main analysis does not change when the richer specification is used (Figure 6). The distinction between the impulse responses of the two regimes remains statistically significant and monetary policy is observed to be neutral in both regimes. As in the case of a contractionary shock, the confidence bands of the impulse responses of the high-uncertainty regime increase and this is responsible for the fact that the different reaction of uncertainty in the two regimes becomes less evident than in the more parsimonious specification.

6.1.2 Interpretation and Comment

Looking at the literature, the fact that monetary policy, at least in the case of fiscal consolidations, plays a relevant role is not surprising. Some papers specifically investigate the interaction between fiscal and monetary policy and they try to understand the most common and appropriate reaction of the monetary authority to fiscal shocks.[7] Instead, other papers about fiscal policy impact find it appropriate to include in their specification a monetary policy variable [8]

Mertens and Ravn (2013) observe, in a linear framework, that output responses to personal income and corporate income tax cuts are not changed by the inclusion of a monetary policy variable. On the contrary, Mountford and Uhlig (2009) observe that, in response to an increase in government revenues, interest rates rise and reserves fall.

Our empirical results in general support the view that, when monetary policy is changed in a significant way in response to a tax shock, the move counterbalances the fiscal stimulus. This is true when looking at the impulse responses in the case of a contractionary tax shock in the high-uncertainty regime: monetary stance is strongly accommodative in this case. On the contrary, when future macroeconomic developments are characterized by low uncertainty levels, the reaction of reference interest rates to tax shocks is gener-

[7]Melitz (1997) finds that monetary and fiscal policy tend to move in opposite directions, behaving therefore as substitutes. Buti, Roeger, and in't Veld (2001) suggest that the type of interdependence between fiscal and monetary policy might be dependent on the type of shock hitting the economy. Muscatelli, Tirelli, and Trecroci (2004) show substantial complementarity in the response of monetary policy to fiscal measures.

[8]Batini, Callegari, and Melina (2012) show that, also in the case of the United States, real interest rates rise instead of falling following a fiscal consolidation. Baum, Poplawski-Ribeiro, and Weber (2012) find that tax-based fiscal consolidation have a worse impact on output than expenditure-based consolidation because, among other, monetary policy is more accommodating in the latter case. Woodford (2011) and Christiano, Eichenbaum, and Rebelo (2011) argue that fiscal multipliers are larger than one in periods when the zero lower bound is binding and monetary policy is neutralized, which is confirmed by Hall (2009) in his review.

ally muted. So, the bottom line might be that the relation between monetary and fiscal policy is particularly relevant when uncertainty about the future state of the economy is high and that this relation implies that the two policy instruments go in opposite directions.

6.2 Removing the effect of business cycle

In order to further examine the possible influence of the business cycle situation on our findings, in this subsection we replicate our TVAR model with sign nonlinearity using as a threshold variable the residual of a regression of the macroeconomic uncertainty measure on the business cycle proxy by Auerbach and Gorodnichenko (2012). This should capture the share of macro uncertainty unrelated to current economic conditions.

Contractionary tax shock The robustness of our results is strong when considering a contractionary shock. The reaction of GDP and consumption is significantly negative when ex-ante macroeconomic uncertainty is high, while it is neutral in the low-uncertainty regime (Figure 7). As to investments, we observe them rising slightly on impact even though uncertainty increase in high-uncertainty, which seems to weaken the argument proposed in subsection 4.4.1. There is an evident difference across regimes also in the case of the saving rate, with the response being positive in the high-uncertainty regime and negative in the low one, consistently with agents doing consumption smoothing in more tranquil times. Government spending falls significantly in the high-uncertainty regime and more mildly in the low one; macroeconomic uncertainty increases further in the high regime and is stable in the low one. Again, if we add the monetary policy variable in the specification, consistently with previous evidence, the responses in the two regimes become more similar as FFR fall by more in the high-uncertainty regime, counteracting the worse reaction of the economy (figures reported in the Appendix to this paper).

Expansionary tax shock Even though the degree of overlapping between IRFs of different uncertainty regimes is higher than in our main analysis, Figure 8 shows that, also when removing the share of macroeconomic uncertainty correlated with the business cycle, we can observed that the response of GDP to a 1% tax cut is more positive during less uncertain periods than in more uncertain ones, with the effect mainly driven by investments, for which the distinction across regimes is evident. Instead, for consumption the nonlinearity over uncertainty levels is negligible. The fall in government revenues, while mild in the low-uncertainty regime, is stronger in the high one. On the contrary, government spending tends to grow more in the low-uncertainty regime, but only over the medium run. Uncertainty responds mildly to the shock when it is ex-ante high, but falls significantly in the low-uncertainty regime. As a final note, if we include the monetary policy variable in the specification, the difference across regimes becomes more marked for GDP and visible, in the expected direction, also for consumption (figures reported in the Appendix to this paper).

6.3 The role of the uncertainty measure

As previously pointed out, in the Appendix we perform robustness checks with other uncertainty variables, specifically macroeconomic, policy, and financial uncertainty variables. We consider two additional measures of macro uncertainty. The first is by Carriero, Clark and Marcellino (2016) and the second is by Rossi and Sekhposyan (2015). Also, we check the Economic Policy Uncertainty Index by Baker and Bloom (2016). and, as to financial uncertainty, we focus on that obtained by Ludvigson, Ma and Ng (2016), on the one by Carriero, Clark and Marcellino (2016), and on the VXO, a measure of financial market volatility based on options. For all these variables, we compute information criteria (BIC and AIC), using, for sake of comparability, a specification including neither the uncertainty measure nor the FFR as an endogenous variable. As shown in Table 1, we observe that the model fit between macro and financial uncertainty variables is comparable. Also, among macro uncertainty measures, the one by Rossi and Sekhposyan is the best, while the VXO should be preferred, in terms of information criteria, among financial measures. Below we comment on those two variables, while a full comment for all specifications can be found in the Appendix. Finally we note that the uncertainty measures give lower AIC and BIC than the output-based measure by Auerbach and Gorodnichenko (2012).

Switching variable	AIC	BIC
Macro Unc. (JLN)	3.16E+03	7.51E+03
Macro Unc. (CCM)	3.16E+03	7.51E+03
Macro Unc. (RS)	2.77E+03	6.34E+03
Macro Unc. Residuals	3.14E+03	7.48E+03
EPU Index (Baker at al.)	3.27E+03	8.91E+03
Financial Unc. (LMN)	3.16E+03	7.50E+03
Financial Unc. (CCM)	3.12E+03	7.46E+03
VXO	3.04E+03	7.20E+03
AG business cycle proxy	3.27E+03	8.96E+03

Table 1: Goodness of fit of different models using alternative threshold variables for the definition of regimes. AIC and BIC are computed for the specification without endogenous uncertainty and without FFR

6.3.1 Results with Rossi and Sekhposyan (2015) measure

Rossi and Sekhposyan (2015) also focus, as JLN, on the concept of uncertainty as reduced predictability of the evolution of the economy rather than on the simple increased volatility of macroeconomic variables. In particular, they consider the forecasts, for the main macroeconomic aggregates, provided by the Survey of Professional Forecasters over different time horizons and they define their uncertainty measure as the percentile of the historical distribution of forecast errors that is associated with the observed forecast error. One of the advantages of their approach is that they take into account both ex ante and ex post uncertainty about macroeconomic aggregates.

In the case of a contractionary tax shock, we see (Figure 9) that evidence is consistent with the one from the main specification. GDP and consumption are neutral in the low-uncertainty regime and the saving rate decreases slightly. Instead, in the high-uncertainty regime, the responses are negative and quite evidently distinct from the ones of the other regime. In this case, the drop in consumption and GDP might be linked to the increase in the saving rate in periods of high uncertainty. Focusing on expansionary shocks, we observe in Figure 10 that the overall pattern is similar to usual evidence, but confidence bands for the low-uncertainty regime are somewhat larger. IRFs referred to the specification with FFR and a more comprehensive comment are available in the Appendix.

6.3.2 Results with VXO

The VXO is built by the CBOE and it is meant to track expectations for short-term (30 days) volatility in the US stock market. This is done by measuring the implied volatility on S&P 100 options and therefore can be considered a measure of uncertainty of investors about future market developments. In the case of both contractionary and expansionary tax shocks, we find evidence which is consistent with the main analysis (Figures in the Appendix). We argue that this is because the VXO also captures, to a certain extent, uncertainty related to the macro realm, and therefore it is, among the financial uncertainty measures considered, the closest to the object of our main analysis. We observe that, as the concept of uncertainty considered becomes more dissimilar from our preferred one, also empirical results become different.

6.4 Composition of the fiscal changes

The interpretation of the results could be affected by the fact that shocks to taxes and government spending might occur in a coordinated fashion or by the different type of taxes considered[9]. In practice, this would mean that, when we look at impulse responses to a 1% tax cut or increase, we might be seeing also the effect of related adjustments to government spending. This would be a relevant piece of information to take into account.

Therefore, we check the extent of the correlation between the narrative shocks to taxes identified by Romer and Romer and the narrative shocks to government spending identified by Ramey (2011). The contemporaneous cor-

[9] The literature has shown that, starting from the Romer and Romer (2010) narrative shocks, one can further distinguish, thanks to the narrative approach, between anticipated and unanticipated tax shocks, where the former are implemented with some lag with respect to the announcement (Mertens and Ravn (2012)). It is also possible to disentangle tax shocks referring to personal or corporate income (Mertens and Ravn (2013)). Unfortunately, such further decompositions are not feasible in our context because, when we split the tax shocks according to their sign and to the uncertainty phases, we are sometimes left with very few observed shocks, which in addition are not evenly distributed according to the uncertainty phases. As a consequence, the response functions, which are available upon request, are not reliable from an econometric point of view and are hardly interpretable economically.

relation between the two series is -0.007 and also correlation between tax shocks and leads and lags of government spending shocks is around 0. However, if we check Granger causality between the two series, we find that while the test rejects the hypothesis that shocks to government revenues Granger cause G shocks, the opposite is not true, i.e. it seems that G shocks anticipate T shocks. Hence, we investigate the robustness of our results by using, as exogenous tax shocks series, the residuals of a regression of Romer and Romer narrative shocks on Ramey shocks to G and lags of those. Results (reported in the Appendix) are broadly consistent with those form the main analysis. Therefore, even though we see in IRFs that government spending reacts to narrative tax shocks, results are robust also if we remove from the Romer and Romer shocks the part which is correlated with G adjustments.

6.5 Regime-specific variance-covariance matrices

One issue worth analyzing regards the way in which we treat the error variance: our framework does not allow for different values of it in the two identified regimes. However, in the high-uncertainty regime, the variance-covariance matrix of model's innovations is larger than the one related to the low-uncertainty regime. Even though the concerns about not taking into account this feature in our framework are mitigated by our identification strategy, which does not require the Cholesky decomposition of the variance-covariance matrix in order to identify structural shocks, we conduct a robustness check on the results by adapting the 3SLS estimator presented in Judge et al. (1980, Chapter 15 pp. 599-601) in order to implement a FGLS estimator with regime-specific variance covariance matrices. Judge et al. (1980) presents, under conditions provided by Dhrymes (1974, pp. 183-184), a consistent FGLS estimator for the parameters of a simultaneous equations model, using the variance-covariance matrix of 2SLS model residuals. In our context, we use OLS residuals because we are interested only in reduced form parameters and we use regime-specific variance-covariance matrices, modifying Judge et al.'s estimator as described in a technical note reported in the Appendix.

As to the empirical results, we implement the described procedure to our main specification with both sign and uncertainty-driven nonlinearity. Figures reported in the Appendix show that the impulse responses derived from the model estimated with this iterated FGLS estimator are virtually identical to those obtained with the traditional OLS estimator. Output and consumption respond more negatively to a tax increase when ex-ante uncertainty is high, while they remain neutral in the low-uncertainty regime. Instead, when taxes are cut, the economy responds more positively in periods of low macroeconomic uncertainty and neutrally in high-uncertainty.

6.6 Generalized IRFs

The responses we have reported so far do not allow for the possibility that the tax shocks also induce a change in regime. This might be a minor issue, because we are interested in the reaction of the economy to tax shocks depending on the uncertainty condition prevailing before the shock and the model is indeed linear within-regimes. However, it is per se interesting to understand whether the tax shocks we analyze are capable of inducing shifts in uncertainty regimes and, also, whether the strategies we adopt to minimize the feedback effect of macro variables on regimes' definition are effective.

Therefore, we compute generalized impulse response functions (GIRF), as suggested by Koop, Pesaran and Potter (1996). In the implementation, we follow Fagiolo, Ferraresi and Roventini (2014) (details in Appendix) and we find that our results are broadly consistent with the ones presented in the main analysis. Figures for the specification without and with FFR are reported in the Appendix. The most important difference with the main analysis is that, in response to a tax increase, in the specification with the FFR, we observe a stronger monetary accommodation in the high-uncertainty regime and therefore the response of GDP and consumption is more positive. Finally, the most interesting point is that, since evidence from linear IRFs and from GIRF is basically the same, the implicit assumption of no regime-shifts is confirmed in the data, so that tax shocks induce changes in uncertainty levels not wide enough for regime shifting.

7 Concluding Remarks

In this work we document that tax shocks have a remarkably different impact on economic aggregates depending on the degree of macroeconomic uncertainty that agents face. In the case of expansive fiscal measures, it is anyway better for the policymaker to implement them when uncertainty about future developments in the economy is low. On the contrary, policy implications in the case of tax increases are less clear-cut, with monetary policy and the dynamic behavior of government playing a determinant role. Possibly, given the observed importance of monetary policy, it seems to be particularly important to coordinate fiscal measures with the monetary authority reaction, in order to soften the negative consequences of a tax increase during more uncertain times. Finally, we observe that, while tax shocks induce movements in uncertainty, these are not large enough to induce regime shifts.

Thanks to the empirical evidence we find, we also confirm that uncertainty is indeed an important driver of agents' behavior, giving further ground to theoretical results drawn by the large body of literature on uncertainty shocks. Possibly, this calls for further theoretical research about the way in which the nature of the policy measure and the situation of uncertainty interact and on the way this interaction contributes to the definition of agents' behavior.

References

[1] Aastveit K. A., Natvik G. J., Sola S., 2013, " Economic uncertainty and the effectiveness of monetary policy", Norges Bank Research, Working Paper 17

[2] Afonso A., Baxa J., Slavik M., 2011, " Fiscal Developments and Financial Stress: A Threshold VAR Analysis", ECB Working Paper Series, N. 1319

[3] Alesina A., Azzalini G., Favero C., Giavazzi F., Miano A., 2016, "Is it the "How" or the "When" that Matters in Fiscal Adjustments?", NBER Working Paper N. 22863, November

[4] Alessandri P., Mumtaz H., 2014, " Financial regimes and uncertainty shocks", BCAM Working Papers 1404, Birkbeck Centre for Applied Macroeconomics

[5] Arellano C., Bai Y., Kehoe P., 2016, "Financial Frictions and Fluctuations in Volatility", NBER Working Paper No. w22990

[6] Auerbach, A. J., Gorodnichenko Y., 2012, "Measuring the Output Response to Fiscal Policy", American Economic Journal: Economic Policy, 4(2): 1-27

[7] Auerbach, A. J., Gorodnichenko Y., 2017, "Fiscal Stimulus and Fiscal Sustainability", Working Paper, mimeo

[8] Bachmann R., Elstner S., Sims E. R., 2013, "Uncertainty and Economic Activity: Evidence from Business Survey Data", American Economic Journal: Macroeconomics, 5(2): 217-49

[9] Bachmann R., Moscarini G., 2011, "Business Cycles and Endogenous Uncertainty", Meeting Papers n.36, Society for Economic Dynamics

[10] Baker S. R., Bloom N., Davis S. J., 2016, "Measuring Economic Policy Uncertainty", The Quarterly Journal of Economics (2016) 131(4): 1593-1636

[11] Basu S., Bundick B., 2017, "Uncertainty Shocks in a Model of Effective Demand", Econometrica, Volume 85, Number 3, May 2017, Pages 937-958

[12] Bernanke B. S., 1983, "Irreversibility, Uncertainty, and Cyclical Investment", The Quarterly Journal of Economics, 98(1): 85-106

[13] Blanchard O., Perotti R., 2002, "An empirical characterization of the dynamic effects of changes in government spending and taxes on output", The Quarterly Journal of Economics, Oxford University Press, 117(4):1329-1368

[14] Bloom N., 2009, "The Impact of Uncertainty Shocks", Econometrica, Econometric Society, 77(3): 623-85

[15] Bloom N., 2014, "Fluctuations in Uncertainty", The Journal of Economic Perspectives, 28(2):153-176

[16] Bloom N., Floetotto M., Jaimovich N., Saporta-Eksten I., Terry S. J., 2012, "Really Uncertain Business Cycles", NBER Working Paper 18245

[17] Buti, M., Roeger W., in't Veld J., 2001, "Stabilising Output and Inflation: Policy Conflicts and Co-operation under a Stability Pact", Journal of Common Market Studies, Wiley Blackwell, 39(5): 801-828, December

[18] Caggiano G., Castelnuovo E., Nodari G., 2017, "Uncertainty and Monetary Policy in Good and Bad Times", Bank of Finland Discussion Paper No. 8/2017

[19] Callegari G., Cimadomo J., Ricco G., 2016, " Signals from the Government: Policy Disagreement and the Transmission of Fiscal Shocks", Journal of Monetary Economics, Elsevier, 82(C): 197-118

[20] Carriero A., Clark T. E., Marcellino M., 2016, "Measuring uncertainty and its impact on the economy", Review of Economics and Statistcs, forthcoming

[21] Casarin R., Foroni C., Marcellino M., Ravazzolo F., 2016, "Uncertainty Through the Lenses of A Mixed-Frequency Bayesian Panel Markov Switching Model", IGIER Working Papers, 2016/585

[22] Christiano L., Eichenbaum M., Rebelo S., 2011, "When Is the Government Spending Multiplier Large?", Journal of Political Economy, Vol. 119(1): 78-121

[23] De Vries P., Guajardo J., Leigh D., Pescatori A. (2011), "A New Action-based Dataset of Fiscal Consolidation", IMFWorking Paper No 11/128, International Monetary Fund

[24] Dhrymes P. J., 1974, "Econometrics", Springer-Verlag, New York

[25] Fama E. F., French K. R., 1992, "The Cross-Section of Expected Returns.", Journal of Finance 47 (2): 427–65.

[26] Favero C., Giavazzi F., 2012, "Measuring Tax Multipliers: The Narrative Method in Fiscal VARs.", American Economic Journal: Economic Policy 4 (2): 69-94

[27] Fernández-Villaverde J., Guerrón-Quintana P. A., Rubio-Ramirez J., Uribe M., 2011, "Risk Matters: The Real Effects of Volatility Shocks", American Economic Review 101(6): 2530-61

[28] Ferraresi T., Roventini A., Fagiolo G., 2014, "Fiscal Policies and Credit Regimes: A TVAR Approach", Journal of Applied Econometrics, Vol. 30 (7): 1047-1072

[29] Fotiou A., 2016, "Non-linearities and Fiscal Policy", mimeo

[30] Gilchrist S., Sim J. W., Zakrajsek E., 2014, "Uncertainty, Financial Frictions, and Investment Dynamics", NBER Working Papers 20038, National Bureau of Economic Research, Inc.

[31] Jones P. M., Enders W., 2016, " The Asymmetric Effects of Uncertainty on Macroeconomic Activity", Macroeconomic Dynamics, 20(5), pp. 1219–1246

[32] Judge G. G., Griffiths W. E., Hill R. C., Lutkepohl H, Tsoung-Chao Lee, 1980, "The Theory and Practice of Econometrics", John Wiley & Sons Inc.

[33] Jurado K., Ludvigson S. C., Ng S., 2015, "Measuring Uncertainty", The American Economic Review, 105(3): 1177-1216

[34] Koop G., Pesaran M.H., Potter S.M., 1996, "Impulse Response Analysis in Nonlinear Multivariate Models", Journal of Econometrics, vol.74(1): 119-147

[35] Leduc S., Liu Z., 2016, "Uncertainty Shocks are Aggregate Demand Shocks", Journal of Monetary Economics, Elsevier, vol. 82(C), pages 20-35

[36] Ludvigson S. C., Ma S., Ng S., 2016, " Uncertainty and Business Cycles: Exogenous Impulse or Endogenous Response?", NBER Working Papers 21803, National Bureau of Economic Research, Inc.

[37] McDonald R., Siegel D., 1986, "The Value of Waiting to Invest", The Quarterly Journal of Economics, 101(4): 707-727

[38] Mélitz J., 1997, ”Some Cross-Country Evidence about Debt, Deficits, and the Behaviour of Monetary and Fiscal Authorities”, CEPR Discussion Paper No.1653

[39] Mertens K., Ravn M. O., 2010, "Measuring the Impact of Fiscal Policy in the Face of Anticipation: A Structural VAR Approach." Economic Journal, Royal Economic Society, 120 (544): 393-413, 05

[40] Mertens K., Ravn M. O., 2012, "Empirical Evidence on the Aggregate Effects of Anticipated and Unanticipated US Tax Policy Shocks", American Economic Journal: Economic Policy, vol. 4(2), pages 145-181, May

[41] Mertens K., Ravn M. O., 2013, "The Dynamic Effects of Personal and Corporate Income Tax Changes in the United States", American Economic Review, American Economic Association, vol. 103(4), pages 1212-1247, June

[42] Mountford A., Uhlig H., 2009, "What Are the Effects of Fiscal Policy Shocks?" Journal of Applied Econometrics 24 (6): 960-92

[43] Muscatelli V. A., Tirelli P., Trecroci C., 2004, " Fiscal and monetary policy interactions: Empirical evidence and optimal policy using a structural New-Keynesian model ", Journal of Macroeconomics, 2004, vol. 26, issue 2, pages 257-280

[44] Olivei G., Tenreyro S., 2010, "Wage-setting patterns and monetary policy: International evidence", Journal of Monetary Economics 57 (7): 785–802

[45] Pástor L., Veronesi P., 2006, "Was There A Nasdaq Bubble in the Late 1990s?", Journal of Financial Economics, 81(1): 61-100

[46] Pástor L., Veronesi P., 2013, "Political uncertainty and risk premia", Journal of Financial Economics 110(3): 520-545

[47] Pellegrino G., 2015, " Uncertainty and Monetary Policy in the US: A Journey into Non-Linear Territory", "Marco Fanno" Working Papers 0184, Dipartimento di Scienze Economiche "Marco Fanno"

[48] Perotti R.,1999, "Fiscal Policy in Good Times and Bad", The Quarterly Journal of Economics, 114(4): 1399-1436

[49] Ramey V. A., 2011, "Identifying Government Spending Shocks: It's All in the Timing" Quarterly Journal of Economics 126 (1): 1-50

[50] Roeger W., in t' Veld J., 2009, "Fiscal Policy with Credit Constrained Household", European Economy - Economic Papers 2008 - 2015 357, Directorate General Economic and Financial Affairs (DG ECFIN), European Commission

[51] Romer C. D., Romer D. H., 2010, "The Macroeconomic Effects of Tax Changes: Estimates Based on a New Measure of Fiscal Shocks", American Economic Review 100(3): 763-801

[52] Rossi B., Sekhposyan T., 2015, " Macroeconomic Uncertainty Indices Based on Nowcast and Forecast Error Distributions", American Economic Review 105(5): 650-655

[53] Rossi B., Sekhposyan T., Soupre M., 2016, " Understanding the Sources of Macroeconomic Uncertainty", CEPR Discussion Paper No. DP11415

[54] Segal G., Shaliastovich I., Yaron A., 2015, "Good and bad uncertainty: Macroeconomic and financial market implications", Journal of Financial Economics, 117(2): 369- 397

[55] Sims C. A., 1980, "Macroeconomics and Reality", Econometrica, 48(1): 1-48

[56] Stock J. H., Watson M. W., 2012, "Disentangling the Channels of the 2007-2009 Recession", Brookings Papers on Economic Activity. 2012;Spring 2012 :81-135

[57] Van Nieuwerburgh S., Veldkamp L., 2006, "Learning Asymmetries in Real Business Cycles", Journal of Monetary Economics 53(4): 753-772

[58] Van Robays I., 2016, " Macroeconomic Uncertainty and Oil Price Volatlity", Oxford Bulletin of Economics and Statistics, Vol. 78, Issue 5, pp. 671-693, 2016

[59] Woodford, M., 2011, " Simple Analytics of the Government Expenditure Multiplier", American Economic Journal: Macroeconomics 3(1): 1-35

8 Figures

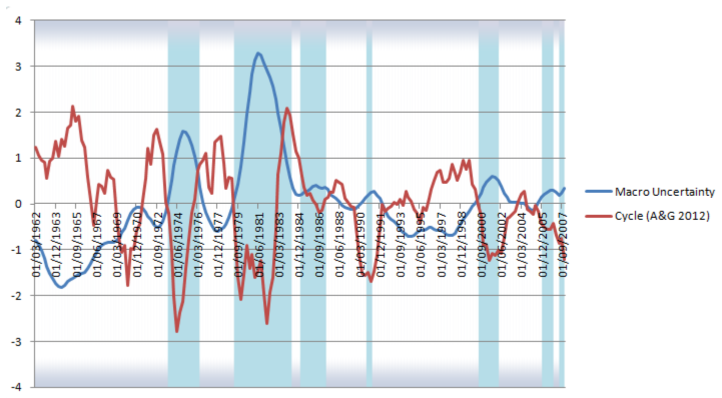

Figure 1: Correlation between macroeconomic uncertainty and Auerbach and Gorodnichenko business cycle proxy. Light blue bars refer to periods that are defined as high-uncertainty regime

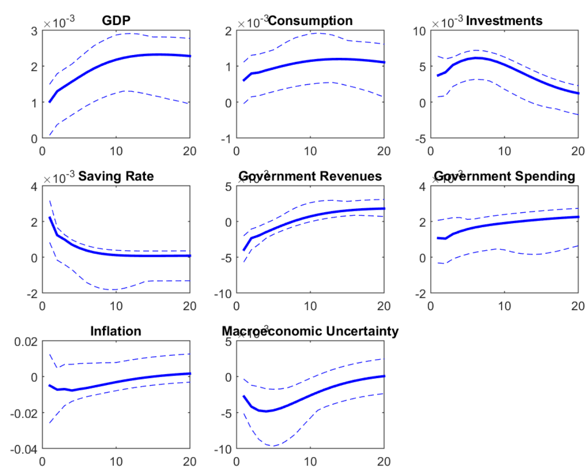

Figure 2: Linear VAR impulse responses, macroeconomic uncertainty model. Dashed lines are 68% confidence bands. IRFs for GDP, C, I and saving rate refer to different specifications. All other plots refer to specification with GDP

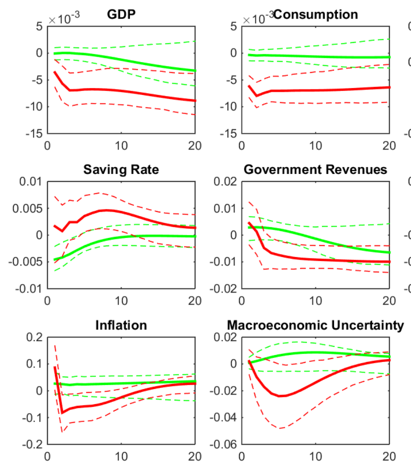

Figure 3: TVAR with sign nonlinearity, contractionary shock, macroeconomic uncertainty model. Green lines refer to low-uncertainty regime, red lines to high-uncertainty one. Dashed lines are 68% confidence bands. IRFs for GDP, C, I and saving rate refer to different specifications. All other plots refer to specification with GDP

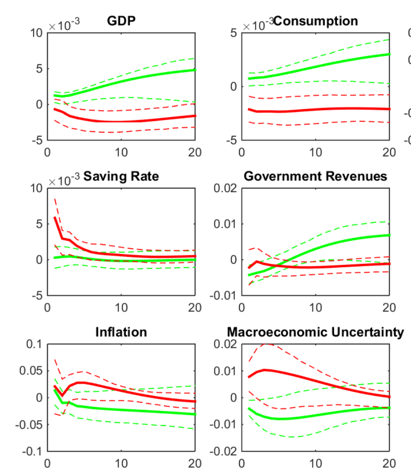

Figure 4: TVAR with sign nonlinearity, expansionary shock, macroeconomic uncertainty model. Green lines refer to low-uncertainty regime, red lines to high-uncertainty one. Dashed lines are 68% confidence bands. IRFs for GDP, C, I and saving rate refer to different specifications. All other plots refer to specification with GDP

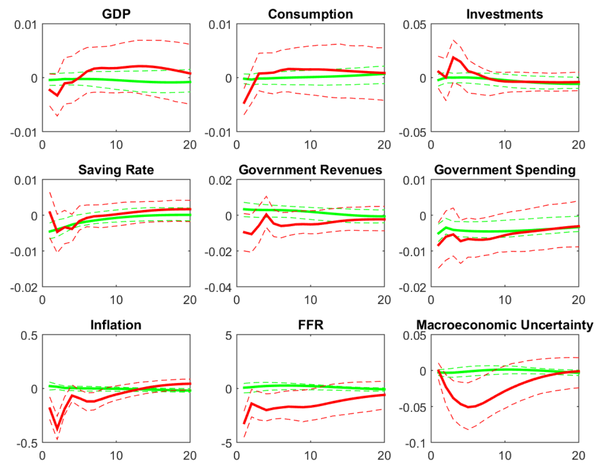

Figure 5: TVAR with sign nonlinearity, contractionary shock, macroeconomic uncertainty model. Specification with FFR. Green lines refer to low-uncertainty regime, red lines to high-uncertainty one. Dashed lines are 68% confidence bands. IRFs for GDP, C, I and saving rate refer to different specifications. All other plots refer to specification with GDP

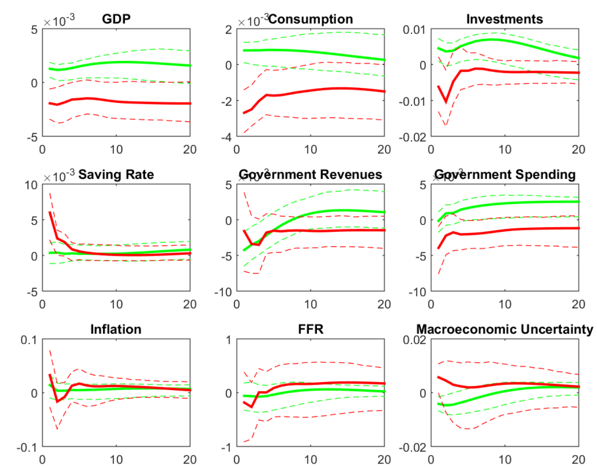

Figure 6: TVAR with sign nonlinearity, expansionary shock, macroeconomic uncertainty model. Specification with FFR. Green lines refer to low-uncertainty regime, red lines to high-uncertainty one. Dashed lines are 68% confidence bands. IRFs for GDP, C, I and saving rate refer to different specifications. All other plots refer to specification with GDP

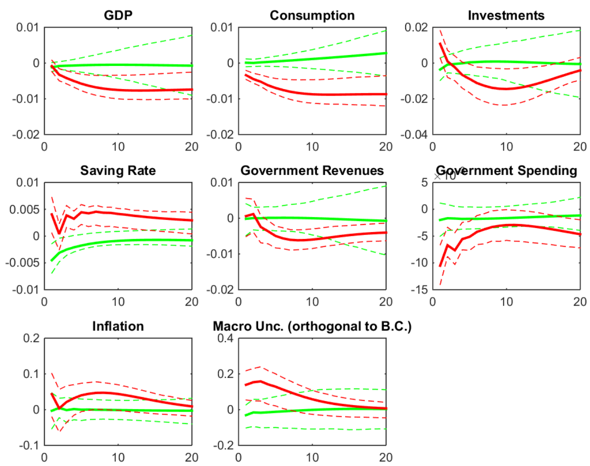

Figure 7: TVAR with sign nonlinearity, model with macroeconomic uncertainty residuals. Contractionary shock. Green lines refer to low-uncertainty regime, red lines to high-uncertainty one. Dashed lines are 68% confidence bands. IRFs for GDP, C, I and saving rate refer to different specifications. All other plots refer to specification with GDP

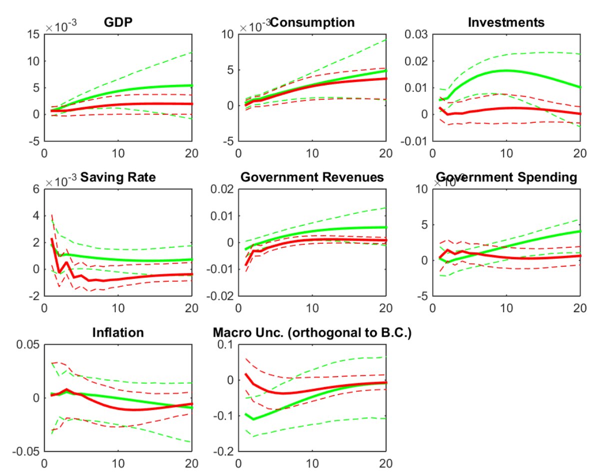

Figure 8: TVAR with sign nonlinearity, model with macroeconomic uncertainty residuals. Expansionary shock. Green lines refer to low-uncertainty regime, red lines to high-uncertainty one. Dashed lines are 68% confidence bands. IRFs for GDP, C, I and saving rate refer to different specifications. All other plots refer to specification with GDP

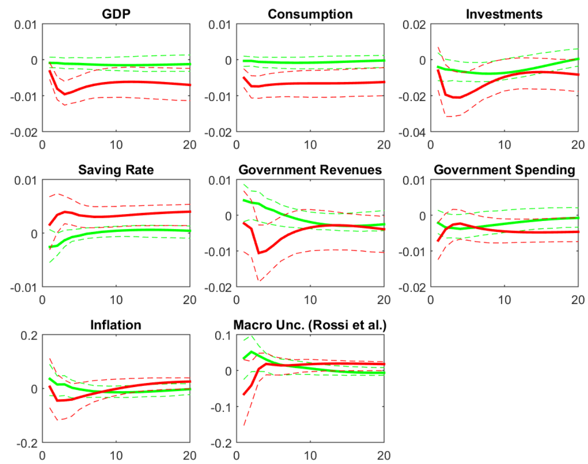

Figure 9: TVAR with sign nonlinearity, Rossi et al. macro uncertainty model. Contractionary shock. Specification without FFR and with endogenous uncertainty. Green lines refer to low-uncertainty regime, red lines to high-uncertainty one. Dashed lines are 68% confidence bands. IRFs for GDP, C, I and saving rate refer to different specifications. All other plots refer to specification with GDP

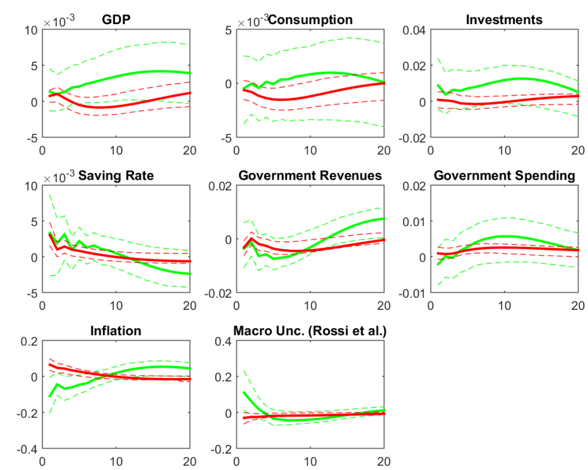

Figure 10: TVAR with sign nonlinearity, Rossi et al. macro uncertainty model. Expansionary shock. Specification without FFR and with endogenous uncertainty. Green lines refer to low-uncertainty regime, red lines to high-uncertainty one. Dashed lines are 68% confidence bands. IRFs for GDP, C, I and saving rate refer to different specifications. All other plots refer to specification with GDP

Tax shocks with high and low uncertainty

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September 2017

Online Appendix

Contents

1 VAR with sign nonlinearity

Hussain and Malik (2014) study the effect of tax shocks in a nonlinear framework, where nonlinearity is introduced with respect to the sign of the shock. They use the Romer and Romer (2010) narrative tax shocks and employ the same narrative identification method, so that they also use a small scale VAR (2 variables at most). Here, we try to answer the same question as Hussain and Malik (2014), integrating their empirical strategy for identifying sign nonlinearities in the Favero and Giavazzi (2012) identification scheme. In Figures 1, 2 and 3, it can be seen that the reaction of GDP does not display relevant nonlinearity in the sign of the shock, while evidence is more favorable to sign nonlinearity in the case of consumption and investments. For the former variable, the negative reaction to a contractionary shock appears to be stronger than the positive one after an expansionary shock. As to investments, instead, the maximum absolute value of the response is analogous, but, while in the case of an expansionary shock this level is reached few quarters after the shock and then the response reverts to pre-shock levels, in the presence of a tax increase the adjustment is gradual. Saving rate does not show considerable nonlinearity in sign. On the contrary, tax revenues fall by more, in absolute terms, after a tax cut compared to the increase after a fiscal contraction and government spending falls significantly during episodes of tax increases - consistently, again, with coordinated episodes of fiscal tightening - but are unchanged when taxes are reduced.

2 Threshold VAR

Impulse responses Evidence from the TVAR model without sign nonlinearity is a bit mixed and it should be considered preliminary in relation to the fully nonlinear specification, which considers the possibly different effect of expansionary and contractionary shocks. We observe in Figure 4 that, after a tax cut, the response of GDP is positive from a statistical point of view (68% confidence level) in the low-uncertainty regime, while it is statistically indistinguishable from zero in the high-uncertainty one. At this stage, however, the observed difference between the two regimes is limited, mainly due to the quite relevant width of the confidence bands for the high-uncertainty-regime impulse response. Also in view of the evidence from the model with sign nonlinearity, we argue that one of the reasons might be that not distinguishing the direction of the shock may create noise and inflate the confidence bands of the impulse responses. A similar reasoning holds for consumption and investments. Saving rates grow in both regimes, consistently with the evidence from the linear model, signaling that part of the tax cut is saved rather than consumed. Government revenues fall by more in the low-uncertainty regime, while, on the contrary, government spending is more expansionary in the high-uncertainty regime and neutral in the low one. Similarly, inflation grows a bit in the first quarters after the shock when ex-ante macroeconomic uncertainty is high, while it seems to be unaffected in low uncertainty situations. As to the reaction of macroeconomic uncertainty, it grows on impact in the high-uncertainty regime – and then it reverts to initial levels – and it decreases only slightly in the low regime.

Tests When comparing IRFs from the two different uncertainty regimes, in the specification with GDP, the first test, based on the absolute maximum distance of IRFs, finds a p-value of 0.53, while the second one, considering the cumulative distance, delivers a lower p-value of 0.39. These values are above commonly-used statistical significance levels, but, again, this might be induced by the fact that, in this specification, we fail to take into account sign nonlinearity.

3 Additional Robustness Checks

3.1 Alternative specification without uncertainty

In this robustness check, we drop the uncertainty variable from the vector of endogenous variables and we keep it only as external threshold variable. In the TVAR model with sign nonlinearity, the robustness of the results is strong. In the case of a 1% tax increase (Figure 6), the nonlinearity across uncertainty regimes is even more marked than in the favored specification and the magnitude of the negative impact in the high-uncertainty regime is stronger. Evidence is also fully robust when analyzing tax cuts (Figure 7). The only difference, in this case, is that the distance between impulse responses relative to different regimes is a bit narrower than in the main specification.

3.2 Alternative macroeconomic uncertainty measures

We check whether replicating the analysis with alternative measures of macroeconomic uncertainty delivers results that are consistent with our previous ones. In particular, we focus on a measure of macro uncertainty built by Carriero, Clark and Marcellino (2016) and on another by Rossi and Sekhposyan (2015). An explanation of how these measures are built is detailed below.

3.2.1 Macroeconomic Uncertainty by Carriero, Clark and Marcellino (2016)

Carriero, Clark and Marcellino (2016) model a set of macroeconomic and financial variables of interest with an heteroskedastic VAR, in which they use a large cross section of variables and, in addition, they assume that volatilities have a factor structure with a common and an idiosyncratic component. Then, the chosen measure of macroeconomic uncertainty is defined as the common component referred to the macroeconomic variables in the dataset, with another measure of financial uncertainty being similarly defined with reference to financial variables. With respect to Jurado, Ludvigson, and Ng (2016) (henceforth, JLN) measure of macroeconomic uncertainty, the one by Carriero, Clark and Marcellino (2016), apart from using a smaller set of macroeconomic variables, has two specific features missing in JLN: 1) the specification of the factor model is such that the uncertainty measure depends on the past values of the variables to which uncertainty refers, so that it takes into account business cycle fluctuations, and 2) macroeconomic uncertainty influences financial uncertainty and vice-versa and the two measures are allowed to be cross-correlated in the model. The advantage of the methodology outlined in Carriero, Clark and Marcellino (2016) is that it allows to build the uncertainty measures and to estimate their effects on real variables in a single step, whereas JLN do so in two different steps. In particular, they find that both macro and financial uncertainty shocks lead to a decline in economic activity, with the effect of macroeconomic uncertainty shocks being more pronounced, especially on some variables. On a technical side, as in our main analysis, we consider the 6-quarter moving average of this uncertainty variable, in order to have a smoother definition of regimes.

Correlation with the cycle and distribution of shocks Concerning the usual preliminary checks on the features of the chosen uncertainty switching variable, we find that the correlation with the Auerbach and Gorodnichenko (2012) business cycle proxy is negative and not negligible (-0.47), but significantly lower than the one observed for the JLN macroeconomic uncertainty measure used in the main analysis. Overall, the average percentile of the time series distribution of the Carriero, Clark, and Marcellino (2016) macro uncertainty measure in which a tax shock of either sign occurs is the 52nd, while contractionary shocks take place on average when uncertainty is in its 48th percentile and expansionary ones in the 55th.

TVAR In the specification without the monetary policy variable (Figure 8) there seems to be a remarkable difference in the response of GDP in the two regimes, while consumption seems to react more strongly in periods of high uncertainty. Instead, when we include the FFR (Figure 9), the response of GDP is slightly more reactive and positive in the low-uncertainty regime, even though confidence bands are quite wide. As to other variables, there is significant overlapping between confidence bands relative to the two regimes, but overall results are quite in line with the evidence collected in our main analysis

TVAR with sign nonlinearity

Contractionary shock Once more, when we focus on the model taking into account possible nonlinearities in the direction of the tax measure, evidence is more compelling and consistent with our main specification. In the low-uncertainty regime, the response of GDP, consumption and investments to a tax increase (Figure 10) is virtually null, while it is evidently negative when macroeconomic uncertainty is high. Evidence is also very consistent once we include the FFR in the specification (Figure 11), with FFR declining quite strongly on impact. Confidence bands for the high-uncertainty regime become very wide and also the shape of the responses changes, so that the nonlinearity across regimes can be hardly evaluated.

Expansionary shock In presence of an expansionary tax shock, in the specification neglecting monetary policy reaction (Figure 12), we see a positive reaction of the main aggregates when ex ante uncertainty is low, but the response is null or even slightly negative in the high-uncertainty regime. When adding FFR to the specification (Figure 13), confidence bands for the high-uncertainty regime become again wider, so that, for example, difference across regimes becomes less compelling for GDP. On the contrary, consumption still reacts more positively when uncertainty is low.

3.2.2 Macroeconomic Uncertainty by Rossi and Sekhposyan (2015)

An alternative macroeconomic uncertainty measure to test is the one proposed by Rossi and Sekhposyan (2015). They also focus, as JLN, on the concept of uncertainty as reduced predictability of the evolution of the economy rather than on the simple increased volatility of macroeconomic variables. In particular, they consider the forecasts, for the main macroeconomic aggregates, provided by the Survey of Professional Forecasters over different time horizons and they define their uncertainty measure as the percentile of the historical distribution of forecast errors that is associated with the observed forecast error. One of the advantages of their approach is that they take into account both ex ante and ex post uncertainty about macroeconomic aggregates. On a technical side, as in our main analysis, we consider the 6-quarter moving average of this uncertainty variable, in order to have a smoother definition of regimes.

Correlation with the cycle and distribution of shocks The correlation of this macroeconomic uncertainty series with the business cycle proxy by Auerbach and Gorodnicheko (2012) is virtually zero, which is quite positive if one is concerned about results being driven by the prevailing situation of the economy rather than by the macroeconomic uncertainty level. The picture is slightly different when we look at the distribution of Romer and Romer (2010) shocks over the uncertainty distribution. Shocks of either sign occur on average in the 51st percentile, which is quite balanced, but, while contractionary tax shocks occur on average in the 57th, when uncertainty is on average higher, expansionary ones take place around the 43rd, when uncertainty is lower.

TVAR TVAR evidence is quite consistent with the one from the main analysis. While in the specification without FFR (Figure 14) the difference across uncertainty regime is not remarkable, it becomes a bit clearer in the more complete specification (Figure 15). In general, the reaction of the aggregates is quite positive and responsive in the low-uncertainty regime, while it is in general more confused in the high-uncertainty regime.

TVAR with sign nonlinearity

Contractionary shock In the case of a contractionary tax shock, we see, in the specification without FFR (Figure 16), that GDP and consumption do not respond negatively in the low-uncertainty regime, perhaps also due to the slight decrease of the saving rate. Instead, in the high-uncertainty regime, the responses are negative and quite evidently distinct from the ones of the other regime. In this case, the drop in consumption and GDP might be linked to the increase in the saving rate in periods of high uncertainty. However, similarly to our main analysis, this evidence becomes confused when we add the FFR to the specification (Figure 17), with the confidence bands of the high-uncertainty regime being extremely wide.

Expansionary shock In the case of an expansionary shock, in the model without FFR, we observe in Figure 18 usual evidence regarding the main aggregates. The response of GDP, consumption, and investments is more positive when ex ante uncertainty is low, while it is negligible in the high-uncertainty situations. As a further note, the uncertainty variable seems to jump a bit initially in the low-uncertainty regime, while it is unchanged in the high-uncertainty one. Evidence suffers the inclusion of the FFR in the specification (Figure 19), with the distinction among the IRFs and the related confidence bands becoming less marked across uncertainty regimes but for the case of consumption, when the behavior of the aggregate remains fully consistent with the more parsimonious specification.

3.2.3 Comment on the results

The bottom line of these robustness checks in which we use alternative measures of macroeconomic uncertainty is that results are in general very consistent with our preferred model, especially with respect to the specification without FFR. Apart from one case, evidence is consistent also when we take into account the reaction of monetary policy into the VAR specification. Overall, this seems to give quite a strong support to our main findings that expansionary tax shocks are more effective in periods of ex ante low macroeconomic uncertainty, while tax increases are particularly harmful when macroeconomic uncertainty is high before the shock.

3.3 Specification with Economic Policy Uncertainty index

Before commenting on the results, we provide a description of this uncertainty variable. The index is built by making a month-by-month search on several newspapers (Wall Street Journal, New York Times, Washington Post, Chicago Tribune, LA Times, and Boston Globe up to 1985 and the previous ones along with USA Today, Miami Herald, Dallas Morning Tribune, and San Francisco Chronicle for the following period) for terms related to economic policy uncertainty. In particular, the Authors look for the term "uncertainty" or "uncertain", the terms "economic", "economy", "business", "commerce", "industry", and "industrial", as well as one or more of the following words: "congress", "legislation", "white house", "regulation", "federal reserve", "deficit", "tariff", or "war". Essentially, in order to be considered, the article must include terms in all three categories dealing with uncertainty, economy, and policy. Moreover, the Authors apply a normalization to the raw count of the articles by dividing the absolute value figure by the total number of articles pertaining to economy or business in the newspapers. The positive aspect of this variable is that values are available from the immediate post-war period, so that the full series of Romer and Romer shocks is used. On the contrary, in our main analysis with macroeconomic uncertainty, the series starts only in 1960Q3, so that the sample is shorter. On the contrary, the Economic Policy Uncertainty index has many drawbacks that might influence the results and that are partially accounted for in the following analysis. First, it refers to overall economic policy uncertainty, so that also monetary policy is included. As we want to study the effect of tax changes this might complicate the interpretation of the results, especially in the case when the monetary policy variable is excluded from the specification. Therefore, in the present case, the specification with FFR should be considered as the preferred one. Second, the variable shows a trending behavior for the first half of the sample and more, so that using a threshold approach might be problematic in that, in addition to different uncertainty levels, the results might be driven by the fact the regimes capture the different reaction of the economy over different periods of time. Since Favero and Giavazzi (2012) show that there is remarkable difference in the fiscal multiplier before and after the 1980's, this might become a really relevant issue. In order to take care of this issue, in addition to smoothing the series with a 6 quarters moving average as done for the macroeconomic uncertainty measure, we linearly detrend it.

Correlation with the cycle and distribution of shocks The EPU index shows limited correlation with the economic cycle. After having transformed the series in the way just described, the correlation with the 7 quarters moving average of GDP growth used in Auerbach and Gorodnichenko (2012) is a low -0.14. The negative sign confirms the fact that uncertainty tends to increase when economic conditions are worse, but the low value ensures that variability genuinely related to policy uncertainty prevails. As to the distribution of shocks over the different percentiles of economic policy uncertainty, the average percentile at which a shock of whatever sign occurs is the 55th, it is the 56th for tax increases, and the 54th for tax cuts. So, also in this case, shocks seem to be quite evenly distributed over uncertainty levels.

TVAR In the specification without FFR (Figure 20), nonlinearity across regimes is not very evident, with confidence bands of IRFs referring to the alternative uncertainty situations showing considerable overlapping. In the specification with FFR (Figure 21), instead, evidence is more in line with our main findings: despite nonlinearity being not extremely evident, GDP and consumption are more reactive in the low-uncertainty regime.

TVAR with sign nonlinearity

Contractionary shock In Figure 22 (specification without FFR) is shown that the reaction of GDP and consumption to a 1% GDP tax increase is neutral in the low-uncertainty regime, while it is statistically negative in the high-uncertainty one. As to investments, instead, the model does not show relevant nonlinearity across uncertainty regimes. Saving rate is unchanged in the high-uncertainty regime, while it decreases slightly in the low one, confirming that, when agents face lower levels of uncertainty, also with respect to future policy developments, they tend to smooth consumption over time by lowering the saving rate. Tax revenues increase in the low-uncertainty regime and are unchanged in the high-one, likely due to the different behavior of the level of economic activity in the two regimes. Finally, EPU falls in both regimes, but the fall is more marked in periods of high ex-ante uncertainty. In the model with FFR included (Figure 23), evidence is coherent and the shape of IRFs for GDP is even more similar to the model with macroeconomic uncertainty.

Expansionary shock In the case of a tax cut (Figure 24, model without FFR), results are not in line with what expected, but, as we explained above, this might be due to the fact that, while the EPU index is directly and critically influenced also by the behavior of monetary policy, in the specification without FFR we do not take into account in any way the possible moves of the monetary policy authority. Our guess is somewhat confirmed by the fact that, when we examine the results from the model where the monetary policy variable is added to the model (Figure 25), the response of GDP, consumption and investments is significantly positive when ex-ante economic policy uncertainty is low, in line with our main evidence. On the contrary, IRFs of these variables are neutral in the high-uncertainty regime. FFR falls by similar levels in both regimes, while uncertainty falls by more in the low-uncertainty regime.

Comment The evidence we found in our main specification using macroeconomic uncertainty seems to be robust to the use of the EPU index, provided that the peculiarities and the problems of this variable are taken into account. The robustness of our findings to the EPU is particularly relevant since, from a slightly different perspective, it matches quite well our preferred concept of uncertainty, which is best embodied by macroeconomic uncertainty. In addition, this suggests something in terms of policy announcement and implementation: it is in general negative, both in the case of tax increases and in the case of tax cuts, to increase uncertainty about economic policy, which should, instead, be minimized.

3.4 Alternative specifications with financial uncertainty measures

We also try to replicate the main analysis with three measures of financial uncertainty. Even though the exact meaning of financial uncertainty depends on which one we consider, in general they deal with reduced predictability of future returns of a number of portfolios or of financial variables or with predicted increased volatility in market prices. Two of the variables we use are the closest counterparts of our macro uncertainty measures: The first is a financial uncertainty variable built by Carriero, Clark and Marcellino (2016) and the second is the one proposed by Ludvigson, Ma and Ng (2016). The third financial variable we use to check results is the VXO, a measure of options' implied volatility 30 days ahead. Differently from the case of macroeconomic uncertainty, it is not easy to have a prior about the link between financial uncertainty and the way in which agents react to tax shocks and, therefore, about the results one can find. The easiest guess is that saving decisions should play a role. As we will see, evidence varies depending on which uncertainty variable is considered and it is partially at odds with previous one obtained from macroeconomic and economic policy uncertainty. Overall, this should not be too surprising, since, as we have said, financial uncertainty differs remarkably from the concept of uncertainty which we are mainly interested in and, in addition, there is no clear theoretical framework according to which one should evaluate results.

3.4.1 Financial Uncertainty measure by Carriero, Clark, and Marcellino (2016)

In brief, this uncertainty variable is built within the same framework of Carriero, Clark and Marcellino (2016) described before. The difference is that it considers the common component of the volatility referred to financial variables in the model instead of macroeconomic ones. It is relevant to recall at this point that, given the way in which this uncertainty measure is built: 1) financial uncertainty is influenced by and influences macroeconomic uncertainty and 2) innovations of both are allowed to be cross-correlated.

Correlation with the cycle and distribution of shocks As to the preliminary description of the behavior of this series, we find that the correlation with the business cycle proxy by Auerbach and Gorodnicheko (2012) is negative, as expected, but lower than in the case of macroeconomic uncertainty (-0.39). Overall, also in this case the distribution of tax shocks over the time series distribution of the uncertainty measure is quite balanced: A shock of either sign occurs on average in the 48th percentile of the uncertainty distribution and the figure is the same also for positive and negative shocks.

TVAR We find evidence which is consistent with previous one and strengthens it further, as the distinction between regimes is even stronger than in the main analysis. In particular, in both specifications with and without FFR (Figures 27 and 26), all the main aggregates seem to be more reactive during the low-uncertainty regime, while the response is either muted or in the wrong direction in high-uncertainty periods.

TVAR with sign nonlinearity

Contractionary shock In the TVAR with sign nonlinearity, in the case of a tax increase, we find that the reaction of the economy is in general neutral in the low-uncertainty regime, similarly in the two specifications with (Figure 29) and without (Figure 28) the FFR. Instead, in the high-uncertainty regime, the responses are more negative in the specification without FFR, while the evidence is more mixed in the specification including FFR, especially with regard to investments.

Expansionary shock Evidence is virtually identical across specifications (Figures 30 and 31) and it sees the reaction of GDP, consumption, and investments being more responsive - in the positive direction - in the low-uncertainty regime and negligible in the high-uncertainty one. Instead, inflation increases in the high-uncertainty regime and, perhaps as a consequence, we also see monetary policy being contractionary in the same regime.

3.4.2 Financial Uncertainty measure by Ludvigson, Ma, and Ng (2016)

The financial uncertainty variable is built in a similar way as the macroeconomic uncertainty variable in JLN, but it is the weighted average of MSFE of variables capturing the returns of several financial portfolios. Therefore it should capture the level of uncertainty agents face about future returns in the financial market.

Correlation with the cycle and distribution of shocks The correlation of this uncertainty variable with the Auerbach and Gorodnichenko (2012) business cycle variable is a quite low -0.37, so that common movements appear to be quite limited in this case. The distribution of shock over different uncertainty levels seems to be, also in this case, quite even. Shocks of any sign occur on average in the 47th percentile of the time series distribution of uncertainty. These percentiles are the 46th for contractionary shocks and the 47th for expansionary ones. As we will comment below, results related to this uncertainty variable are the most different from those obtained in our main analysis and this can be explained in view of the fact that this uncertainty variable, among all those employed, also captures the most dissimilar concept of uncertainty.

TVAR In both specifications with and without FFR (Figures 33 and 32 respectively), we find that evidence for GDP, consumption and investments is consistent with our main findings, in that aggregates seem to be more responsive when ex-ante financial uncertainty is low, while the response is more muted in the high-uncertainty regime.

TVAR with sign nonlinearity

Contractionary shock In the specification without FFR (Figure 34), GDP responds, to a 1% tax increase, negatively and similarly in both regimes. The same is true for consumption, but for the fact that the aggregate tends to fall more in the high-uncertainty regime towards the end of the time horizon. On the contrary, investments respond negatively, as one would expect, in the low-uncertainty regime, and positively in the high one.

When we include FFR in the specification (Figure 35), GDP response in the high-uncertainty regime is slightly positive at first - but zero is included in the confidence bands on the entire horizon - and then neutral. On the other hand, the reaction in the low-uncertainty regime is negative in a statistically significant way for few quarters after the shock, with a zero-reverting behavior over the horizon. Analogous behavior is shown by consumption. Investments, instead, are in practice unchanged when ex-ante financial uncertainty is low, while, in the high-uncertainty regime, they first rise on impact, have a peak around the fifth quarter after the shock, and then revert back to zero. Interestingly, the saving rate follows an inverted pattern. While it is virtually unaffected in the low-uncertainty regime, it falls evidently in the high one, with the maximum decrease at 5 quarters after the shock, and then reverts back to pre-shock levels.

Expansionary shock In the specification not including FFR (Figure 36), GDP, consumption and investments seem to respond more positively to a tax cut in the low uncertainty regime, with the difference with the high-uncertainty regime being particularly evident in the case of consumption.

When we include FFR (Figure 37), the behavior of the main aggregates is mixed and finding a pattern across uncertainty regimes is not easy. For example, GDP rises on impact in the high-uncertainty regime and falls on impact in low one, but thereafter, while the response in the high-uncertainty regime remains positive but weaker in magnitude, the reaction in the low-uncertainty situation becomes positive and stronger in magnitude as quarters go. Consumption instead is virtually unaffected in the high-uncertainty regime, but it gradually increases over time in the low one. Investments, instead, jump up considerably when ex-ante uncertainty about future financial returns is high, but then this positive reaction vanishes quite rapidly. On the contrary, in the low-uncertainty regime, the positive response is muted first and then increases mildly. As to saving rate, even though the degree of overlapping between confidence bands is relevant, the pattern suggests a sharper increase when financial uncertainty is low and a lower increase when uncertainty is high.

3.4.3 VXO

As a further robustness check to our results, we use the VXO, an alternative measure of financial uncertainty, as uncertainty variable. It is built by the CBOE and it is meant to track expectations for short-term (30 days) volatility in the US stock market. This is done by measuring the implied volatility on S&P 100 options and therefore can be considered a measure of uncertainty of investors about future market developments. While the VIX is a wider measure of uncertainty, because it is based on the S&P 500 options, it is available on a shorter span of time and that is why we choose to used the VXO.

Correlation with the cycle and distribution of shocks We notice that the correlation with the business cycle measure by Auerbach and Gorodnichenko (2012) is negative but low (-0.24) and also that narrative tax shocks are quite evenly distributed over uncertainty levels, with shocks occurring on average in the 47th percentile of the historical VXO distribution.

TVAR In Figures 38 and 39 we see impulse responses of the TVAR model without sign nonlinearity in the specifications without and with FFR. In general, we see the direction of the movements being quite in line with the main analysis. The reaction is stronger, in the positive direction, in the low-uncertainty regime, but with this measure of financial uncertainty bands of impulse responses are much wider and the pattern is overall less clear than in the case of macro uncertainty.

TVAR with sign nonlinearity

Contractionary shock In the specification without FFR (Figure 40), we have evidence which is consistent with the main analysis. The response of GDP and consumption is quite evidently negative in the high-uncertainty regime, while it is neutral in the low one. Also, in this case we see government revenues vary by similar amounts in both regimes and the fall in government spending in the high-uncertainty regime is less marked that in the specification with the macro uncertainty measure by JLN. As before, we have the saving rate increasing slightly in the high-uncertainty regime and falling strongly in periods when ex-ante uncertainty is high. As to investments, zero is always included in confidence bands for both regimes, but the direction of the movement is, in both uncertainty situations, towards the negative side. However, the reaction seems to be better in the high-uncertainty regime, as we see the uncertainty measure (VXO) falling strongly in this regime. Evidence is also partially in line with the previous one when we include FFR (Figure 41): the nonlinearity in uncertainty vanishes for GDP and consumption, but the FFR does not show strong accommodation in the high-uncertainty regime as in the main analysis. However, investments increase in the high-uncertainty regime (and decrease slightly in the low one) as the VXO falls by more in this regime.

Expansionary shock As to tax cuts, we see similar evidence in both specifications without (Figure 42) and with (Figure 43) the FFR. The response of aggregates seems to be slightly more positive in the low-uncertainty regime. The reaction of government revenues and government spending is similar in both regimes and saving rate increase by more in the high-uncertainty regime. VXO increases following a tax cut in the high-uncertainty regime and falls in the low-uncertainty regime, consistently across specifications.

3.4.4 Comment on the results

As previously pointed out, commenting on the results obtained using financial uncertainty measures is not easy, both because they are dependent on the choice of the variable and also because we have no theoretical prior to use as a benchmark. We think that, in this context, it is worth trying to explain the observed differences in the results obtained with the three different measures. As we have previously outlined, the financial uncertainty variable by Carriero, Clark and Marcellino (2016) is allowed to be affected by macroeconomic uncertainty and correlation between the two is modelled. Similarly, the VXO, which is based directly on market-implied volatilty, reflects not only variations purely related to financial issues, but also reflects uncertainty about future developments in the macroeconomic field. Instead, the uncertainty measure by Ludvigson, Ma and Ng (2016) is based on a dataset of financial portfolios returns only and therefore is not explicitly influenced by fluctuations in macro uncertainty. Our view is that this feature might be behind the observed differences. Moreover, our guess is that results regarding financial uncertainty are different from our main analysis, first of all, because the object of investigation changes if the concept of uncertainty we deal with changes. This guess is supported by the fact that results are otherwise robust to analysis with other measures of macro and economic policy uncertainty. In addition, the fact that the variable by Carriero, Clark and Marcellino (2016) and the VXO are more directly linked with and influenced by our preferred concept of uncertainty is consistent with observing more similar results than in the case of the Ludvigson, Ma and Ng (2016) variable.

4 Application of the model to Auerbach and Gorodnichenko (2012) proxy

In this section we replicate our TVAR model with sign nonlinearity using as a threshold variable first the business cycle proxy by Auerbach and Gorodnichenko (2012) in order to see how their results might be affected by the change of econometric framework and identification strategy.

Contractionary tax shock The response of GDP to a 1% tax increase (Figure 44) shows no remarkable difference, at least with respect to point estimates, across regimes. However, the upper bound of the confidence bands, in the case of the bad-economic-conditions regime, is very far from the point-estimate of the IRF and at very high levels. The case of consumption is different: in presence of ex-ante worse economic conditions, the response of consumption seems to be worse than in periods when the economy is in better shape, even though also in this case the upper confidence band of the former regime is very wide. Investments, instead, spike on impact in the bad-conditions regime (and then revert to zero), but are unaffected by a tax increase when economic conditions are good. A look at the IRF of saving rate suggests an explanation for the observed behavior of consumption: propensity to save income increases after a tax increase during economic downturns, while it decreases slightly during periods of economic expansion.

Expansionary tax shock Figure 45 reports the results for an expansioanry tax shock: the difference between impulse responses of different regimes is much less evident than in our main analysis. GDP seems to react slightly more positively to a tax expansion in the low-regime, i.e. when the economic conditions are worse, but the reaction is statistically positive in both regimes. The same holds true for consumption and for investments, where the initial increase in the bad-economic-conditions regime is quite marked compared to the one in the other regime. Interestingly, evidence shows that the response of the saving rate is strongly positive in the case of ex-ante bad economic conditions and remarkably stronger than in the alternative regime, where the IRF is nonetheless positive. Government revenues fall by analogous amounts in both regimes and inflation increases more in the good-economic-conditions regime, which is perfectly in line with the theory of fiscal stimuli carried out when the economy is already in an expansionary phase of the cycle.

Comment Overall, the results we get with the Auerbach and Gorodnicheko transition variable are quite different from theirs, since fiscal measures are not observed to have a remarkable different impact in economic expansions and downturns. Obviously, there are a number of crucial differences between our framework and theirs, of which the most immediate and evident one is our interest in tax shocks rather than in government spending shocks. A more sensible comparison regards how well a model defining regimes with respect to macroeconomic uncertainty performs as opposed to a model having as a threshold variable a business cycle proxy. So, we compute information criteria for our main specification and for the robustness model under analysis. The multivariate Akaike information criterion seems to prefer the business cycle model (3,963 of the uncertainty model vs 2,939 of the "business cycle" one), however the Bayesian Information Criterion prefers our main specification with macroeconomic uncertainty (8,331 vs 8,651). Overall, the fact that the two information criteria are very close and, in addition, give contrasting answers depending on which one is considered suggest that the fit of the model nonlinear with respect to uncertainty is at least as good as the one considering the business cycle.

5 Description of the Iterated FGLS estimator

In order to derive our estimator with regime-specific variance-covariance matrices we start from Judge et al. (1980, Chapter 15 pp. 599-601) model for systems of simultaneous equations. They start from the model:

$$Y\Gamma = XB + E$$

where Y and E are $T \times M$ matrices and X is $T \times K$. For the $i-th$ equation, they assume that m_i^* of the M endogenous variables and k_i^* of the K predetermined variables have zero coeffients. The remaining $m_i = M - m_i^* - 1$ unkown elements of $\mathit{\Gamma}_i$ ($\gamma_{ii} = -1$) and the remaning $k_i = K - k_i^*$ unknown elements of B_i are to be estimated. In our case, we have that, for the $i-th$ equation, all coefficients of $\mathit{\Gamma}_i$ - the $i-th$ row of $\mathit{\Gamma}$ - apart from γ_{ii} are null and $k_i^* = 0$. Therefore, the $i-th$ equation can be rewritten as:

$$\mathbf{y}_i = \begin{bmatrix} Y_i & X_i \end{bmatrix} \begin{bmatrix} \gamma_\mathbf{i} \\ \beta_\mathbf{i} \end{bmatrix} + \mathbf{e_i}$$

$$= Z_i\delta_i + \mathbf{e_i}, \quad i = 1, \ldots, M$$

where, in our case, $Z_i = X$, $\gamma_\mathbf{i} = \mathbf{0}$, and $\mathbf{y}_i = X\beta_i + \mathbf{e}_i$. The system of equations can be further re-written as

$$\begin{bmatrix} \mathbf{y_1} \\ \mathbf{y_2} \\ \vdots \\ \mathbf{y_M} \end{bmatrix} = \begin{bmatrix} X & & & \\ & X & & \\ & & \ddots & \\ & & & X \end{bmatrix} \begin{bmatrix} \beta_\mathbf{1} \\ \beta_\mathbf{2} \\ \vdots \\ \beta_\mathbf{M} \end{bmatrix} + \begin{bmatrix} \mathbf{e_1} \\ \mathbf{e_2} \\ \vdots \\ \mathbf{e_M} \end{bmatrix}$$

and, more compactly $\mathbf{y} = Z\beta + \mathbf{e}$. In our framework, the model written in this way delivers the reduced form parameters in which we are interested in vector form and we estimate them by OLS. Then, Judge et al. (1980) derive a 2SLS estimator for β, which is clearly needed if Z_i includes some endogenous variables, but it is not needed if, as in our case, all variables on the r.h.s are predetermined and the OLS estimator for β is consistent. Indeed, the 2SLS estimator in Judge is

$$\tilde{\beta}_{\mathbf{i}} = \left(\hat{Z}_i'\hat{Z}_i\right)^{-1}\hat{Z}_i'\mathbf{y_i} \tag{1}$$

where $\hat{Z}_i = \begin{bmatrix} \hat{Y}_i & X_i \end{bmatrix} = \begin{bmatrix} X\hat{\Pi}_i & X_i \end{bmatrix}$and $\hat{\Pi}_i$ is the OLS estimator of the reduced form model ($\Pi = B\Gamma^{-1}$). In our context, we have that, since all the coefficients related to the $\hat{Y}_i$ term in $\hat{Z}_i$ are zero, then $\hat{Z}_i = X$ and $\tilde{\beta}_{\mathbf{i}} = \beta_{\mathbf{i}}^{\mathbf{OLS}} = \Pi_i$ and the 2SLS estimator of Judge et al (1980) coincides with the OLS one. Then Judge et al. go further and propose a 3SLS estimator, because under conditons normally fulfilled in practice they show that the efficiency of the estimator for β improves if all M equations are estimated jointly by a GLS estimator. They show that the formula for this estimator is

$$\tilde{\beta}^{*} = \left\{Z'\left[\Sigma^{-1} \otimes X\left(X'X\right)^{-1}X'\right]Z\right\}^{-1}Z'\left[\Sigma^{-1} \otimes X\left(X'X\right)^{-1}X'\right]\mathbf{y}$$

where $\otimes$ denotes the Kronecker product and, as we have previously pointed out, in our case $Z = I_M \otimes X$. The feasible version of this GLS estimator is obtained using the residuals from the 2SLS estimation, which, in our case, coincide with the OLS residuals. In particular, in the present case residuals will be in vector form

$$\mathbf{e} = \begin{bmatrix} \mathbf{e_1} \\ \mathbf{e_2} \\ \vdots \\ \mathbf{e_M} \end{bmatrix}$$

and should be rearranged in matrix form as $E = \begin{bmatrix} \mathbf{e_1} & \mathbf{e_2} & \cdots & \mathbf{e_M} \end{bmatrix}$, so that $\hat{\Sigma} = E'E$.

In our framework, the problem is that Σ is a weighted average of the variance-covariance matrix of the error terms of the two uncertainty regimes. Indeed, if we define $\mathbf{1_j} = \underbrace{\begin{bmatrix} 1 & 1 & \cdots & 1 \end{bmatrix}}_{j\ times}$ and $\mathbf{1_{ij}} = \underbrace{\begin{bmatrix} 1 & 1 & \cdots & 1 \\ 1 & 1 & \cdots & 1 \\ \vdots & \vdots & \ddots & \vdots \\ 1 & 1 & \cdots & 1 \end{bmatrix}}_{j\ times} {}_{i\ times}$ and we call $\mathbf{d}$ the $0-1$ vector defining regimes, then we can compute empirically

$$\hat{\Sigma}_1 = \left[(\mathbf{d} \otimes \mathbf{1_M})E\right]'\left[(\mathbf{d} \otimes \mathbf{1_M})E\right] \tag{2}$$

and

$$\hat{\Sigma}_0 = \left[((\mathbf{1_T'} - \mathbf{d}) \otimes \mathbf{1_M})E\right]'\left[((\mathbf{1_T'} - \mathbf{d}) \otimes \mathbf{1_M})E\right] \tag{3}$$

which are the regime-specific variance-covariance matrices.

Therefore, after having estimated the reduced form model, we estimate the two matrices $\hat{\Sigma}_0$ and $\hat{\Sigma}_1$ with the residuals and we compute an adaptation of Judge et al's 3SLS estimator. In particular, if we define $D = \mathbf{d} \otimes \mathbf{1}_T$, then our proposed estimator is:

$$\beta_{FGLS-RSV} = \left\{ Z' \left[\hat{\Sigma}_*^{-1} * \left(X \left(X'X \right)^{-1} X' \right) \right] Z \right\}^{-1} Z' \left[\hat{\Sigma}_*^{-1} * \left(X \left(X'X \right)^{-1} X' \right) \right] \mathbf{y} \tag{4}$$

where $\hat{\Sigma}_*^{-1} = \left[\hat{\Sigma}_0^{-1} \otimes (\mathbf{1}_{TT} - D) + \hat{\Sigma}_1^{-1} \otimes D \right]$, $*$ denotes the element-by-element product and all other objects entering the expression are defined above. Taking the residuals from the model using the new estimator, we can compute the updated regime-specific variance-covariance matrices. It is important to notice that, in our nonlinear framework, in the passage from OLS to FGLS we allow the threshold to vary, i.e. we take into account that the threshold level of the switching variable minimizing the sum of squared residuals may change when we change the estimation method.

As a further step, once we have estimated the new coefficients, residuals, and regime-specific variance-covariances, we iterate the previous FGLS estimator until there is a convergence of the estimated coefficients, i.e. until the norm distance between the estimates at two subsequent steps is sufficiently small (we fix it at 10^{-6}). To sum up, the steps are:

1. Estimate the OLS model with Y in vector form $\mathbf{y}$ according to (1)
2. Rearrange the residuals in matrix form $E = \left[\begin{array}{cccc} \mathbf{e_1} & \mathbf{e_2} & \cdots & \mathbf{e_M} \end{array} \right]$ and, according to (2) and (3) compute the regime-specific variance-covariance matrices given the threshold for the switching variable identified by the OLS model.
3. Compute, doing grid search over all possible thresholds of the switiching variable, $\beta_{FGLS-RSV}^{(1)}$ according to (4), where the superscript refers to the fact that this is the first iteration. Then choose the estimate minimizing the sum of squared residuals and compute the residuals $E^{(1)}$, $\hat{\Sigma}_0^{(1)}$ and $\hat{\Sigma}_1^{(1)}$.
4. Repeat step 3 until there is convergence between estimates, keeping in mind that, at each iteration, the chosen threshold level for the switching variable can change. Written with the correct superscripts, the FGLS estimator at step (i) is

$$\beta_{FGLS-RSV}^{(i)} = \left\{ Z' \left[\hat{\Sigma_*^{(i-1)}}^{-1} * \left(X \left(X'X \right)^{-1} X' \right) \right] Z \right\}^{-1} Z' \left[\hat{\Sigma_*^{(i-1)}}^{-1} * \left(X \left(X'X \right)^{-1} X' \right) \right] \mathbf{y}$$

and the iteration is repeated until $\left\| \beta_{FGLS-RSV}^{(i)} - \beta_{FGLS-RSV}^{(i-1)} \right\| < \varepsilon$, with $\|\cdot\|$ denoting the norm and ε being a chosen tolerance level.

6 Computation of the GIRFs

The algorithm for GIRF specific to each regime with a time horizon of h has the following steps:

1. choose a history $\{\Omega_{t-i}\}_{i=0}^{p}$ from original Y data, where p is the order of the VAR;
2. choose a sequence of shocks of length h considering a random starting point;
3. given the history $\{\Omega_{t-i}\}_{i=0}^{p}$, the estimated coefficients from the original model and chosen sequence of residuals, simulate the evolution of the model over the desired time horizon not considering exogenous shocks to taxes;
4. repeat step 3 adding to time 0 variables the estimated impact of a 1% narrative tax shock;
5. repeat B=200 times the steps from 2 to 4;
6. compute the average difference between the shocked path (point 4) and the non-shocked one (point 3);
7. repeat steps from 1 to 6 considering all the possible starting points (histories);
8. the average GIRF associated with a specific regime is the average of those GIRFs obtained considering starting conditions for which the regime at time 0 was the one of interest

Once GIRFs are obtained, confidence bands are obtained by bootstrapping, following this algorithm:

1. "simulated" data are generated recursively using estimated coefficients and the bootstrapped residuals from the nonlinear model;
2. using the "new" dataset, the nonlinear model is re-estimated keeping the threshold defining regimes fixed and storing the "new" residuals;
3. with the original dataset for starting conditions and the newly computed coefficients and errors, GIRFs are computed following the steps described above;
4. steps 1-3 are repeated S = 300 times to generate a sample distribution of the GIRFs from which confidence bands are drawn at the respective significance level.

References

[1] Auerbach, A. J., Gorodnichenko Y., 2012, "Measuring the Output Response to Fiscal Policy", American Economic Journal: Economic Policy, 4(2): 1-27

[2] Carriero A., Clark T. E., Marcellino M., 2016, “Measuring uncertainty and its impact on the economy”, Review of Economics and Statistics, forthcoming

[3] Favero C., Giavazzi F., 2012, "Measuring Tax Multipliers: The Narrative Method in Fiscal VARs.", American Economic Journal: Economic Policy 4 (2): 69-94

[4] Hussain M. S., Malik S., 2014, "Asymmetric Effects of Tax Changes", Journal of Economic Dynamics and Control, 2016, vol. 69, issue C, pages 268-300

[5] Judge G. G., Griffiths W. E., Hill R. C., Lutkepohl H, Tsoung-Chao Lee, 1980, “The Theory and Practice of Econometrics”, John Wiley & Sons Inc.

[6] Jurado K., Ludvigson S. C., Ng S., 2015, "Measuring Uncertainty", The American Economic Review, 105(3): 1177-1216

[7] Ludvigson S. C., Ma S., Ng S., 2016, " Uncertainty and Business Cycles: Exogenous Impulse or Endogenous Response?", NBER Working Papers 21803, National Bureau of Economic Research, Inc.

[8] Mertens K., Ravn M. O., 2012, "Empirical Evidence on the Aggregate Effects of Anticipated and Unanticipated US Tax Policy Shocks", American Economic Journal: Economic Policy, vol. 4(2), pages 145-181, May

[9] Mertens K., Ravn M. O., 2013, "The Dynamic Effects of Personal and Corporate Income Tax Changes in the United States", American Economic Review, American Economic Association, vol. 103(4), pages 1212-1247, June

[10] Romer C. D., Romer D. H., 2010, "The Macroeconomic Effects of Tax Changes: Estimates Based on a New Measure of Fiscal Shocks", American Economic Review 100(3): 763-801

[11] Rossi B., Sekhposyan T., 2015, " Macroeconomic Uncertainty Indices Based on Nowcast and Forecast Error Distributions", American Economic Review 105(5): 650-655

7 Figures

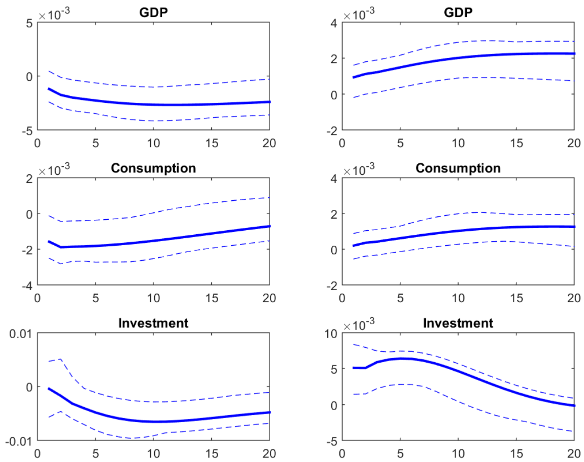


Figure 1: VAR with sign nonlinearity, macroeconomic uncertainty model. Dashed lines are 68% confidence bands. The left column refers to a contractionary tax shocks, right column to expansionary tax shock. IRFs for GDP, C, I and saving rate refer to different specifications. All other plots refer to the specification with GDP

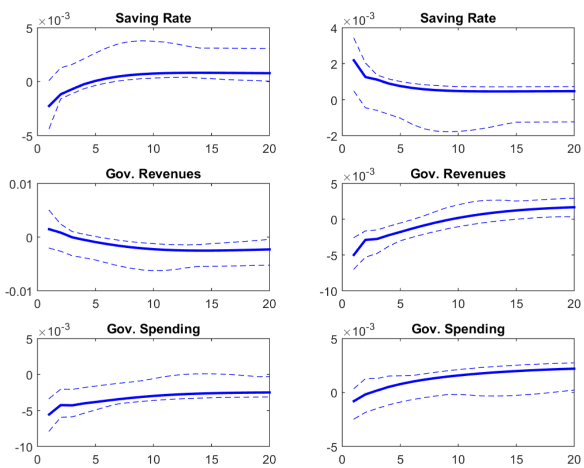
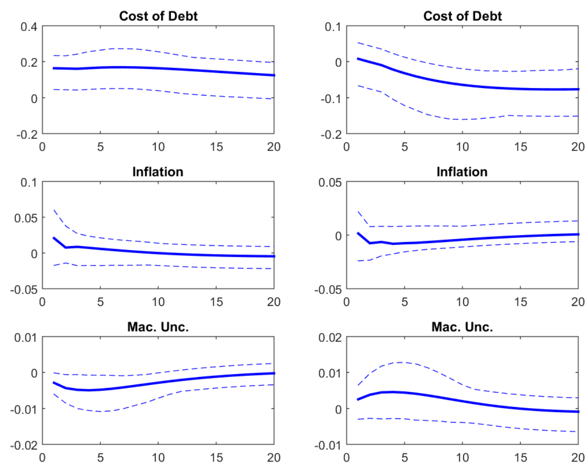


Figure 2: VAR with sign nonlinearity, macroeconomic uncertainty model. Dashed lines are 68% confidence bands. The left column refers to a contractionary tax shocks, right column to expansionary tax shock. IRFs for GDP, C, I and saving rate refer to different specifications. All other plots refer to the specification with GDP



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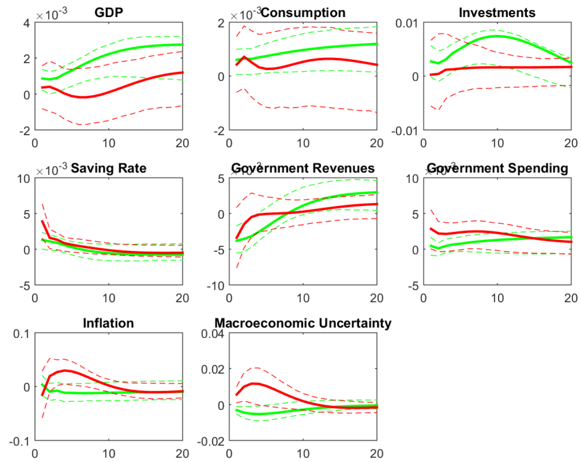

Figure 4: TVAR impulse responses, macroeconomic uncertainty model. Specification without FFR. Green lines refer to low-uncertainty regime, red lines to high-uncertainty one. Dashed lines are 68% confidence bands. IRFs for GDP, C, I and saving rate refer to different specifications. All other plots refer to the specification with GDP

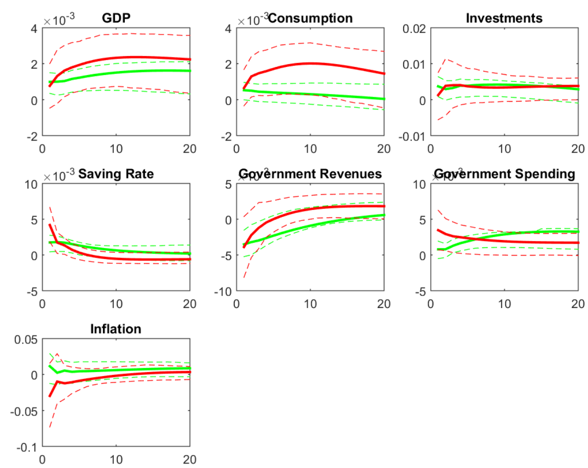

Figure 5: TVAR macroeconomic uncertainty model. Specification without macroeconomic uncertainty variable endogenous. Green lines refer to low-uncertainty regime, red lines to high-uncertainty one. Dashed lines are 68% confidence bands. IRFs for GDP, C, I and saving rate refer to different specifications. All other plots refer to the specification with GDP

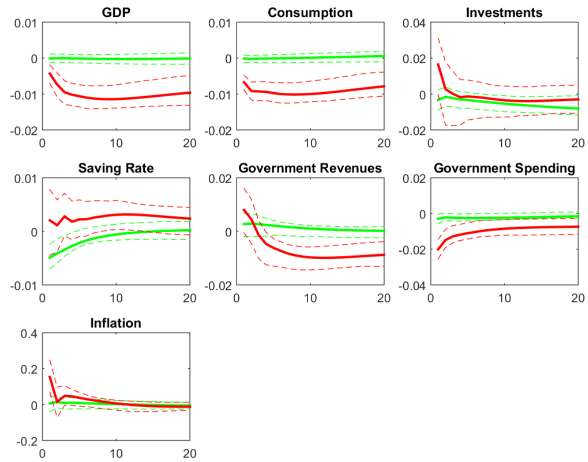

Figure 6: TVAR with sign nonlinearity, macroeconomic uncertainty model. Contractionary shock. Specification without macroeconomic uncertainty variable endogenous. Green lines refer to low-uncertainty regime, red lines to high-uncertainty one. Dashed lines are 68% confidence bands. IRFs for GDP, C, I and saving rate refer to different specifications. All other plots refer to the specification with GDP

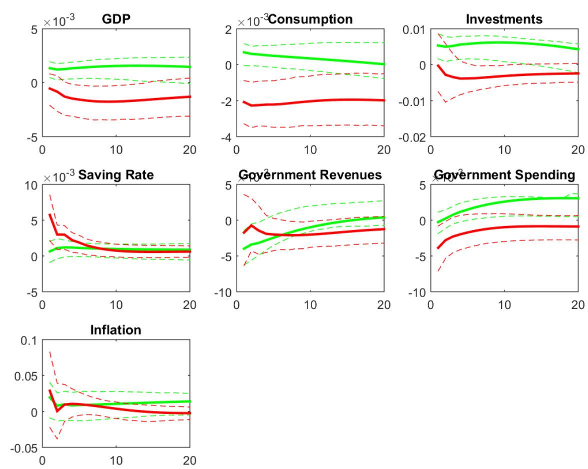

Figure 7: TVAR with sign nonlinearity, macroeconomic uncertainty model. Expansionary shock. Specification without macroeconomic uncertainty variable endogenous. Green lines refer to low-uncertainty regime, red lines to high-uncertainty one. Dashed lines are 68% confidence bands. IRFs for GDP, C, I and saving rate refer to different specifications. All other plots refer to the specification with GDP

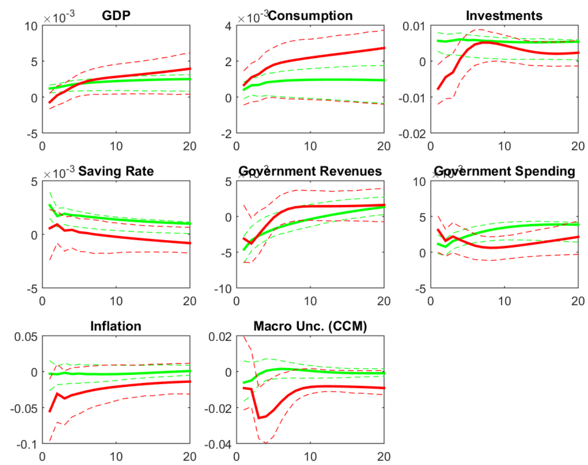

Figure 8: TVAR, CCM macro uncertainty model. Specification without FFR and with uncertainty variable. Green lines refer to low-uncertainty regime, red lines to high-uncertainty one. Dashed lines are 68% confidence bands. IRFs for GDP, C, I and saving rate refer to different specifications. All other plots refer to the specification with GDP

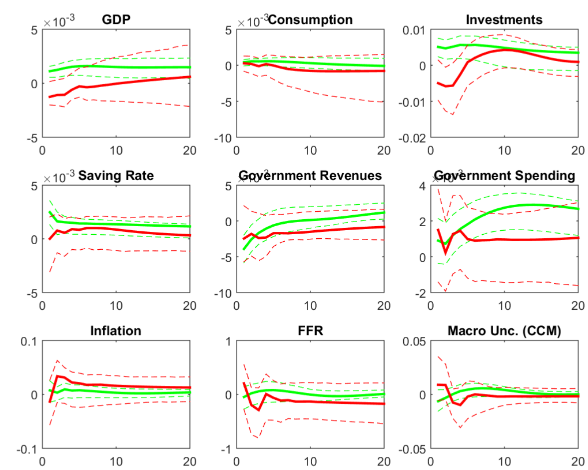

Figure 9: TVAR, CCM macro uncertainty model. Specification with FFR and with uncertainty variable. Green lines refer to low-uncertainty regime, red lines to high-uncertainty one. Dashed lines are 68% confidence bands. IRFs for GDP, C, I and saving rate refer to different specifications. All other plots refer to the specification with GDP

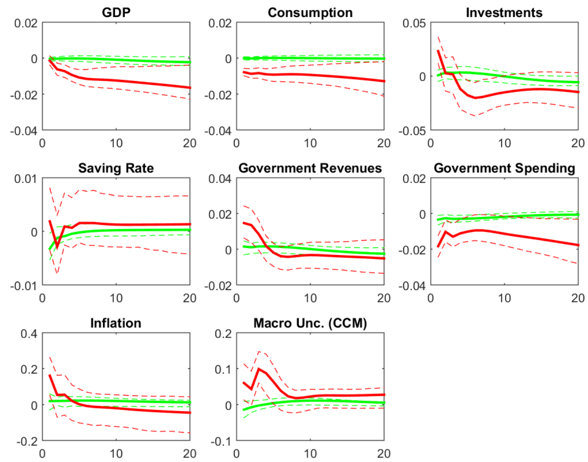

Figure 10: TVAR with sign nonlinearity, CCM macro uncertainty model. Contractionary shock. Specification without FFR and with uncertainty endogenous. Green lines refer to low-uncertainty regime, red lines to high-uncertainty one. Dashed lines are 68% confidence bands. IRFs for GDP, C, I and saving rate refer to different specifications. All other plots refer to the specification with GDP

Figure 11: TVAR with sign nonlinearity, CCM macro uncertainty model. Contractionary shock. Specification with FFR and with uncertainty endogenous. Green lines refer to low-uncertainty regime, red lines to high-uncertainty one. Dashed lines are 68% confidence bands. IRFs for GDP, C, I and saving rate refer to different specifications. All other plots refer to the specification with GDP

Figure 12: TVAR with sign nonlinearity, CCM macro uncertainty model. Expansionary shock. Specification without FFR and with uncertainty endogenous. Green lines refer to low-uncertainty regime, red lines to high-uncertainty one. Dashed lines are 68% confidence bands. IRFs for GDP, C, I and saving rate refer to different specifications. All other plots refer to the specification with GDP

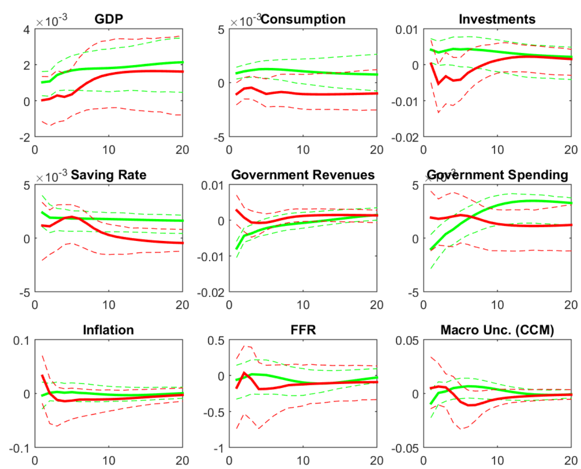

Figure 13: TVAR with sign nonlinearity, CCM macro uncertainty model. Expansionary shock. Specification with FFR and with uncertainty endogenous. Green lines refer to low-uncertainty regime, red lines to high-uncertainty one. Dashed lines are 68% confidence bands. IRFs for GDP, C, I and saving rate refer to different specifications. All other plots refer to the specification with GDP

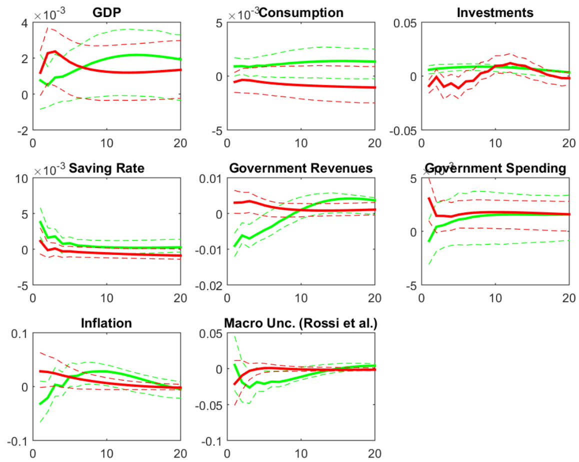

Figure 14: TVAR, Rossi et al. macro uncertainty model. Specification without FFR and with uncertainty variable. Green lines refer to low-uncertainty regime, red lines to high-uncertainty one. Dashed lines are 68% confidence bands. IRFs for GDP, C, I and saving rate refer to different specifications. All other plots refer to the specification with GDP

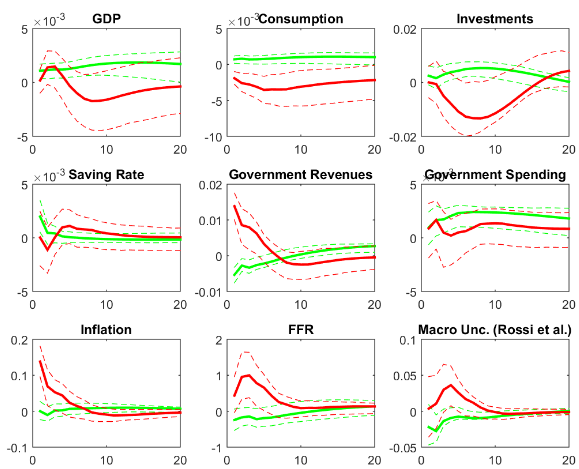

Figure 15: TVAR, Rossi et al. macro uncertainty model. Specification with FFR and with uncertainty variable. Green lines refer to low-uncertainty regime, red lines to high-uncertainty one. Dashed lines are 68% confidence bands. IRFs for GDP, C, I and saving rate refer to different specifications. All other plots refer to the specification with GDP

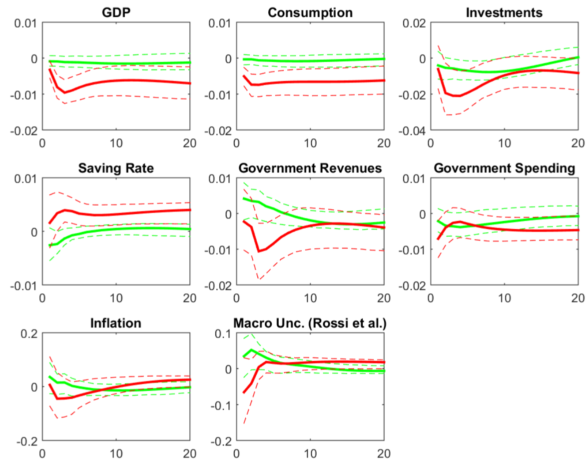

Figure 16: TVAR with sign nonlinearity, Rossi et al. macro uncertainty model. Contractionary shock. Specification without FFR and with uncertainty endogenous. Green lines refer to low-uncertainty regime, red lines to high-uncertainty one. Dashed lines are 68% confidence bands. IRFs for GDP, C, I and saving rate refer to different specifications. All other plots refer to the specification with GDP

Figure 17: TVAR with sign nonlinearity, Rossi et al. macro uncertainty model. Contractionary shock. Specification with FFR and with uncertainty endogenous. Green lines refer to low-uncertainty regime, red lines to high-uncertainty one. Dashed lines are 68% confidence bands. IRFs for GDP, C, I and saving rate refer to different specifications. All other plots refer to the specification with GDP

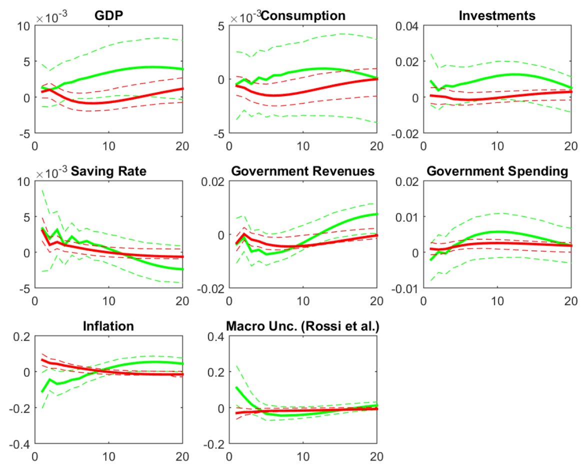

Figure 18: TVAR with sign nonlinearity, Rossi et al. macro uncertainty model. Expansionary shock. Specification without FFR and with uncertainty endogenous. Green lines refer to low-uncertainty regime, red lines to high-uncertainty one. Dashed lines are 68% confidence bands. IRFs for GDP, C, I and saving rate refer to different specifications. All other plots refer to the specification with GDP

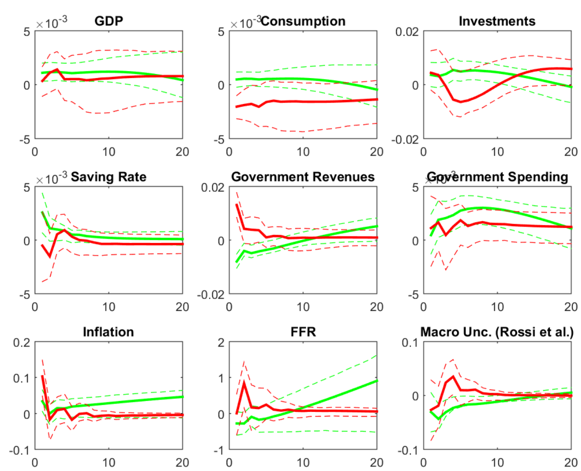

Figure 19: TVAR with sign nonlinearity, Rossi et al. macro uncertainty model. Expansionary shock. Specification with FFR and with uncertainty endogenous. Green lines refer to low-uncertainty regime, red lines to high-uncertainty one. Dashed lines are 68% confidence bands. IRFs for GDP, C, I and saving rate refer to different specifications. All other plots refer to the specification with GDP

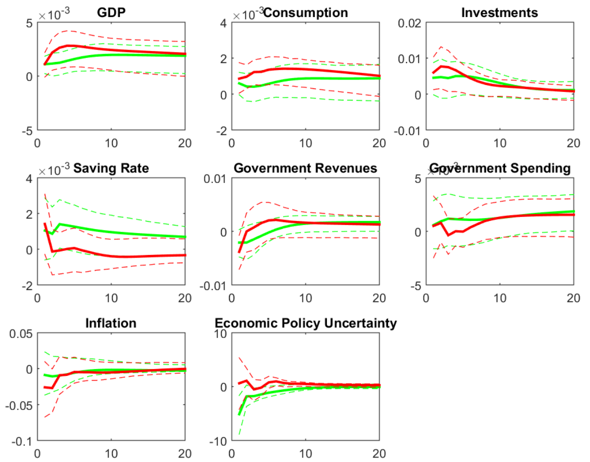

Figure 20: TVAR, economic policy uncertainty model. Specification without FFR and with economic policy uncertainty variable endogenous. Green lines refer to low-uncertainty regime, red lines to high-uncertainty one. Dashed lines are 68% confidence bands. IRFs for GDP, C, I and saving rate refer to different specifications. All other plots refer to the specification with GDP

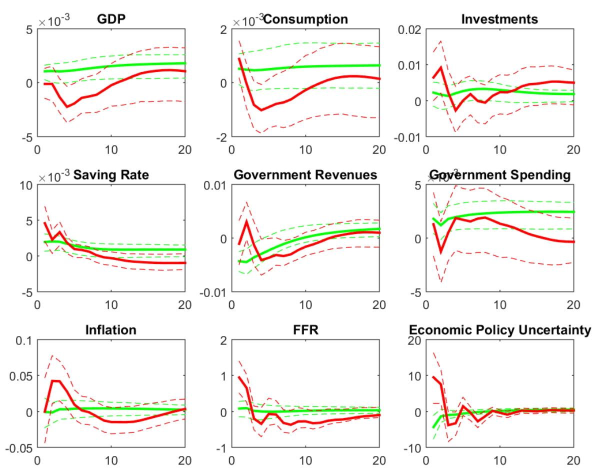

Figure 21: TVAR, economic policy uncertainty model. Specification with FFR and with economic policy uncertainty variable endogenous. Green lines refer to low-uncertainty regime, red lines to high-uncertainty one. Dashed lines are 68% confidence bands. IRFs for GDP, C, I and saving rate refer to different specifications. All other plots refer to the specification with GDP

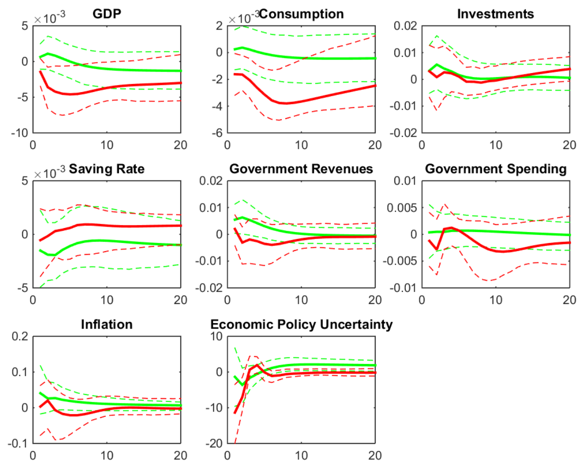

Figure 22: TVAR with sign nonlinearity, economic policy uncertainty model. Contractionary shock. Specification without FFR and with economic policy uncertainty variable endogenous. Green lines refer to low-uncertainty regime, red lines to high-uncertainty one. Dashed lines are 68% confidence bands. IRFs for GDP, C, I and saving rate refer to different specifications. All other plots refer to the specification with GDP

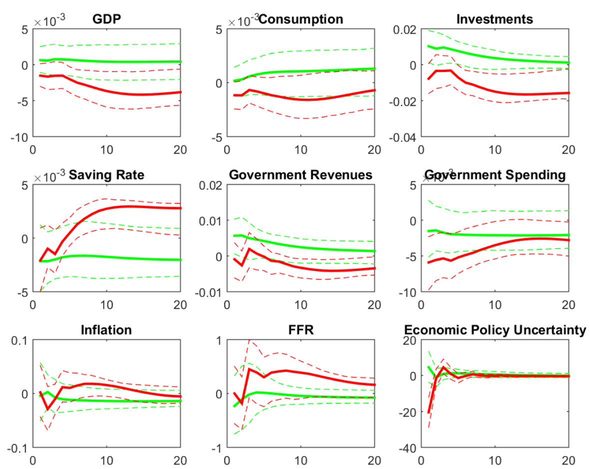

Figure 23: TVAR with sign nonlinearity, economic policy uncertainty model. Contractionary shock. Specification with FFR and with economic policy uncertainty variable endogenous. Green lines refer to low-uncertainty regime, red lines to high-uncertainty one. Dashed lines are 68% confidence bands. IRFs for GDP, C, I and saving rate refer to different specifications. All other plots refer to the specification with GDP

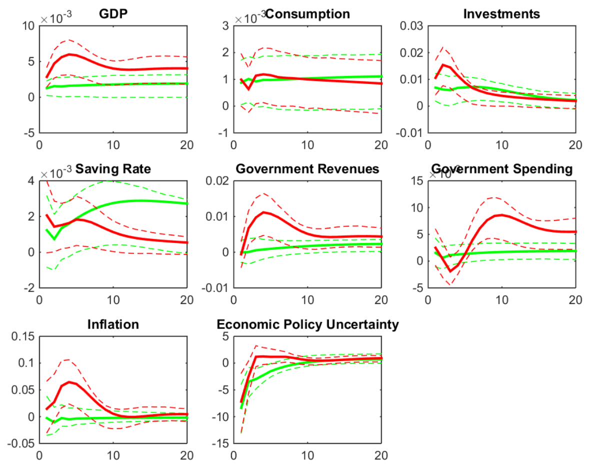

Figure 24: TVAR with sign nonlinearity, economic policy uncertainty model. Expansionary shock. Specification without FFR and with economic policy uncertainty variable endogenous. Green lines refer to low-uncertainty regime, red lines to high-uncertainty one. Dashed lines are 68% confidence bands. IRFs for GDP, C, I and saving rate refer to different specifications. All other plots refer to the specification with GDP

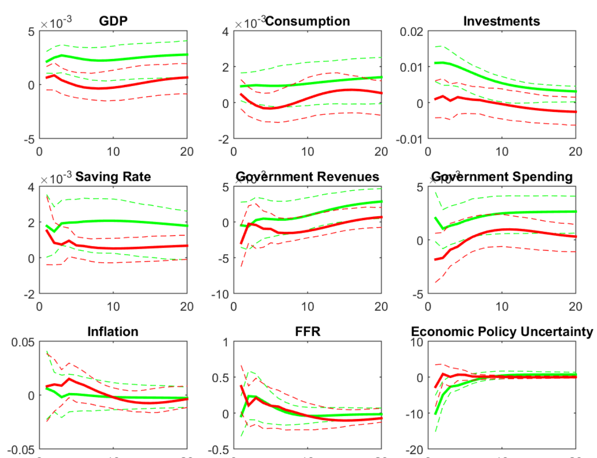

Figure 25: TVAR with sign nonlinearity, economic policy uncertainty model. Expansionary shock. Specification with FFR and with economic policy uncertainty variable endogenous. Green lines refer to low-uncertainty regime, red lines to high-uncertainty one. Dashed lines are 68% confidence bands. IRFs for GDP, C, I and saving rate refer to different specifications. All other plots refer to the specification with GDP

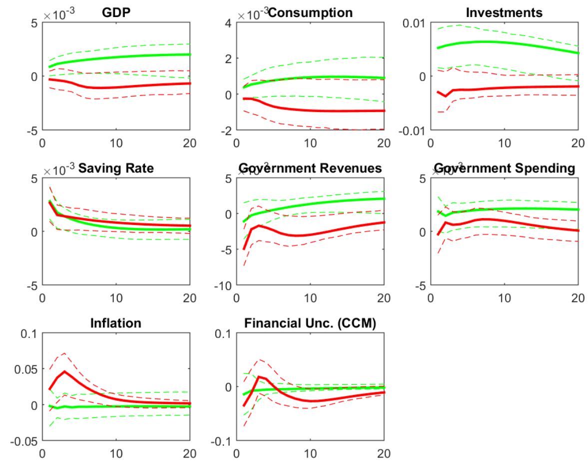

Figure 26: TVAR, CCM financial uncertainty model. Specification without FFR and with uncertainty variable endogenous. Green lines refer to low-uncertainty regime, red lines to high-uncertainty one. Dashed lines are 68% confidence bands. IRFs for GDP, C, I and saving rate refer to different specifications. All other plots refer to the specification with GDP

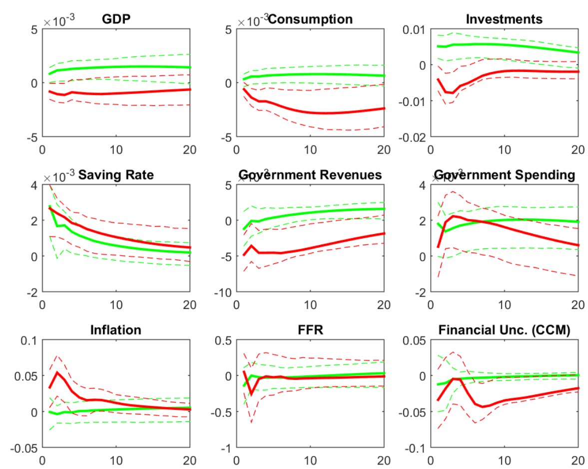

Figure 27: TVAR, CCM financial uncertainty model. Specification with FFR and with uncertainty variable endogenous. Green lines refer to low-uncertainty regime, red lines to high-uncertainty one. Dashed lines are 68% confidence bands. IRFs for GDP, C, I and saving rate refer to different specifications. All other plots refer to the specification with GDP

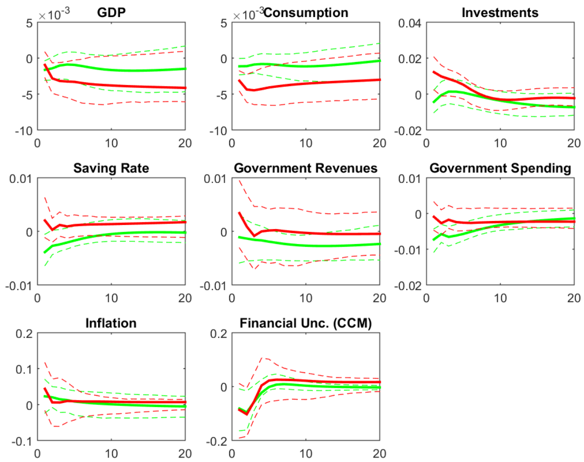

Figure 28: TVAR with sign nonlinearity, CCM financial uncertainty. Specification without FFR and with uncertainty variable endogenous. Contractionary shock. Green lines refer to low-uncertainty regime, red lines to high-uncertainty one. Dashed lines are 68% confidence bands. IRFs for GDP, C, I and saving rate refer to different specifications. All other plots refer to the specification with GDP

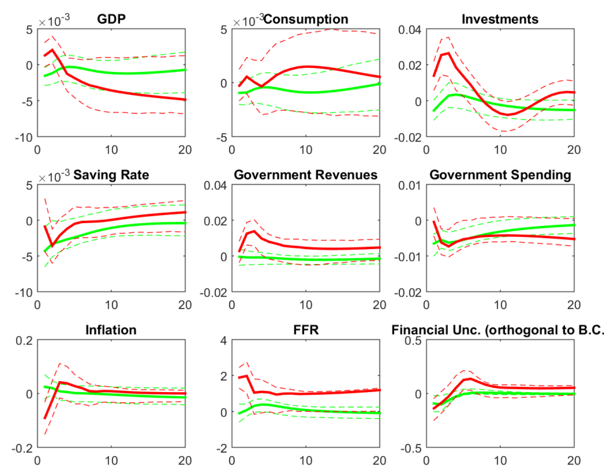

Figure 29: TVAR with sign nonlinearity, CCM financial uncertainty. Specification with FFR and with uncertainty variable endogenous. Contractionary shock. Green lines refer to low-uncertainty regime, red lines to high-uncertainty one. Dashed lines are 68% confidence bands. IRFs for GDP, C, I and saving rate refer to different specifications. All other plots refer to the specification with GDP

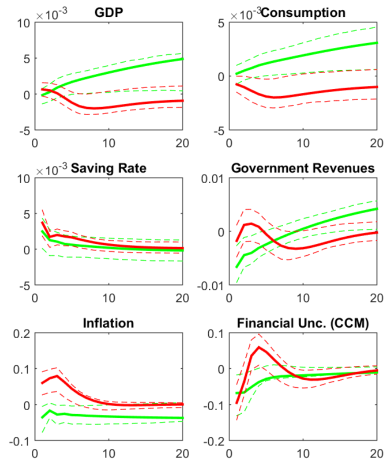

Figure 30: TVAR with sign nonlinearity, CCM financial uncertainty. Specification without FFR and with uncertainty variable endogenous. Expansionary shock. Green lines refer to low-uncertainty regime, red lines to high-uncertainty one. Dashed lines are 68% confidence bands. IRFs for GDP, C, I and saving rate refer to different specifications. All other plots refer to the specification with GDP

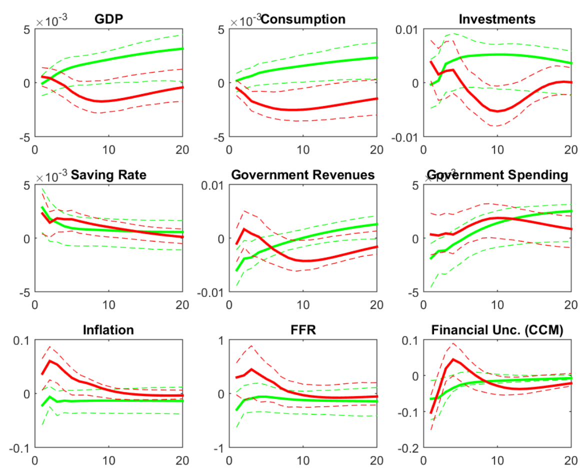

Figure 31: TVAR with sign nonlinearity, CCM financial uncertainty. Specification with FFR and with uncertainty variable endogenous. Expansionary shock. Green lines refer to low-uncertainty regime, red lines to high-uncertainty one. Dashed lines are 68% confidence bands. IRFs for GDP, C, I and saving rate refer to different specifications. All other plots refer to the specification with GDP

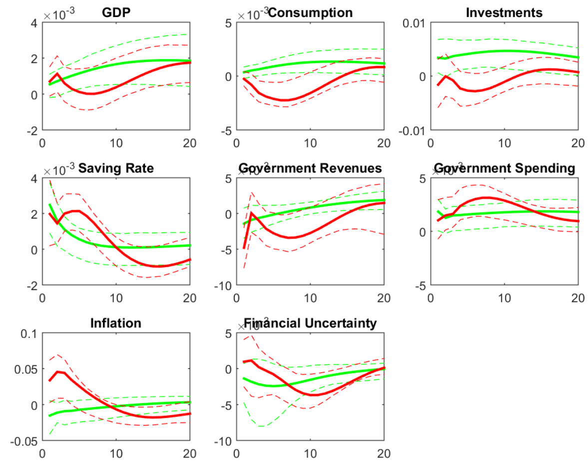

Figure 32: TVAR, LMN financial uncertainty model. Specification without FFR and with uncertainty variable endogenous. Green lines refer to low-uncertainty regime, red lines to high-uncertainty one. Dashed lines are 68% confidence bands. IRFs for GDP, C, I and saving rate refer to different specifications. All other plots refer to the specification with GDP

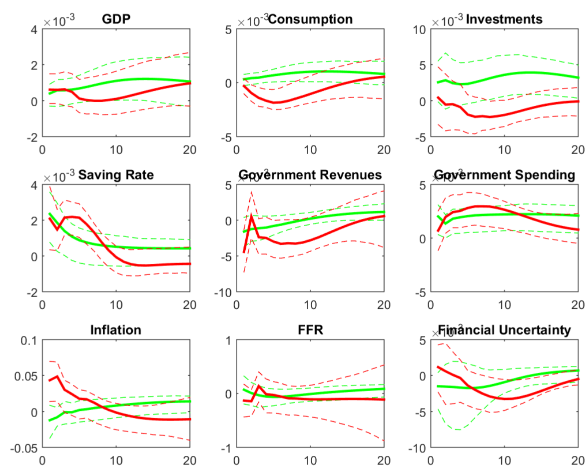

Figure 33: TVAR, LMN financial uncertainty model. Specification with FFR and with uncertainty variable endogenous. Green lines refer to low-uncertainty regime, red lines to high-uncertainty one. Dashed lines are 68% confidence bands. IRFs for GDP, C, I and saving rate refer to different specifications. All other plots refer to the specification with GDP

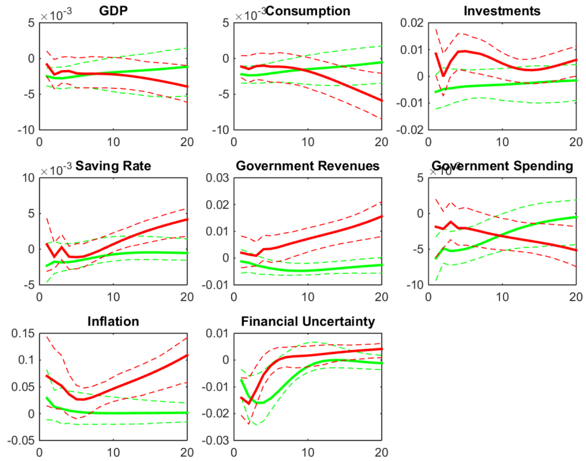

Figure 34: TVAR with sign nonlinearity, LMN financial uncertainty model. Contractionary shock. Specification without FFR and with uncertainty variable endogenous. Green lines refer to low-uncertainty regime, red lines to high-uncertainty one. Dashed lines are 68% confidence bands. IRFs for GDP, C, I and saving rate refer to different specifications. All other plots refer to the specification with GDP

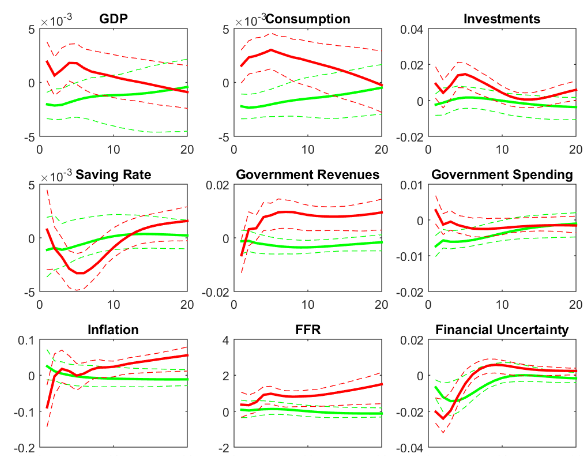

Figure 35: TVAR with sign nonlinearity, LMN financial uncertainty model. Contractionary shock. Specification with FFR and with uncertainty variable endogenous. Green lines refer to low-uncertainty regime, red lines to high-uncertainty one. Dashed lines are 68% confidence bands. IRFs for GDP, C, I and saving rate refer to different specifications. All other plots refer to the specification with GDP

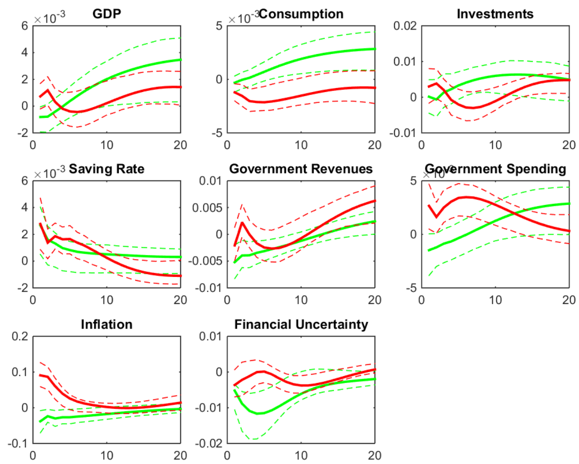

Figure 36: TVAR with sign nonlinearity, LMN financial uncertainty model. Expansionary shock. Specification without FFR and with uncertainty variable endogenous. Green lines refer to low-uncertainty regime, red lines to high-uncertainty one. Dashed lines are 68% confidence bands. IRFs for GDP, C, I and saving rate refer to different specifications. All other plots refer to the specification with GDP

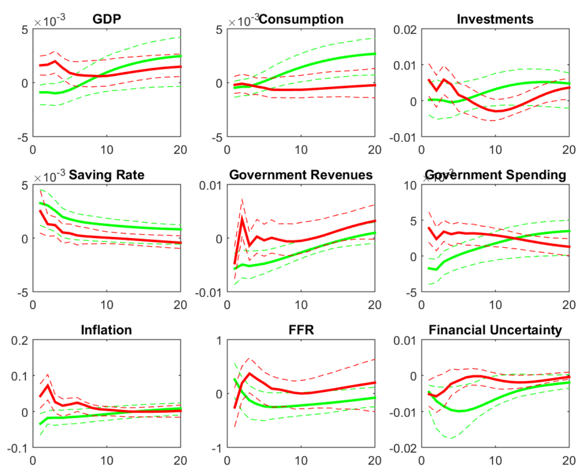

Figure 37: TVAR with sign nonlinearity, LMN financial uncertainty model. Expansionary shock. Specification with FFR and with uncertainty variable endogenous. Green lines refer to low-uncertainty regime, red lines to high-uncertainty one. Dotted lines are 68% confidence bands. IRFs for GDP, C, I and saving rate refer to different specifications. All other plots refer to the specification with GDP

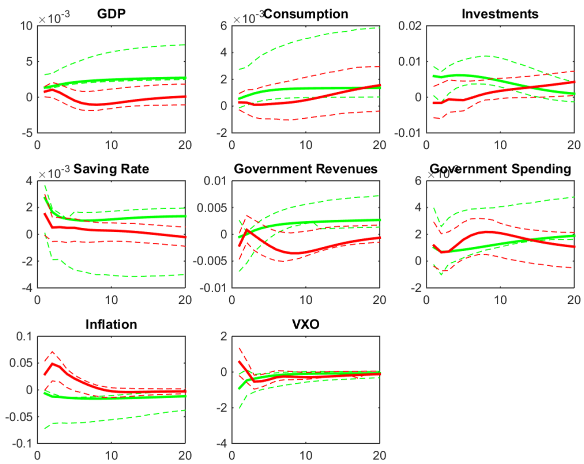

Figure 38: TVAR, VXO model. Specification without FFR and with uncertainty variable endogenous. Green lines refer to low-uncertainty regime, red lines to high-uncertainty one. Dashed lines are 68% confidence bands. IRFs for GDP, C, I and saving rate refer to different specifications. All other plots refer to the specification with GDP

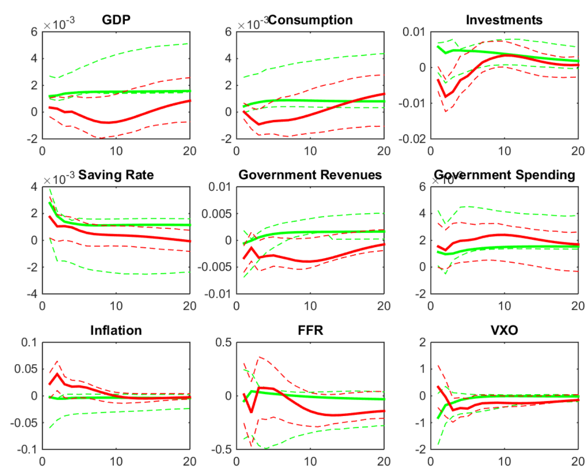

Figure 39: TVAR, VXO model. Specification with FFR and with uncertainty variable endogenous. Green lines refer to low-uncertainty regime, red lines to high-uncertainty one. Dashed lines are 68% confidence bands. IRFs for GDP, C, I and saving rate refer to different specifications. All other plots refer to the specification with GDP

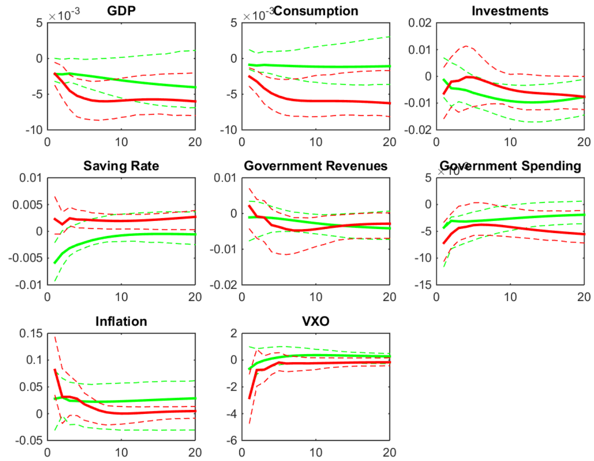

Figure 40: TVAR with sign nonlinearity, VXO model. Contractionary shock. Specification without FFR and with uncertainty variable endogenous. Green lines refer to low-uncertainty regime, red lines to high-uncertainty one. Dashed lines are 68% confidence bands. IRFs for GDP, C, I and saving rate refer to different specifications. All other plots refer to the specification with GDP

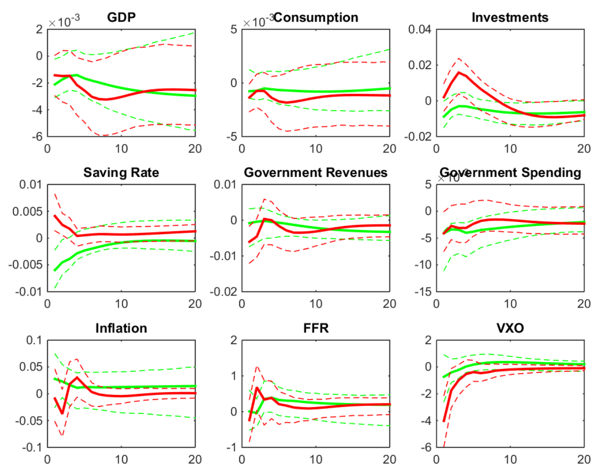

Figure 41: TVAR with sign nonlinearity, VXO model. Contractionary shock. Specification with FFR and with uncertainty variable endogenous. Green lines refer to low-uncertainty regime, red lines to high-uncertainty one. Dashed lines are 68% confidence bands. IRFs for GDP, C, I and saving rate refer to different specifications. All other plots refer to the specification with GDP

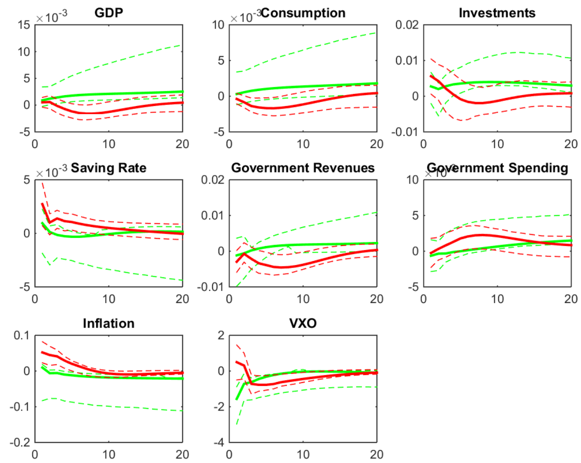

Figure 42: TVAR with sign nonlinearity, VXO model. Expansionary shock. Specification without FFR and with uncertainty variable endogenous. Green lines refer to low-uncertainty regime, red lines to high-uncertainty one. Dashed lines are 68% confidence bands. IRFs for GDP, C, I and saving rate refer to different specifications. All other plots refer to the specification with GDP

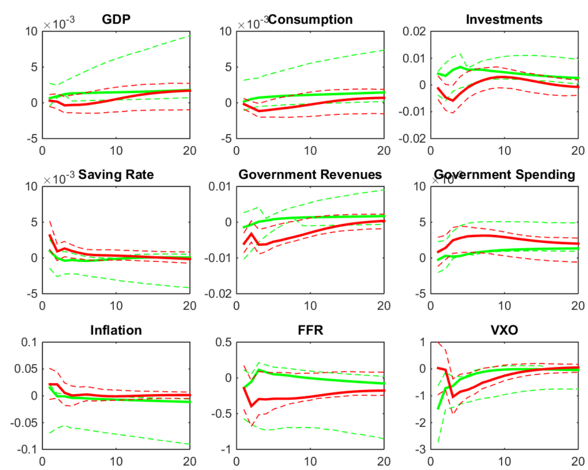

Figure 43: TVAR with sign nonlinearity, VXO model. Expansionary shock. Specification with FFR and with uncertainty variable endogenous. Green lines refer to low-uncertainty regime, red lines to high-uncertainty one. Dashed lines are 68% confidence bands. IRFs for GDP, C, I and saving rate refer to different specifications. All other plots refer to the specification with GDP

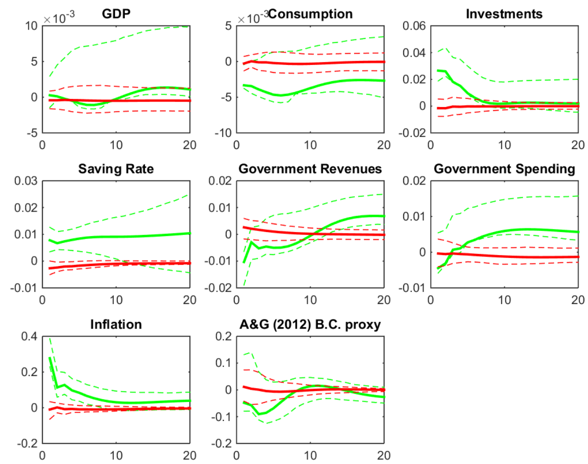

Figure 44: TVAR with sign nonlinearity, business cycle model. Contractionary shock. Green lines refer to recession regime, red lines to expansion one. Dashed lines are 68% confidence bands. IRFs for GDP, C, I and saving rate refer to different specifications. All other plots refer to the specification with GDP

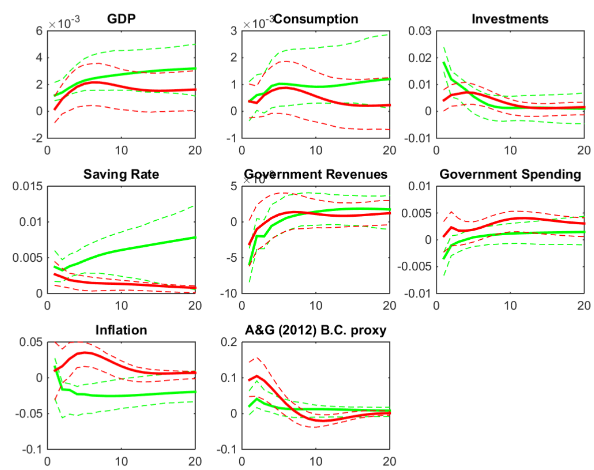

Figure 45: TVAR with sign nonlinearity, business cycle model. Expansionary shock. Green lines refer to recession regime, red lines to expansion one. Dashed lines are 68% confidence bands. IRFs for GDP, C, I and saving rate refer to different specifications. All other plots refer to the specification with GDP

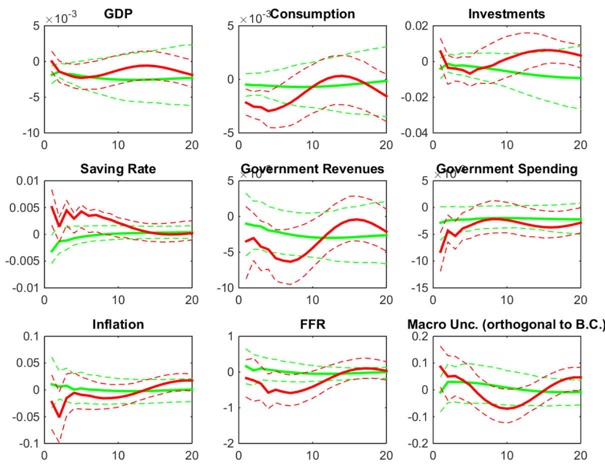

Figure 46: TVAR with sign nonlinearity, model with macroeconomic uncertainty residuals. Contractionary shock. Specification with FFR and with uncertainty variable endogenous. Green lines refer to low-uncertainty regime, red lines to high-uncertainty one. Dotted lines are 68% confidence bands. IRFs for GDP, C, I and saving rate refer to different specifications. All other plots refer to the specification with GDP

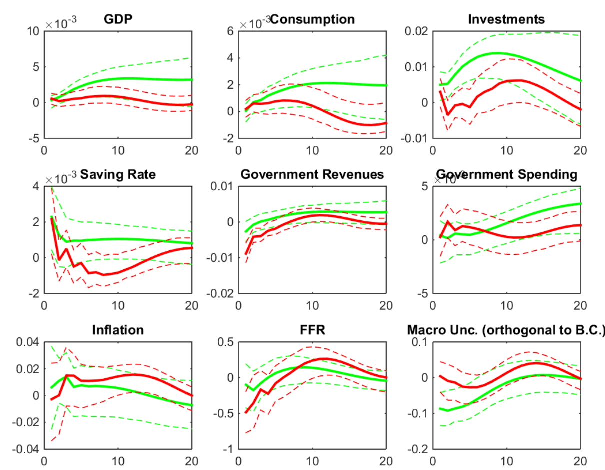

Figure 47: TVAR with sign nonlinearity, model with macroeconomic uncertainty residuals. Expansionary shock. Specification with FFR and with uncertainty variable endogenous. Green lines refer to low-uncertainty regime, red lines to high-uncertainty one. Dashed lines are 68% confidence bands. IRFs for GDP, C, I and saving rate refer to different specifications. All other plots refer to the specification with GDP

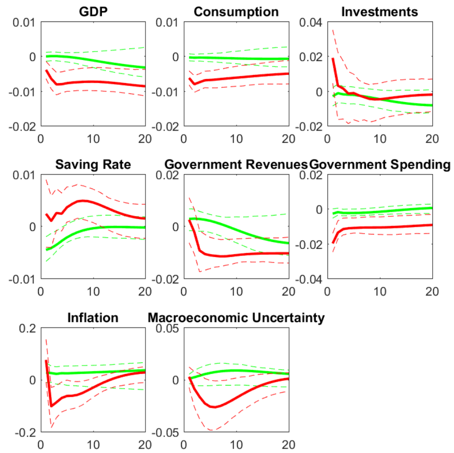

Figure 48: TVAR with sign nonlinearity, main specification, IFGLS model with regime-specific VCV matrix. Contractionary shock. Green lines refer to low-uncertainty regime, red lines to high-uncertainty one. Dashed lines are 68% confidence bands. IRFs for GDP, C, I and saving rate refer to different specifications. All other plots refer to the specification with GDP

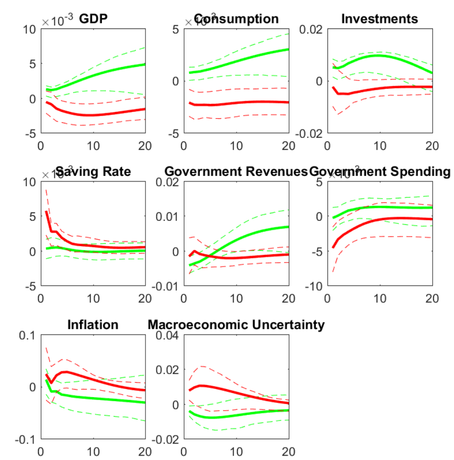

Figure 49: TVAR with sign nonlinearity, main specification, IFGLS model with regime-specific VCV matrix. Expansionary shock. Green lines refer to low-uncertainty regime, red lines to high-uncertainty one. Dashed lines are 68% confidence bands. IRFs for GDP, C, I and saving rate refer to different specifications. All other plots refer to the specification with GDP

Figure 50: TVAR with sign nonlinearity, contractionary shock, macroeconomic uncertainty model. Narrative shocks are residuals of a regression of Romer and Romer tax shocks on Ramey G shocks. Specification without FFR. Green lines refer to low-uncertainty regime, red lines to high-uncertainty one. Dashed lines are 68% confidence bands. IRFs for GDP, C, I and saving rate refer to different specifications. All other plots refer to the specification with GDP

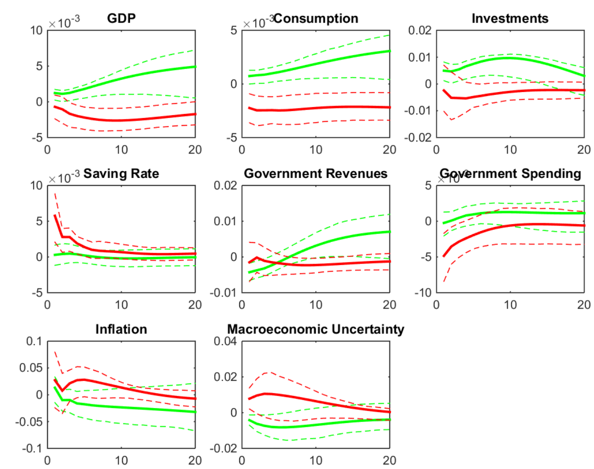

Figure 51: TVAR with sign nonlinearity, expansionary shock, macroeconomic uncertainty model. Narrative shocks are residuals of a regression of Romer and Romer tax shocks on Ramey G shocks. Specification without FFR. Green lines refer to low-uncertainty regime, red lines to high-uncertainty one. Dashed lines are 68% confidence bands. IRFs for GDP, C, I and saving rate refer to different specifications. All other plots refer to the specification with GDP

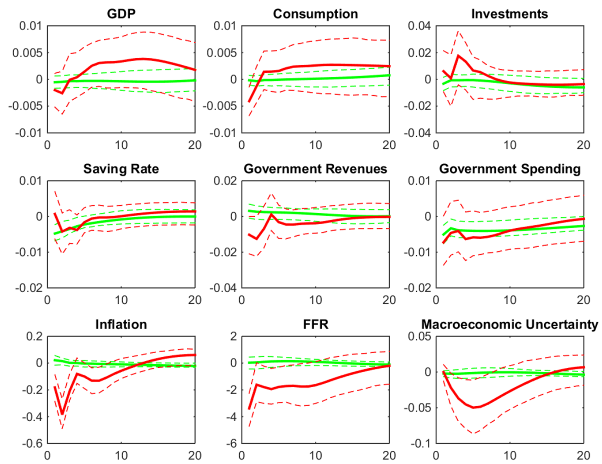

Figure 52: TVAR with sign nonlinearity, contractionary shock, macroeconomic uncertainty model. Narrative shocks are residuals of a regression of Romer and Romer tax shocks on Ramey G shocks. Specification with FFR. Green lines refer to low-uncertainty regime, red lines to high-uncertainty one. Dashed lines are 68% confidence bands. IRFs for GDP, C, I and saving rate refer to different specifications. All other plots refer to the specification with GDP

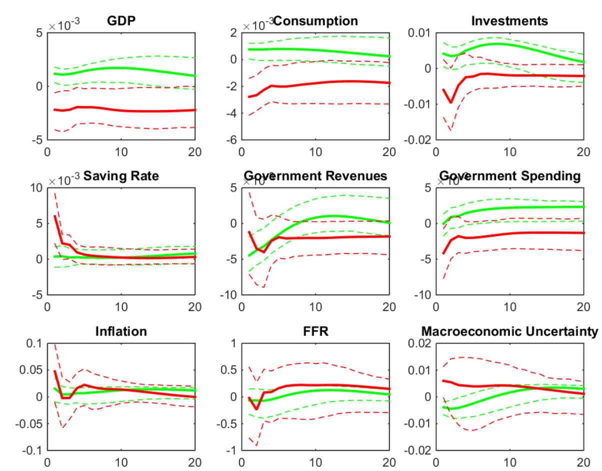

Figure 53: TVAR with sign nonlinearity, expansionary shock, macroeconomic uncertainty model. Narrative shocks are residuals of a regression of Romer and Romer tax shocks on Ramey G shocks. Specification with FFR. Green lines refer to low-uncertainty regime, red lines to high-uncertainty one. Dashed lines are 68% confidence bands. IRFs for GDP, C, I and saving rate refer to different specifications. All other plots refer to the specification with GDP

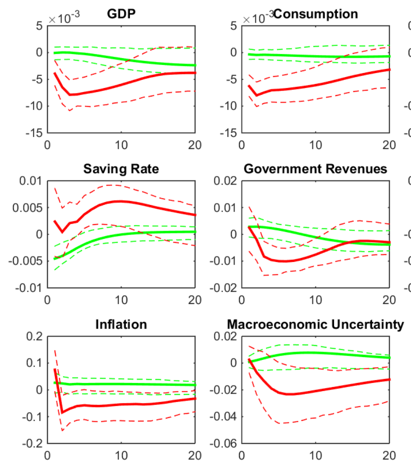

Figure 54: Generalized IRFs. TVAR with sign nonlinearity, contractionary shock, macroeconomic uncertainty model. Green lines refer to low-uncertainty regime, red lines to high-uncertainty one. Dashed lines are 68% confidence bands. IRFs for GDP, C, I and saving rate refer to different specifications. All other plots refer to the specification with GDP

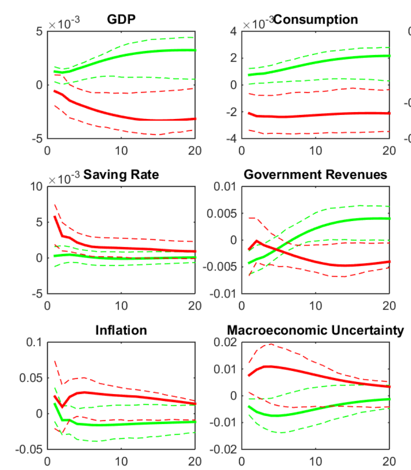

Figure 55: Generalized IRFs. TVAR with sign nonlinearity, expansionary shock, macroeconomic uncertainty model. Green lines refer to low-uncertainty regime, red lines to high-uncertainty one. Dashed lines are 68% confidence bands. IRFs for GDP, C, I and saving rate refer to different specifications. All other plots refer to the specification with GDP

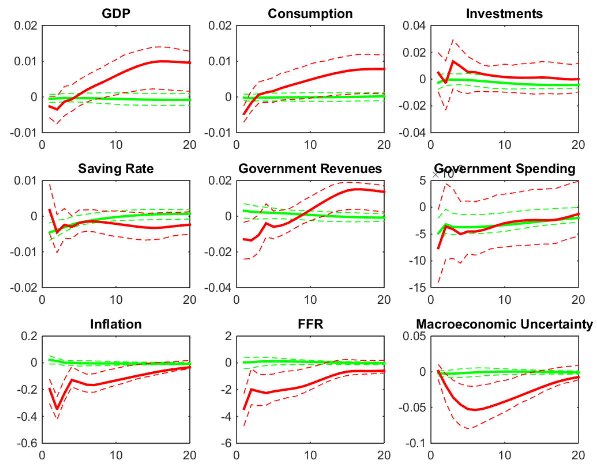

Figure 56: Generalized IRFs. TVAR with sign nonlinearity, contractionary shock, macroeconomic uncertainty model. Specification with FFR. Green lines refer to low-uncertainty regime, red lines to high-uncertainty one. Dashed lines are 68% confidence bands. IRFs for GDP, C, I and saving rate refer to different specifications. All other plots refer to the specification with GDP

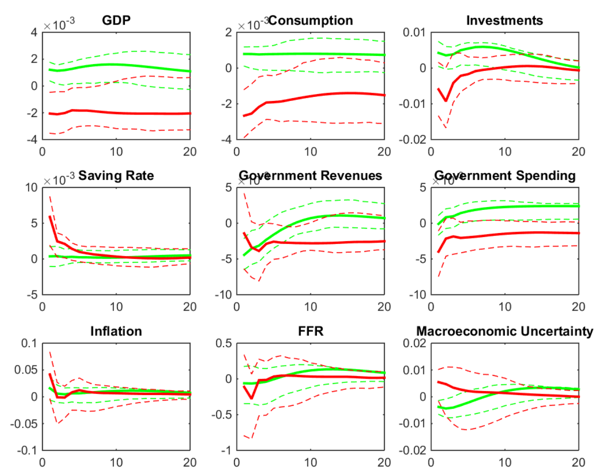

Figure 57: Generalized IRFs. TVAR with sign nonlinearity, expansionary shock, macroeconomic uncertainty model. Specification with FFR. Green lines refer to low-uncertainty regime, red lines to high-uncertainty one. Dashed lines are 68% confidence bands. IRFs for GDP, C, I and saving rate refer to different specifications. All other plots refer to the specification with GDP