

Opening the Red Budget Box: Nonlinear Effects of a Tax Shock in the UK*

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Abstract

This paper studies the real effects of an exogenous UK tax change in recessions and expansions. The tax shock is identified via the measure recently proposed by Cloyne (2013). Combining local projection techniques (Jordá, 2005) with smooth transition regressions (Granger and Teräsvirta, 1994), tax policy shock is found to affect UK macroeconomic variables depending on the phase of business cycle the economy is when tax shock occurs. A positive tax shock in recessions triggers a large, persistent, negative, and statistically significant reaction in output, consumption, investment, imports and government consumption. The results suggest that output tax multipliers are negative and above one (in absolute value) in recessions but not in expansions. The size and the sign of responses of a number of macroeconomic variables are also found to be state-contingent.

JEL classification: E32, E62, H20

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1 Introduction

Each year in Spring, the UK Chancellor of Exchequer puts the Budget Statement in a red bag, the red budget box, and carries it from 11 Downing Street to the House of Commons to read the Financial Statement and Government's proposals for change in taxation. Suppose the Chancellor proposes an unexpected increase in taxes, then the following questions arise: *What are the effects of tax changes on output? Are tax shock effects different in recessions and in expansions? How large are tax multipliers in the UK?*

This paper studies the heterogeneous impact of tax shocks in the UK in recessions and expansions. We show that unexpected tax changes exert different effects on a number of macroeconomic variables depending on the phase of business cycle the economy is in when the tax change occurs. Disentangling the (nonlinear) effects of taxes on the GDP components (consumption, investment, imports, exports, and government consumption), we highlight which variable drives the GDP reaction in recessions and expansions. We quantify tax multipliers on output and its components in "good" and "bad" times.

We find that the reaction of several variables is asymmetric along the business cycle. In particular, the position in the business cycle when the shock occurs statistically affects the sign and the size of tax multipliers on real variables. In recessions, tax multipliers are negative and above one (in absolute value) on consumption, investments, exports, imports, and output but below one on government consumption. In expansions, tax multipliers are estimated to be negative and above one (in absolute value) on investments but positive and above one on exports and government consumption. Multipliers are found statistically different across regimes. We show that the effects of tax shocks are quantitatively larger in recessions and smaller in expansions than those predicted by a linear framework.

These results support the empirical evidences that tax policy changes may generate different outcomes according to the macroeconomic conditions. Tagkalakis (2008), analysing a panel of nineteen OECD countries, finds that the effects of tax shocks on private consumption are different in recessions and expansions. This asymmetry can be explained by liquidity constraints of households that can be more severe in recessions than in expansions. Blanchard and Leigh (2013) emphasise that during the "Great Recession" the size of fiscal multipliers have been underestimated. This suggests that fiscal multipliers may vary over time.

Despite the importance to evaluate whether the effects of a tax shock is asym-

metric across the business cycle (i.e., in recessions and in expansions), the literature focusing on the nonlinear effects of tax change is scant. Indeed, it focuses on the linear effects of a tax shock on output on a single country (i.e., Pereira and Wemans, 2013; Hayo and Uhl, 2014; Cloyne, 2013), and particularly on the US economy (i.e., Blanchard and Perotti, 2002; Mountford and Uhlig, 2009; Romer and Romer, 2010; Favero and Giavazzi, 2012; Perotti, 2012; Mertens and Ravn, 2014), whereas a few studies have focused on a cross-country panel datasets (see e.g., Guajardo, Leigh, and Pescatori, 2011) or on multi-country analysis (i.e., Bénassy-Quéré and Cimadomo, 2012). As for the literature dealing with nonlinear effects of UK tax shocks, one exception is Baum, Poplawski-Ribeiro, and Weber (2012) which estimate the effects of a tax shock on output relying on a Threshold VAR. They find that the output tax multiplier is very small and not statistically significant. It means that whether the Chancellor of the Exchequer proposes a cut or an increase in taxes, his proposal is unlikely to stimulate or dampen the economic activity, whatever are the economic conditions.¹

Two issues make our aim challenging. Firstly, the identification of tax changes because of the endogeneity problem between tax revenues and GDP. For instance, tax revenues shocks might trigger output fluctuations, while shocks affecting output might cause revenue fluctuations. To overcome the endogeneity problem, two main approaches have been proposed in the empirical literature. The first one, pioneered by Blanchard and Perotti (2002), relies on structural vector autoregressive (SVAR) analysis in which cyclically adjusted tax revenues are used to proxy tax shocks, and it is based on some assumptions about the implementation lags in fiscal policymaking and on the calibration of the fiscal elasticity.² The second one, the narrative approach proposed by Romer and Romer (2010), identifies an unexpected tax change analysing written official records and distinguishing tax shocks due to reasons not related to countercyclical concerns

¹Afonso, Baxa, and Slavik (2011) study the nonlinear effects of a fiscal policy in Germany, Italy, the UK, and the US. However, using the debt ratio as a proxy for fiscal policy shock, they do not distinguish between revenues and government spending shock.

²In the Blanchard and Perotti (2002) approach a change in tax revenues depend on the automatic response of taxes to output and on exogenous tax changes. To purge the tax revenues from automatic stabilizers, they calibrate the elasticity of taxes to output via the OECD method and assumptions proposed by Giorno, Richardson, Roseveare, and van den Noord (1995) and van den Noord (2002). The elasticity of taxes to output is calibrated combining the estimation of elasticity of tax revenues to their tax base with the elasticity of tax base to output. The tax revenues purged by its automatic response to output are the cyclically-adjusted measure of tax revenues. Then, the calibrated elasticity is used to pin down the relations linking the reduced form residual to the structural shock in a SVAR framework. The identification of structural shocks is recovered relying on some assumptions about the implementation lags.

(exogenous) from those related to them (endogenous).³ Several concerns arise from the identification of tax shocks *à la* Blanchard and Perotti (2002), because it may fail to capture tax shifts that are exogenous. For instance, Romer and Romer (2010) argue that other non-policy movement (i.e., asset and commodity price fluctuation) may affect the cyclically-adjusted revenues and a SVAR may not to address the correlations between these factors. Caldara and Kamps (2012) find that the effects of tax shocks on output may be very sensitive to the calibrated elasticity. Furthermore, Auerbach and Gorodnichenko (2012) claim that the calibrated elasticity may vary across the business cycle. Secondly, Ramey and Zubairy (2014) raise another issue that may be behind biased results for the fiscal multipliers in SVAR analysis. The estimated size of fiscal multipliers may be very sensitive to the value of *ex post* conversion factor, i.e. the ratio of the GDP/fiscal variables, used to convert elasticity into multiplier when the model is estimated including logarithm transformed variables.⁴

Our analysis jointly tackles these two issues. We estimate a (linear) Structural VARs identifying the structural tax shock *à la* Blanchard and Perotti (2002). We set the elasticity of taxes to output borrowing two coefficient restriction's values proposed by Perotti (2005) and Cloyne (2013), 0.76 and 1.61, respectively. Then, we convert elasticities into multipliers using different *ex post* conversion factors. The results suggest that tax multipliers increase in the value of coefficient restrictions (i.e., lower when the coefficient restriction is set to 0.76 and higher when it is equal to 1.61). This result for the UK is in line with the one found by Caldara and Kamps (2008) for the US. They highlight that the effects of tax shock will be biased downward whether the calibrated elasticity is too small. Moreover, estimating two different sample sizes (1963:I-2001:II and 1955:I-2009:IV), we find that increasing the value of the coefficient restriction affects the persistence of tax shocks. Furthermore, the combination of identifying tax shock via coefficient restrictions with *ex post* conversion factors may lead to another bias on tax multiplier estimates (see Appendix A for details).

To overcome the tax shock identification problem discussed above, we identify the UK tax shocks using the measure constructed by narrative-approach and

³This method has been advocated to identify government spending shocks (see e.g., Ramey and Shapiro, 1998; Ramey, 2011), fiscal consolidations (see e.g., Devries, Guajardo, Leigh, and Pescatori, 2011; Guajardo, Leigh, and Pescatori, 2011), tax shocks in the US (Romer and Romer, 2010), in Portugal (Pereira and Wemans, 2013), in Germany (Hayo and Uhl, 2014), and in the UK (Cloyne, 2013).

⁴The transformation of variables in logarithm form is a common practice in the VAR literature, but not only. Indeed, Auerbach and Gorodnichenko (2013a) relying on Local Projection regressions use log-transformed variables.

proposed by Cloyne (2013), whereas to avoid the *ex post* conversion factor one we define the variables as in Hall (2009) and in Barro and Redlick (2011). To estimate the effects of tax shocks conditionally on the state of economy and to avoid dealing with some implicit assumptions of the regime-switching model, we combine the Local Projection (Jordá, 2005) estimations with smooth transition regressions (Granger and Teräsvirta, 1994).⁵

Our main results show that the impact of tax shocks on the macroeconomic variables is asymmetric over the business cycle. Researchers disagree over the (linear) effects of a tax shock in the UK. For instance, Perotti (2005), relying on the Blanchard and Perotti (2002) approach, finds that a positive tax shock has expansionary effects on output, opposite to the conventional wisdom. Cloyne (2013), identifying the tax shock à la Romer and Romer (2010), finds opposite results: an unexpected increase in taxes has negative and statistically significant effects on output (-0.5 and -2.15 over three years). We reconcile these differences considering the phase of the economy in which tax shock occurs. The difference of the results across regimes (recessions and expansion) lies on the relative position of the AD-AS curves. To rationalise these results we consider an AS curve which is relatively flat before the point of full employment level of national income, and then it becomes almost vertical afterwards. In expansions, the aggregate demand curve is in the steeper part of the aggregate supply curve and the effects of tax shocks on output are small. Conversely, in recessions the aggregate demand curve is in the flatter part of the aggregate supply curve, and therefore the variation of output to taxes is greater in recessions than in expansions. We show that the effects of such shocks are quantitatively different than those predicted by a linear framework. A linear estimation overshadows the effects of tax shocks across regimes because it works as an average of the two different effects. Our results are important for a policy standpoint, calling for a tailored use of fiscal policy instruments across the business cycle.

A battery of robustness checks, dealing with alternative specification of tax shocks and different specifications of baseline regressions, confirms the asymmetric effects of a tax shock on GDP and its components.

Our paper is close to Perotti (2005), Cloyne (2013), and Baum, Poplawski-Ribeiro, and Weber (2012). There are differences between their contributions

⁵The use of single-equation technique in a nonlinear framework has been also advocated by Auerbach and Gorodnichenko (2013a; 2013b; 2014), Owyang, Ramey, and Zubairy (2013), Ramey and Zubairy (2014), Ben Zeev and Pappa (2014), Leduc and Wilson (2003) and others as an simple alternative to the VARs.

and ours in terms of identification of tax shocks and model specification. First, Perotti (2005) relies on the Blanchard and Perotti coefficient restriction scheme, whereas we identify the tax shock via narrative tax shock measure provided by Cloyne (2013). Cloyne (2013) studies the linear effects of tax shocks on key macroeconomic variables. Conversely, we investigate the impact of tax shocks conditionally on the phase of the business cycle the economy is when tax shocks occurs. Second, Baum, Poplawski-Ribeiro, and Weber (2012) study the effects of tax shocks in a nonlinear specification and identifying the structural shock *à la* Blanchard and Perotti (2002). Differently, we identify the tax shocks via the narrative measure proposed by Cloyne (2013), and to estimate the effects of tax shocks on output, but also on its components, we rely on a nonlinear version of the Local Projection (Jordá, 2005) technique.

The remainder of this paper is organized as follows. Section 2 presents the linear Local Projection exercise and relative results. Section 3 extends the previous section focusing on a nonlinear framework. Section 4 provides some robustness checks, whereas section 5 concludes.

2 Data definition and Linear Model

We estimate the effects of a tax shock on UK macroeconomic aggregates relying on the Local Projection (LP) technique introduced by Jordá (2005). LP allows to project the value of the dependent variable shifted h periods ahead on the information set available at time t . Thus, those projections are local to each horizon.

Consider a h set of regressions for $h = 0, 1, 2, \dots, H$ for each variable of interest, \tilde{X}_{t+h} , such as output, consumption, investment, imports, exports and government consumption:

$$\tilde{X}_{t+h} = \alpha_h + \zeta_h + B_{Lh}(L)y_{t-i} + \theta_{Lh}\epsilon_t^{Cloyne} + u_{t+h} \quad (1)$$

where α and ζ are the constant and the linear trend, B_{Lh} is the coefficient matrix at each horizon h and y_{t-i} is the vector of control variables which include i lags of variables that usually enter in a "fiscal" VAR, such as the log real per-capita terms of the government spending, GDP and tax revenues.⁶ To

⁶Different model specifications have been proposed in the tax literature. For instance, Romer and Romer (2010) regress the dependent variable (GDP) on the contemporaneous value and 12 lags of their tax measure. Cloyne (2013) includes 12 lags of his tax measure, as in Romer and Romer (2010), but in an "augmented" VAR which includes the consumption, investment

avoid degree of freedom constraints due to lag length and dimension of covariate vector on the maximum horizon h (Jordá, 2005), we opt for a parsimonious specification of y_{t-i} which includes four lags for each variables, as in Auerbach and Gorodnichenko (2013a).⁷ The tax shock variable (ϵ_t^{Cloyne}) in equation (1) is the new tax change measure proposed by Cloyne (2013). It is constructed via the narrative approach proposed by Romer and Romer (2010) and allows to separate exogenous components of tax changes from the endogenous ones (i.e., tax policy change not due to countercyclical concern versus these due as response to the macroeconomic fluctuations). In particular, Cloyne's tax shock measure includes four categories of exogenous tax changes.⁸ Firstly, it includes "long-run" economic reforms not aimed at offsetting macroeconomic fluctuations. The second component is the "ideological" tax changes adopted for political reasons, whereas the third one refers to the "external change" (for example, imposed from a court judgments or European directives). The fourth component is the "deficit consolidation" not driven by current movement in deficit or as consequence of other macroeconomic shock but, for example, to anchor Government's credibility. The series is aggregated according the implementation date to avoid contemporaneous endogeneity of tax revenue to GDP. The changes in revenues are normalized by the GDP and expressed as percentage. Then, a change in Cloyne's measure will reflect the forecast "full year" change in revenues in each quarter. The fact of having an estimate of the unanticipated fiscal shock enables us to employ a uniequational approach to compute dynamic responses of a given macroeconomic variable of interest. In other words, we need not appeal to a VAR framework to identify the effects of an exogenous variations in taxes. The advantage of the uniequational approach is that it is less prone to model misspecification, hence – all else being equal - it reduces the risk of producing biased impulse responses. For further discussions on this approach, see Alesina, Favero, and Giavazzi (2014). The effects of a tax change (ϵ_t^{Cloyne}) on each variables of interest (\tilde{X}_{t+h}) are captured by parameter θ_{Lh} in equation (1). Thus, the IRFs are constructed as a sequence of estimated $\{\theta_{Lh}\}_{h=0}^{20}$.

The main advantage of this methodology for the tax multiplier estimations is

and GDP equations, as in Mertens and Ravn (2014). Favero and Giavazzi (2012) include only the contemporaneous value of the Romer and Romer (2010) tax shock in a VAR which models, among variables, also the revenues one. Our specification is very close to the one in Favero and Giavazzi (2012). However, we address the issue of different lag length of tax shocks to be included in our specification in the robustness check section.

⁷This lag specification is quite standard in the VARs estimated on quarterly data.

⁸The source for revenue estimates are the Financial Statement and Budget report and the official parliamentary record

that it does not require that the left-hand side variables in equation (1) should be specified in the same form as the right-hand side variables. This property allows to define each dependent variable of interest \tilde{X}_{t+h} as in Hall (2009), Barro and Redlick (2011) and Owyang, Ramey, and Zubairy (2013). In particular, \tilde{X}_{t+h} is defined as following:

$$\tilde{X}_{t+h} \approx (\ln X_{t+h} - \ln X_{t-1}) \frac{X_{t-1}}{GDP_{t-1}} \quad (2)$$

where $(\ln X_{t+h} - \ln X_{t-1})$ refers to the accumulated change from time $t-1$ to $t+h$, whereas the ratio X_{t-1}/GDP_{t-1} converts *ex ante* the percent change to pound change at each point on time, as in Owyang, Ramey, and Zubairy (2013). Thus, this specification overcomes the problem of *ex post* conversion factors, and avoid bias in the estimation of tax multipliers.

Jordà's method implies the serial correlation in the error terms. To account for it, we computed confidence intervals relying on the block bootstrap (Politis and Romano, 1992).⁹ We estimate equation (2) using quarterly data from 1955Q1-2009Q4. The beginning of the period is motivated by the availability of the quarterly data, whereas the end by the exogenous tax change measure. Table 1 summarizes the variables used and their sources.

3 The Nonlinear Model

Do tax multipliers change according to the state of the economy? Following Auerbach and Gorodnichenko (2013a; 2013b; 2014) we study the nonlinear effect of a fiscal shock on variables of interest combining the LPs (Jordà, 2005) with smooth transition regressions (Granger and Teräsvirta, 1994). The response of dependent variables \tilde{X}_{t+1} to a tax shock is estimated by the following regression:

$$\tilde{X}_{t+h} = F(z_{t-i})(B_{R,h}(L)y_{t-i} + \theta_{R,h}\epsilon_t^{Cloyne}) + (1 - F(z_{t-i}))(B_{E,h}(L)y_{t-i} + \theta_{E,h}\epsilon_t^{Cloyne}) + u_{t+h} \quad (3)$$

where R stands for Recession and E for Expansion. We estimate the equation (3) including a constant and a linear trend. Each variable of interest \tilde{X}_{t+1} is projected on the same vector of covariates y_{t-i} of the linear specification, and

⁹The procedure used implies: 1) run a regression at time $t+h$, obtain the estimators and calculate the fitted value and residuals; 2) resample a block of residuals (1) with replacement and calculate the bootstrapped dependent variable; 3) run the regression with the bootstrapped dependent variables and the original regressors; 4) repeat B-times by going back to 2). In our linear and nonlinear estimation B=1,000 and l=10.

$B_{R,h}$ and $B_{E,h}$ refer to coefficient matrices of the recessionary and expansionary phase, respectively. The lagged variables in y_{t-i} are used to control for the history of the shock, as in Auerbach and Gorodnichenko (2013a). The effect of a tax shock on \tilde{X}_{t+h} at horizon h is captured in recessions by $\theta_{R,h}$, whereas in expansions by $\theta_{E,h}$.

As in Auerbach and Gorodnichenko (2013a; 2013b; 2014), the transition of \tilde{X}_{t+1} from one regime to another is governed by a logistic function that depends on z_t :

$$F(z_t) = \frac{\exp(-\gamma z_t)}{1 + \exp(-\gamma z_t)}, \quad \gamma > 0, \quad z_t \sim N(0, 1) \quad (4)$$

The transition function in (4) is a monotonically increasing function of z_t , where F is a continuous transition function bounded between zero and one and z_t is the transition variable. The slope parameter γ determines the smoothness of the change between zero (strong expansions) to one (strong recessions), and the identification restriction is that $\gamma > 0$. If $\gamma \rightarrow \infty$ in (4), then equation (3) becomes a two-regime switching regression model.

Before estimating equation (3) for each variable of interest \tilde{X}_{t+h} , we formally test for the presence of nonlinearities. Linearity is tested replacing the transition variable $F(z_{t-i})$ by the third order Taylor series approximation around $\gamma = 0$, as suggested by Lukkonen, Saikkonen, and Teräsvirta (1988).

We test linearity as following:

$$X_t = w_t \beta'_0 + (\tilde{w}_t z_{t-i})' \beta_1 + (\tilde{w}_t z_{t-i}^2)' \beta_2 + (\tilde{w}_t z_{t-i}^3)' \beta_3 + u_t \quad (5)$$

where vector w_t contains four lags of covariates (log-real GDP, government spending, revenues) and the contemporaneous value of tax shock (ϵ_t^{Cloyne}). Testing the null hypothesis of linearity versus nonlinearity is equivalent to perform an LM (χ^2) test of $H'_0 : \beta_\iota = 0, \iota = 1, 2, 3$, against H'_1 : at least one $\beta_\iota \neq 0$. We perform the linearity test plugging in X_t each variable of interest and in z_{t-i} each potential transition variable, such as the lagged $(t-i)$ standardized backward-looking moving average (MA) over (j) quarter(s) of the output growth rate with $i \in I = 1, \dots, 5$ and $j \in J = 2, \dots, 8$. The choice of i is justified to avoid that tax shocks may have some contemporaneous feedback on the state of economy. Notice that all the transition variable candidates have been standardized in order to be comparable. Table 2 reports the p-value (multiplied by 100) of linearity tests. The tests suggest a clear rejection of the null hypothesis of linearity. We choose

for each variable of interest the transition variables $MA(j)$ lagged at time $t-i$ corresponding to the smallest p-value (Teräsvirta, 1988). That because whether there is a correct transition variable among the different alternatives, the power of the test is maximized against it. Table 2 highlights that the nonlinearity of the GDP, consumption, investment, exports is governed by a $MA(2)$ lagged at $t-1$, whereas that one of import and government consumption by a $MA(2)$ lagged at time $t-5$.

Then, we calibrate the smoothing parameters γ in order to match the probability of being in recession obtained applying the BBQ algorithm on the logarithm of the real GDP (more details in the Appendix B). We define a recessionary regime a period for which $F(z_t) \geq 0.85 \approx 0.15$. It means that the economy spends about 15% of the time in the recessionary state and 85% of the time in the expansionary one.¹⁰ This implies setting $\gamma = 1.7$. Figure 1 plots Cloyne's tax change measure versus the recessionary (shaded area) and expansionary phases,¹¹ whereas figures 2 and 3 refer to the transition variable z_t and transition function $F(z_t)$, respectively.¹²

Notice that one important advantage of the LPs is that the impulse responses incorporate the average transitions of the economy from one regime to another. According to Ramey and Zubairy (2014), the estimated coefficients in equation (3) depend on the characteristic of the economy from time t to $t+h$, given the initial conditions (the tax shock, the initial state of the economy, and the control variables). Since the control variables in equation (3) do not change at each horizon h , then the estimated coefficients on the covariates capture the average transition of the economy from one state to another occurring in the sample. Also, the estimated coefficients ($\theta_{R,h}$ and $\theta_{E,h}$) on the ϵ_t^{Cloyne} will reflect the effects of the tax shock on the future state of economy. For example, suppose that a tax shock has a negative effect on output in recessions and positive in expansions, and a tax shock occurs in an expansionary period bringing the economy in a recessionary one. Then, the estimated parameters $\theta_{E,h}$ will incorporate the transition of the economy from the expansionary to the recessionary regime

¹⁰The values of γ are in line with estimates obtained regressing in a logit model the dummy variables (R=1 and E=0) obtained by the BBQ algorithm on transition variables (results available upon request).

¹¹The correlation between the tax shock measure and $F(z_t)$ or $(1 - F(z_t))$ is equal to zero.

¹²In the transition function $F(z_t)$ (figure 3), the frequency of non-alternating points is high. It depends on the characteristic of the transition variable z_t . This is in line with Harding (2008) which show that in the UK "the frequency of non-alternating points is four times higher than the US". Of course, if z_t has some non-alternating points, this characteristic will be amplified in the transition function $F(z_t)$ in which those points are bounded between zero and one.

changing its values from positive to negative.¹³

4 Results

Figure 4 depicts the responses of GDP and its components to exogenous increase in taxes of 1% of GDP computed with our linear and nonlinear specification. Notice that in the linear specification the IRFs are constructed as a sequence of estimated $\{\theta_{Lh}\}_{h=0}^{20}$, whereas in recessions and expansions as $\{\theta_{Rh}\}_{h=0}^{20}$ and $\{\theta_{Eh}\}_{h=0}^{20}$ one, respectively. The blue dotted lines denote the IRFs in expansions, the red lines the ones in recessions, whereas the black lines the reaction of macroeconomic indicators estimated via the linear model.¹⁴ The shaded area represent the 16th and 84th percentile percentiles of the distribution of the responses at each horizon. The impulse responses can be interpreted as deviations from the baseline and expressed as percent change of GDP.

Focusing on the recessionary regime, a tax shock has negative effects on GDP and its components. In particular, the impact response of private consumption is negative (-1%), hitting its lowest value (-4.5%) 8 quarters after the shock occurs, then goes back to its steady-state. The investment (gross fixed capital formation) decreases and reaches its trough at -1.3%. Tax shock is found to affect statistically and negatively exports and imports. On impact, imports decrease by -0.3% and, after it troughs at around -2%, then gradually goes back to zero. The positive response of government consumption in the first three quarters is not statistically significant. However, when it troughs at -1.2%, the response becomes statistically significant. Overall, the above effects translate in the output's response. Indeed, following a tax shock the output decreases on impact by -1.2% and hits its lowest value at -4.9% eight quarters after the shock, then gradually returns to the steady-state.

Next, we look at the response of macroeconomic aggregates to a tax shock in expansions. A tax shock has positive effects on consumption for the first nine quarters, although very close to zero and not statistically significant. After this,

¹³Using a SVAR we can account for this feedback only through Generalised IRFs, as in Caggiano, Castelnuovo, Colombo, and Nodari (2015). As noted by Owyang, Ramey, and Zubairy (2013), the difference between GIRFs and LPIRFs is based on how the two IRFs account for this feedback: in the GIRFs using the response at time $t-1$ to estimate the response at time t , whereas in LPs computing the average h -period-ahead value forecast given the information set at time t . See Owyang, Ramey, and Zubairy (2013) for a careful discussion and comparison between the GIRFs and the LPIRFs

¹⁴See Auerbach and Gorodnichenko (2013a), note 6, for analytic comparison between the LPIRFs and the conventional IRFs.

the reaction becomes negative and statistically significant. On impact, the shock affects positively investments (0.12%). However, such reaction is not statistically significant. Also, tax shock is found to not affect statistically the impact reaction of imports and exports. Conversely, government consumption reacts statistically significant and positively to a tax shock increasing on impact by 0.2% and, after reaching its peak at -1.1%, then gradually goes back to zero. The reaction of output to tax shock it is not statistically significant for the first eighteen quarters.

Turning to the linear estimation results, the private consumption decreases on impact by -0.6% hitting a trough of -2.1% , sixteen quarters after the shock occurs. Afterwards, consumption gradually returns to its steady-state. Investment decreases on impact by a small amount (-0.1%) and hits the trough (-0.5%) in the 4th quarter. Tax shock does not affect exports in the short-run, whereas it has a negative and persistent effects on imports. Our estimations predict a positive reaction of government consumption, albeit small. An exogenous tax increase has a negative, statistically significant, and persistent effect on output. The GDP decreases on impact by -0.5% and troughs at -1.8% , 17 quarters after the initial shock, then slowly goes back to its steady state.

Figure 4 shows that the effect of tax shocks varies across the business cycle. In recessions, the increase in taxes reduces consumptions. This results accords with the analysis of Tagkalakis (2008): since the fraction of liquidity constrained households is likely to increase, the increase in taxes decreases their disposable income. A tighter fiscal policy decreasing the disposable income of households has negative wealth effects, and therefore households consume less. Conversely, in expansions the negative effect of an increase in taxes is counteracted by an increase in government consumption. It turns out that the reaction of private consumption is not statistically significant. With regard to output, the results have some similarities to consumption. In recessions, the shock decreases output, but this effect disappears in expansions. Since in our sample consumption represents 57% of GDP, the reaction of output is likely to be driven by the reaction of consumption. This tendency also holds in expansions. Turning to investment, our results show that an increase in taxes has negative effects, both in recessions and in expansions. The increase in taxes reduces the business profits and the investment financed by those profits. The response of imports and exports is asymmetric across the business cycle. In recessions, imports strongly decrease likely because of the fall in income, and therefore in domestic demand for for-

eign goods. The reaction of exports may depends on the exchange rate¹⁵ and on external factors. Interestingly, imports and exports increase in expansions.

The linear IRFs highlight that a linear estimation overshadows the asymmetric effects of macroeconomic variables to tax shocks as it works averaging up the two different effects across the business cycle. The linear estimation tends to underestimate the real effects to a tax shock, whereas it overestimates the ones in expansions.

Overall, our results predict asymmetric effects of tax shocks across the business cycle. The results can be read through the lenses of the AD-AS model. Suppose that the economy is producing at its full employment level of natural income and the aggregate supply curve is flat, and becomes steeper and steeper and vertical at this point. If the economy starts from its equilibrium level and there is an expansionary phase, the aggregate demand shifts rightwards and the impact on output will be small, since the aggregate supply is almost vertical. The only effect is on prices. If the economy is in expansions and the government increases taxes, the new aggregate demand curve will shift towards to the original curve leading to a small loss in output. If the economy is in recession, the original aggregate demand shifts on the left. In this case, the movement of the aggregate demand is happening in a point of the aggregate demand that lies flatter than the one considered before. A backwards shift of the AD curve will affect output negatively stronger than before. Suppose the economy is in a recessionary phase and government increase taxes. This causes a further movement toward left yet in even flatter part of the aggregate supply curve. The negative effects on output of this policy intervention will be in absolute value stronger than the same policy intervention that happens during expansions. The difference between the two phases of the economy (recessions and expansion) lies on the relative position of the AD-AS curves. In expansions, the AD curve is in the steeper part of the AS curve and the effects on output are small. Conversely, in recessions the AD curve is in the flatter part of the AS curve, and therefore the $|\frac{\Delta Y}{\Delta T}|^{Rec} > |\frac{\Delta Y}{\Delta T}|^{Exp}$.

¹⁵Notice that the UK has experimented different exchange rate regimes in the postwar period. Indeed, until 1972 it was part of the Bretton Woods system. From 1972 to 1990 it adopted a semi-managed floating regime. From 1990 to 1992 the UK was part of the European Exchange Rate Mechanism. From 1993 the UK has adopted a floating exchange rate regime. Studying the reaction of the exchange rate to a tax shock is already in the agenda. However, it suffices here to say that focusing on the subsample 1972-2009 -according to Ilzetzki, Mendoza, and Végh (2013) can be considered a flexible exchange rate regime- and adding among the covariates the real exchange rate does not affect the results.

5 Tax Multipliers

How large are the cumulative tax multipliers in the UK? Are tax multipliers state-dependent? Table 3 reports cumulative tax multipliers from one to five years for all the variables of interest computed *à la* Owyang, Ramey, and Zubairy (2013), both for the linear and nonlinear specification. The cumulative multipliers are useful to capture both short-run and permanent tax shock effects. The cumulative tax multipliers from one to five years are computed as the ratio of the cumulative change in the variable \tilde{X}_{t+h} until horizon H to the cumulative change in tax revenues, in response of an unanticipated tax shocks identified by ϵ_t^{Cloyne} ¹⁶

From columns (1) to (3) the table reports the median cumulative tax multipliers for the recessionary, expansionary and linear case, respectively. Bold numbers indicate the multipliers statistically significant at the 68% level, whereas in brackets the related confidence intervals is reported.

In recessions, tax multipliers are statistically significant and negative for all the variables considered. The output and private consumption cumulative multipliers are always larger than one (in absolute value), even for the 1-year cumulative multiplier. The multipliers of imports quantitatively mimic the multipliers for consumption. Also for exports, tax multipliers are larger (in absolute value) than one. The multipliers of investment are close to one (in absolute value) only for the two-year cumulative multiplier, while for government consumption the multipliers are negative but smaller than one.

In expansions, output and private consumption tax multipliers are not statistically significant for the first four-years, whereas for investment ones are negative and larger (in absolute value) than in recessions for the four and five-year cumulative multipliers. The exports and government consumption tax multipliers are positive and larger than one, whereas the import ones are not statistically significant.

Turning to the linear tax multipliers, results show that the cumulative output tax multipliers range between -1.3 (1-year tax multiplier) and -2 (4-year tax

¹⁶Cumulative multipliers are computed as $\frac{\sum_{h=1}^H \Delta \tilde{X}_{S,t+h}}{\sum_{h=1}^H \Delta \text{Revenues}_{S,t+h}}$ with $S=\{L, R, E\}$ and $H=4, 8, 12, 16, 20$. To obtain the estimated θ_{Sh} coefficients of the variable in the denominator (tax revenues), we transform the tax revenues series as in (2), plug it in equation (1) and (3) and we run h set of regressions. After having obtained the distribution of the responses of the tax revenues, we compute the tax multipliers dividing the sum of the distribution of the responses of each variable of interest (θ_{Sh}) until horizon H to the counterpart distribution of the responses of revenues (θ_{Sh}).

multiplier). The tax shock has a bigger effect on the private consumption with multipliers estimated between -1.5 and -2.3 , whereas these on investment are lower and more stable than the ones on consumption (from -0.5 to -1). The tax multipliers on imports are negative and statistically significant overall the periods, ranging from -1 (1 year cumulative multiplier) to -0.7 (5 year cumulative multiplier). Turning to the government consumption multipliers, a tax shock increases the government consumption around 0.5 , albeit very small.

Statistically evidences in favor of state-dependent tax multipliers. According to our estimation tax multipliers are state-dependent. To the best of our knowledge, only Baum, Poplawski-Ribeiro, and Weber (2012) have studied the nonlinear effect of tax shock in the UK (via a Threshold VAR), albeit focusing on the reaction of output. They apply the Blanchard and Perotti (2002) identification strategy and find that a tax increase has negative (-0.4) or positive (0.2) effect on the 1-year output tax multiplier depending on whether the economy is in the "positive output" regime or in the "negative" one, respectively. However, the estimated multipliers are not statistically significant.¹⁷

To statistically support whether the multiplier are different according the regimes, we test the difference between the multipliers estimated under recessionary and expansionary regimes.¹⁸ We run this test for all our variables of interest. Table 4 reports the results. If the value of zero is not included in the confidence bands, then there will be evidence of state-dependent tax multipliers. Results show that we find statistically significant evidences of nonlinearity in the tax multipliers for the GDP and its components. Overall, whether we jointly read table 3 and table 4, there are statistically evidences that tax multipliers in UK are state-dependent. Thus, evaluating tax multipliers in a linear framework may lead to underestimate the effects of increasing taxes in recessions and overestimated the ones in expansions. Blanchard and Leigh (2013) highlight that for the recent recession the size of fiscal multipliers has been underestimated. We highlight that macroeconomic conditions can affect fiscal multiplier estimates.

¹⁷Baum, Poplawski-Ribeiro, and Weber (2012) identify the tax shock in two steps. First of all, they eliminate from the tax revenue series cases of revenues change not related to fiscal policy decisions (i.e., movement in commodity price and asset). To this aim, they compare the IMF (2010) action-based measure with the cyclical adjusted primary balance (CAPB) and whether the divergence between the two measures was large, then revenue changes unrelated to fiscal policy decision are removed from the revenue series. Doing that, the revenues series reflects change in output and fiscal policy decisions. Secondly, to identify a structural tax shock unrelated to movement in output they apply the Blanchard and Perotti (2002) procedure.

¹⁸The empirical density of the difference between multipliers is based on 1,000 realizations of such differences for each horizon h .

6 Robustness checks

Our results highlight that tax multipliers in UK are state-dependent. In this section, we check the robustness of our findings.

Alternative measure of tax shocks. We have identified the tax shock in equation (1) and (3) via the contemporaneous value of the Cloyne tax shock (ϵ_t^{Cloyne}). This specification is close to the Favero and Giavazzi (2012) one, given that we also include in vector y_t lagged values of revenues.¹⁹ The reasons of this specification are twofold. Firstly, we treat ϵ_t^{Cloyne} as an observable and exogenous shock to revenues.²⁰ Secondly, this specification allows us to preserve degrees of freedom given our sample size. Notice that we have extended the linear analysis to the nonlinear one. Whether the inclusion of lagged values of the ϵ_t^{Cloyne} may be not problematic in terms of degree of freedom in the linear specification, it will be in the nonlinear one since the parameters to be estimated double.

As highlighted by Cloyne (2013), the majority of tax changes captured by the narrative measure ϵ_t^{Cloyne} are announced and implemented within the same quarter. However, lagging the tax shock allows to account for the possibility of a partial revision to tax shocks. Another issue rises since tax shock is constructed on the base of policymakers' intentions. For instance, policymakers may declare that tax changes are made for reason unrelated to movements in macroeconomic variables, while in reality they are concerned about these. We tackle the two above issues by regressing the ϵ_t^{Cloyne} on its own 12 lags and on the covariates that enter in vector y_t . Then, we select the number of terms of the MA(p) process by checking the statistical significance of such terms. It turns out that $p=4$ is the last significant term of the process. Thus, we identify the tax shock via the residual obtained regressing ϵ_t^{Cloyne} on its own 4 lags and on the covariates that enter in vector y_t . In this way, we identify a *residual* tax shock purged from the potential revision in tax changes and movements of some macroeconomic variables. The correlation between the ϵ_t^{Cloyne} and the alternative (residual) tax

¹⁹Romer and Romer (2010) study the effect of a tax shock on the US GDP regressing the GDP on the contemporaneous value and 12 lags of their tax measure. Favero and Giavazzi (2012) add to the Romer and Romer (2010) specification some fiscal variables. They show that the truncated moving average representation of Romer and Romer (2010) shocks give biased estimates of the output reaction because of correlation between the Romer and Romer (2010) shocks and distant lags of output and taxation. Because of that they identify the shock via the contemporaneous value of the Romer and Romer (2010) shock (exogenous term) and treat it as the structural shock of the one of the variable included in the VAR (revenues).

²⁰Notice that correlation between the ϵ_t^{Cloyne} and the lagged values of tax revenues, included in vector y_t , is low and range between 0.02 and 0.05.

shock measure is 0.94. We plug such residual in equation (1) and (3) instead of ϵ_t^{Cloyne} , and we estimate them. Figure (5) plots the Cloyne tax measure (in our notation ϵ_t^{Cloyne}) versus the alternative measures of tax shock identified by the residual of the above exercise, whereas table 5 reports tax multipliers from this exercise. The results are in line with the ones obtained in our baseline model (table 3).

The Cloyne's measure used to identify tax shocks includes, among the sub-categories, the tax shocks driven by "deficit consolidation" (DC, henceforth) motivations. As pointed out by Cloyne (2013), the "DC" subcategory is different from the Romer and Romer (2010) one. In Romer and Romer (2010), the "DC" category is treaded as exogenous because it reflects past shocks, not related to macroeconomic conditions. For instance, it captures an increase in taxes to reduce an inherited deficit to long-run economic reasons. Conversely, Cloyne (2013) notes that in the UK part of the tax changes due to fiscal consolidation are related to current macroeconomic conditions (endogenous). For that reason, the "DC" in Cloyne (2013) is more restrictive than in Romer and Romer (2010) one and, it includes only 12 observations. Once again, since tax shock is constructed on the base of policymakers' intentions, we verify the robustness of our results excluding from the ϵ^{Cloyne} the DC subcategory. Table 5 shows that our baseline results, both in the linear and nonlinear specification, are not affected.

Alternative specification. Francis and Ramey (2009) and Owyang, Ramey, and Zubairy (2013) highlight the importance of including a quadratic trend in the US post-WWII period because of the slow-moving demographics. We address this issue for the UK replacing the linear time trend in equation (1) and (3) with the quadratic one. The results from these exercises are reported in table 5.

Furthermore, to control for monetary policy actions we add to the control vector y_t of equation (1) and (3) the policy rate and the inflation.²¹ Table 5 shows that adding other variables to our baseline specification, both in the linear and nonlinear specification, does not affect are results.

Alternative values of the smoothness parameter. We calibrate the smoothness parameter γ to match the frequencies of the UK recessions obtained via the BBQ algorithm (see Appendix B), in our sample $F(z_t) \geq 0.85 \approx 0.15$. According to our metric, the UK economy spends the 15% in recessions. To check the sensitivity of our results to the alternative calibrations of the smoothness

²¹The inflation rate is the annualized Retail Price Index, since the Consumer Price Index is not available from 1955.

parameter, we (re)calibrate γ in order to include in our sample a number of recessions ranging from 10% to 20%. The lower bound is set by the minimum amount of observations each regime should contain (Hansen, 1999). Table 5 show that our results are robust to alternative calibrations of γ parameters.

Alternative indicators of states. In our baseline specification, we discriminate between recessions and expansions via the standardised backward-looking moving average over 2 quarters of the real GDP growth rate. To verify the robustness of our results using alternative indicators of the economic cycle, we run equation (3) plugging in z_{t-i} the standardised deviation of: a) the growth rate (moving average over 2 quarters) of the output from the HP-filtered trend; b) change in the unemployment rate from the HP-filtered trend. To avoid smoothing out deep recessions and strong expansions, we use a large value of the smoothing parameter in the filter ($\lambda=10,000,000$).²² The results are qualitatively in line with our baseline results.

Figure 6 and 7 plot the impulse responses of GDP and its components from the above exercises. Our robustness checks confirm the nonlinearity of tax shock effects on real variables.

7 Conclusions

This paper studies the nonlinear effects of an exogenous tax increase in the UK. The tax shock is identified by the new measure proposed by Cloyne (2013). We model non-linearity via the combination of local projection technique (Jordá, 2005) and smooth transition regressions (Granger and Teräsvirta, 1994). We find that the sign and the size of tax multipliers on real variables change according to the states of economy. In recessions, a positive tax shock dampens the economic activity. The (negative) reaction of output is mainly driven by a fall in private consumption. In expansions, output and consumptions do not respond to a tax shock in the short-run. The reason can be found in the asymmetric reaction of government consumption across the business cycle. Since in expansions government consumption reacts positively to tax shocks, it plays an important role in counteracting the (negative) effect of such shock on output and consumption (but not on investment).

Other studies in the literature, as Perotti (2005) and Cloyne (2013), find

²²Our results are robust using a smoothing weight equal to 1,000,000,000 as in Auerbach and Gorodnichenko (2014). Results not shown here for the sake of brevity, but available upon request.

contrasting results: a positive tax shock has expansionary effect (albeit close to zero) in Perotti (2005), and contractionary one in Cloyne (2013). We reconcile these differences considering the state of the business cycles the economy is when exogenous tax change occurs.

The results documented in this paper lead to new research questions. For example, we have seen that following a tax shock the reaction of imports is different according to the state of economy. It would be interesting to study whether the UK tax shock has some (nonlinear) spillover effects on its trade partner countries. Moreover, Romer and Romer (2010) have constructed a narrative-based tax shock measure for the US. It may worth studying the asymmetric effects of a tax shock in the US and UK, to compare the nonlinear effects of a tax shock in a relatively close (US) versus a small open economy (UK).

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Table 1: Data Sources

Series	Description	Sources
GDP	Real GDP	ONS
Nominal GDP	GDP in current prices	ONS
Consumption	Final household consumption expenditure	ONS
Investment	Gross fixed capital formation	ONS
Imports	Trade in goods and services: Total imports	ONS
Exports	Trade in goods and services: Total exports	ONS
Population	UK total population	Eurostat
Inflation	Change in Retail Prices Index	ONS
Interest rate	Official Bank rate	Bank of England
Government consumption	Government consumption of goods and services	ONS
Tax revenues	Total tax and NI receipts	ONS
Cloyne's Tax Shocks	Exogenous tax changes (Cloyne, 2013)	AER's website

Table 2: Linearity Tests

GDP	z_{t-i}	MA(2)	MA(3)	MA(4)	MA(5)	MA(6)	MA(7)	MA(8)
	t-1	0.00	0.03	0.15	0.03	47.25	84.03	82.97
	t-2	0.38	1.03	0.24	0.05	88.23	95.53	80.73
	t-3	7.68	0.18	3.32	1.71	95.17	93.58	98.44
	t-4	0.54	5.64	2.32	74.12	86.87	96.51	99.35
	t-5	52.3	39.04	6.65	17.13	98.79	99.90	96.69
Priv. Cons.	z_{t-i}	MA(2)	MA(3)	MA(4)	MA(5)	MA(6)	MA(7)	MA(8)
	t-1	0.02	1.34	0.83	0.83	0.83	2.40	3.35
	t-2	3.62	7.62	3.22	1.03	32.14	24.87	17.38
	t-3	10.05	0.61	6.65	12.69	33.94	42.82	19.95
	t-4	2.93	5.01	8.23	26.47	22.42	31.45	60.84
	t-5	28.92	22.69	47.32	47.68	51.51	70.82	60.15
Investments	z_{t-i}	MA(2)	MA(3)	MA(4)	MA(5)	MA(6)	MA(7)	MA(8)
	t-1	0.27	0.36	9.54	24.69	9.39	14.17	25.80
	t-2	25.71	27.62	56.52	42.30	65.88	72.11	66.68
	t-3	63.62	73.92	70.80	74.74	82.36	90.02	97.25
	t-4	28.91	42.24	60.84	60.08	98.49	99.81	98.58
	t-5	95.04	64.13	77.31	78.84	56.96	88.74	70.94
Exports	z_{t-i}	MA(2)	MA(3)	MA(4)	MA(5)	MA(6)	MA(7)	MA(8)
	t-1	7.92	42.68	65.28	68.47	47.25	84.03	82.97
	t-2	47.74	74.95	51.78	21.44	88.23	95.54	80.73
	t-3	94.88	92.55	55.31	81.69	95.17	93.58	98.44
	t-4	51.80	94.22	92.96	90.19	86.87	96.51	99.35
	t-5	46.86	98.17	86.31	95.35	98.79	99.90	96.69
Imports	z_{t-i}	MA(2)	MA(3)	MA(4)	MA(5)	MA(6)	MA(7)	MA(8)
	t-1	2.89	3.78	0.91	0.61	3.06	2.31	5.00
	t-2	8.33	26.78	23.52	2.99	10.72	24.38	64.44
	t-3	9.73	5.66	9.85	11.67	19.79	63.87	53.09
	t-4	11.30	2.39	26.53	17.06	68.56	50.59	29.23
	t-5	0.56	8.74	1.01	43.21	44.37	45.44	25.17
Gov. Cons.	z_{t-i}	MA(2)	MA(3)	MA(4)	MA(5)	MA(6)	MA(7)	MA(8)
	t-1	52.39	67.84	55.39	2.54	3.31	0.21	0.02
	t-2	61.03	9.04	3.12	2.23	0.63	0.02	1.34
	t-3	76.75	14.12	0.93	2.44	0.03	0.65	19.88
	t-4	12.82	0.25	0.84	0.03	2.20	1.91	1.78
	t-5	0.00	0.44	0.32	2.63	6.12	7.08	5.13

Notes: P-values (multiplied by 100) of linearity tests of variables of interest (GDP, private consumption, investments, exports, imports and government consumption). The linearity test is run considering different potential transition variable candidate z_{t-i} , such as the lagged ($t-i$) backward-looking moving average (MA) over (j) quarter(s) of the output growth rate with $i \in I = 1, \dots, 5$ and $j \in J = 2, \dots, 8$. In bolds the transition variable corresponding to the smallest p-value that governs the non-linearity of variables indicated in the left column.

Table 3: Cumulative Tax Multipliers (baseline)

		Cumulative Multipliers			Cumulative Multipliers				
		Recession (1)	Expansion (2)	Linear (3)	Recession (1)	Expansion (2)	Linear (3)		
		Horizon							
		Horizon							
GDP	4	-1.79 [-2.91, -0.98]	0.26 [-0.66, -0.68]	-1.30 [-2.56, 0.63]	Priv. Cons.	4	-2.01 [-3.31, -1.17]	0.14 [-0.53, 0.84]	-1.57 [-2.76, -0.97]
	8	-2.90 [-4.43, -1.97]	0.76 [-0.06, 1.52]	-1.64 [-2.47, -1.12]		8	-2.88 [-4.33, -1.93]	0.48 [-0.00, 1.10]	-1.82 [-2.66, -1.36]
	12	-2.51 [-3.64, -1.78]	0.17 [-0.60, 1.03]	-1.79 [-2.56, -1.30]		12	-2.50 [-3.61, -1.83]	0.18 [-0.36, 0.76]	-2.08 [-2.81, -1.63]
	16	-2.04 [-2.81, -1.54]	-0.72 [-1.73, 0.21]	-2.05 [-2.71, -1.55]		16	-1.94 [-2.64, -1.48]	-1.09 [-2.31, -0.24]	-2.37 [-3.08, -1.91]
	20	-1.70 [-2.36, -1.32]	-2.32 [-5.02, -0.72]	-1.77 [-2.31, -1.39]		20	-1.72 [-2.29, -1.31]	-2.37 [-5.60, -1.0]	-2.22 [-2.80, -1.83]
Investments	4	-0.86 [-1.53, -0.46]	-0.37 [-1.11, 0.16]	-1.01 [-1.74, -0.63]	Exports	4	-1.96 [-3.26, -1.13]	1.52 [0.49, 3.58]	-0.17 [-0.58, 0.15]
	8	-1.03 [-1.60, -0.65]	-0.41 [-0.89, -0.06]	-0.90 [-1.32, -0.65]		8	-1.83 [-2.73, -1.16]	1.66 [0.92, 2.93]	-0.23 [-0.51, 0.02]
	12	-0.64 [-0.96, -0.42]	-0.63 [-1.20, -0.23]	-0.71 [-1.00, -0.53]		12	-1.48 [-2.13, -1.08]	1.98 [1.15, 3.61]	-0.16 [-0.34, 0.00]
	16	-0.32 [-0.51, -0.17]	-1.21 [-2.45, -0.58]	-0.63 [-0.85, -0.49]		16	-1.44 [-1.93, -1.09]	2.69 [1.35, 5.40]	-0.18 [-0.31, -0.04]
	20	-0.17 [-0.32, -0.04]	-1.82 [-3.78, -0.86]	-0.53 [-0.71, -0.40]		20	-1.32 [-1.72, -1.02]	2.79 [1.38, 6.16]	-0.26 [-0.38, -0.16]
Imports	4	-1.00 [-1.82, -0.39]	-0.23 [-1.30, 0.77]	-1.05 [-1.86, -0.561]	Gov. Cons.	4	-0.22 [-0.47, -0.02]	0.97 [0.34, 2.28]	0.45 [0.23, 0.83]
	8	-1.43 [-2.19, -0.88]	0.24 [-0.37, 0.94]	-1.04 [-1.53, -0.73]		8	-0.63 [-1.02, -0.35]	1.77 [1.01, 2.84]	0.47 [0.30, 0.72]
	12	-1.12 [-1.62, -0.77]	0.30 [-0.31, 0.94]	-0.91 [-1.24, -0.69]		12	-0.52 [-0.77, -0.32]	2.05 [1.13, 3.54]	0.44 [0.27, 0.61]
	16	-0.96 [-1.33, -0.68]	0.23 [-0.51, 0.99]	-0.84 [-1.12, -0.66]		16	-0.22 [-0.37, -0.10]	2.32 [1.13, 4.67]	0.47 [0.33, 0.66]
	20	-0.86 [-1.18, -0.65]	-0.22 [-1.11, 0.57]	-0.74 [-0.98, -0.61]		20	-0.05 [-0.17, 0.06]	2.75 [1.32, 5.57]	0.50 [0.34, 0.67]

Notes: the table shows the cumulative multipliers on output, private consumption, investments, exports, imports, government consumption to a tax shock corresponding to 1% of GDP. The multipliers are calculated over one to five years and in recessions, expansions, and the linear case, columns (1) to (3) respectively. The 68% confidence intervals are reported in brackets. Bold numbers indicate coefficients statistically significant at the 68% level.

Table 4: Test

Difference between Multipliers in Recessions and in Expansions					
	(1)		(1)		
	Horizon		Horizon		
GDP	4	-2.13 [-4.04, -0.61]	Priv. Cons.	4	-2.26 [-3.96, -0.90]
	8	-3.79 [-5.73, -2.43]		8	-3.50 [-5.13, -2.34]
	12	-2.83 [-4.41, -1.51]		12	-2.81 [-4.08, -1.73]
	16	-1.46 [-2.92, -0.10]		16	-0.99 [-2.50, 0.59]
	20	0.43 [-1.75, 3.50]		20	0.53 [-1.50, 4.00]
Investments	4	-0.58 [-1.75, 0.39]	Exports	4	-3.92 [-6.17, -1.87]
	8	-0.71 [-1.48, 0.07]		8	-3.59 [-5.45, -2.71]
	12	-0.04 [-0.74, 0.65]		12	-3.57 [-5.14, -2.74]
	16	0.87 [0.08, 2.21]		16	-4.17 [-6.82, -3.01]
	20	1.65 [0.58, 3.66]		20	-4.16 [-7.41, -2.88]
Imports	4	-0.87 [-2.78, 0.77]	Gov. Cons.	4	-1.29 [-2.56, -0.09]
	8	-1.76 [-3.08, -0.68]		8	-2.43 [-3.65, -1.69]
	12	-1.46 [-2.49, -0.61]		12	-2.58 [-4.05, -1.72]
	16	-1.26 [-2.27, -0.30]		16	-2.60 [-4.91, -1.38]
	20	-0.71 [-1.66, 0.35]		20	-2.82 [-5.63, -1.38]

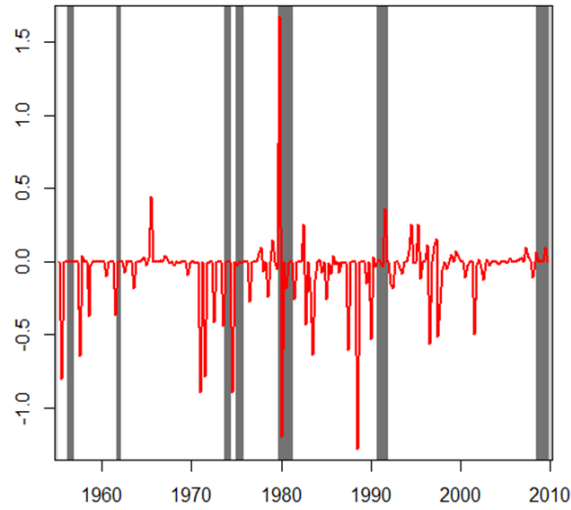
Notes: Empirical densities of the difference between multipliers in recessions and in expansions. Densities based on 10,000 realizations of such differences for each horizon of interest. Bold numbers refer to coefficients statistically significant at the 68% level.

Cumulative Multipliers		Scenario	Recession	Expansion	Linear	Recession	Expansion	Linear
GDP	baseline		-2.51	0.17	-1.79	-2.50	0.18	-2.08
			[-3.64, -1.78]	[-0.60, 1.03]	[-2.56, -1.30]	[-3.61, -1.83]	[-0.36, 0.76]	[-2.81, -1.63]
	excluding DC		-2.55	0.27	-1.90	-2.47	0.40	-2.07
			[-3.64, -1.79]	[-0.38, 0.91]	[-2.59, -1.37]	[-3.58, -1.81]	[-0.01, 0.95]	[-2.87, -1.60]
	$\epsilon^{Residual}$		-3.09	-0.53	-2.02	-3.50	-0.26	-2.11
			[-4.82, -1.96]	[-1.47, 0.24]	[-2.78, -1.51]	[-5.56, -2.34]	[-0.88, 0.28]	[-2.81, -1.64]
	quadratic trend		-2.96	0.31	-1.70	-2.58	-0.20	-1.90
			[-4.34, -1.97]	[-0.50, 1.09]	[-2.56, -1.14]	[-3.73, -1.74]	[-0.73, 0.28]	[-2.82, -1.38]
	int.rate & infl. rate		-2.65	-0.41	-1.42	-2.82	-0.14	-1.86
			[-4.40, -1.65]	[-1.19, 0.19]	[-1.97, -1.02]	[-4.5, -1.82]	[-0.54, 0.25]	[-2.45, -1.44]
Investments	baseline		-2.40	0.36		-2.55	0.59	
			[-3.82, -1.64]	[-0.61, 1.49]		[-4.69, -1.75]	[-0.50, 2.82]	
	excluding DC		-2.51	-0.15		-2.41	-0.34	
			[-3.42, -1.82]	[-0.83, 0.16]		[-3.89, -1.79]	[-0.15, 1.47]	
	$\epsilon^{Residual}$		-0.37	-0.92	-0.72	-1.48	1.98	-0.17
			[-0.83, -0.05]	[-1.45, -0.54]	[-1.01, -0.53]	[-2.13, -21.08]	[1.15, 3.61]	[-0.35, -0.01]
	quadratic trend		-0.58	-0.39	-0.71	-1.68	1.62	-0.16
			[-0.85, -0.36]	[-0.73, -0.13]	[-1.00, -0.52]	[-2.33, -1.21]	[1.06, 2.51]	[-0.34, 0.00]
	int.rate & infl. rate		-0.87	-0.71	-0.72	-2.26	2.13	-0.17
			[-1.52, -0.49]	[-1.25, -0.31]	[-1.10, -0.48]	[-3.52, -1.49]	[1.22, 3.23]	[-0.40, 0.02]
Imports	baseline		-0.95	-0.40	-0.72	-1.75	1.86	-0.13
			[-1.46, -0.63]	[-0.84, -0.04]	[-1.01, -0.53]	[-2.53, -1.19]	[1.12, 3.00]	[-0.30, 0.01]
	excluding DC		-0.39	-0.92	-0.67	-3.23	1.90	-0.17
			[-1.06, 0.00]	[-0.98, -0.46]	[-0.91, -0.49]	[-6.78, -2.01]	[1.03, 4.99]	[-0.34, 0.00]
	$\epsilon^{Residual}$		-0.62	-0.65		-1.56	2.43	
			[-0.97, -0.38]	[-1.35, -0.13]		[-2.33, -1.09]	[-2.5, 7.58]	
	quadratic trend		-0.66	-0.57		-1.39	1.41	
			[-0.94, -0.44]	[-1.04, -0.29]		[-1.98, -1.04]	[0.87, 2.31]	
	int.rate & infl. rate							
Exports	baseline		-1.12	0.30	-0.91	-0.51	2.04	0.43
			[-1.62, -0.77]	[-0.31, 0.94]	[-1.24, -0.69]	[-0.77, -0.32]	[1.13, 3.54]	[0.21, 1.05]
	excluding DC		-1.07	0.26	-0.92	-0.46	1.62	0.42
			[-1.59, -0.73]	[-0.24, 0.79]	[-1.27, -0.69]	[-0.71, -0.28]	[1.04, 2.53]	[0.26, 0.63]
	$\epsilon^{Residual}$		-1.83	0.42	-0.93	-0.92	1.93	0.43
			[-3.06, -1.17]	[-0.21, 1.21]	[-1.28, -0.70]	[-2.29, -0.49]	[0.98, 5.40]	[0.29, 0.62]
	quadratic trend		-1.34	0.44	-0.87	-0.49	1.72	0.41
			[-2.01, -0.85]	[-0.16, 1.16]	[-1.22, -0.66]	[-0.79, -0.27]	[1.00, 2.94]	[-0.26, 0.60]
	int.rate & infl. rate		-2.38	-0.33	-0.87	-1.26	1.86	0.36
			[-3.80, -1.48]	[-0.17, 0.87]	[-1.19, -0.65]	[-2.10, -0.79]	[1.14, 2.81]	[0.24, 0.54]
Gov. Cons.	baseline		-1.26	0.68		-0.57	2.37	
			[-1.98, -0.82]	[-0.17, 1.82]		[-0.92, -0.36]	[1.09, 4.44]	
	excluding DC		-1.04	-0.14		-0.41	1.61	
			[-1.57, -0.72]	[-0.63, 0.33]		[-0.64, -0.26]	[1.01, 2.50]	
	$\epsilon^{Residual}$							
	quadratic trend							
	int.rate & infl. rate							
	$F(z_t) \geq 0.90 \approx 0.10$							
	$F(z_t) \geq 0.80 \approx 0.20$							

Cumulative Multipliers		Scenario	Recession	Expansion	Recession	Expansion
GDP		baseline	-2.51 [-3.64, -1.78]	0.17 [-0.60, 1.03]	-2.50 [-3.61, -1.83]	0.18 [-0.36, 0.76]
		detrended of GDP growth rate	-2.51 [-3.49, -1.83]	0.17 [-0.66, 1.08]	-2.47 [-3.47, -1.80]	-0.10 [-0.66, 0.40]
		detrended change in unemployment rate	-3.68 [-8.14, -1.39]	0.44 [-0.11, 1.10]	-3.34 [-7.19, -1.38]	0.16 [-0.43, 0.80]
Investments		baseline	-0.37 [-0.83, -0.05]	-0.92 [-1.45, -0.54]	-1.48 [-2.13, -21.08]	1.98 [1.15, 3.61]
		detrended GDP growth rate	-0.62 [-0.69, -0.41]	-0.60 [-1.17, -0.17]	-1.53 [-2.18, -1.09]	2.01 [1.16, 3.58]
		detrended change in unemployment rate	-0.88 [-1.99, -0.18]	-0.31 [-0.67, -0.02]	-0.29 [-1.99, -0.18]	0.00 [-0.38, 0.39]
Imports		baseline	-1.12 [-1.62, -0.77]	0.30 [-0.31, 0.94]	-0.51 [-0.77, -0.32]	2.04 [1.13, 3.54]
		detrended GDP growth rate	-0.90 [-1.33, -0.61]	-0.06 [-0.74, 0.56]	-0.47 [-0.70, -0.30]	2.08 [1.14, 3.56.]
		detrended change in unemployment rate	-3.00 [-6.65, -1.29]	-0.08 [-0.51, 0.36]	-0.62 [-1.55, -0.15]	0.61 [0.39, 0.99]

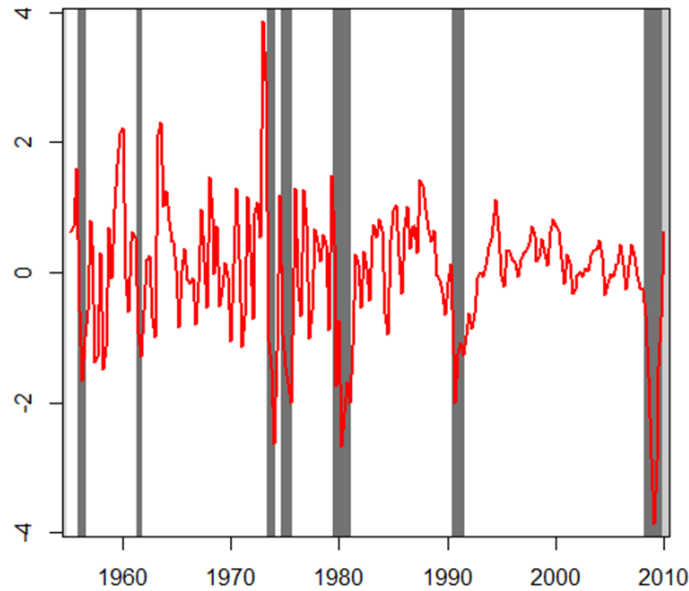
Notes: the table shows the 3-year cumulative multipliers on output, private consumption, investments, exports, imports, government consumption to a tax shock corresponding to 1% of GDP. The 68% confidence intervals are reported in brackets. Bold numbers indicate coefficients statistically significant at the 68% level.

Figure 1: Tax shock vs Business cycle



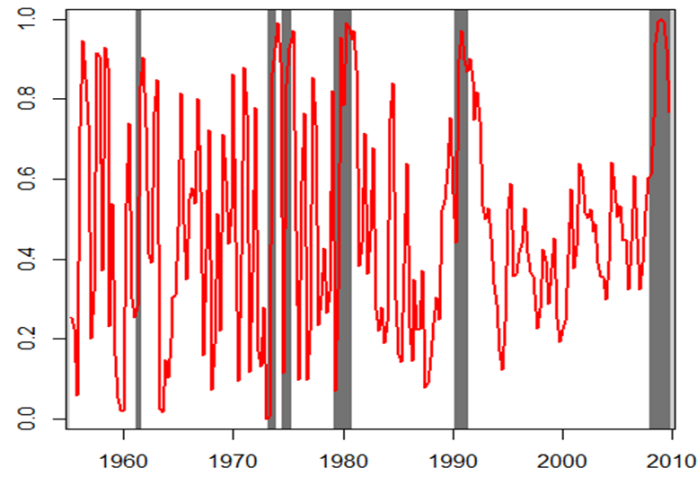
Notes: The shaded area indicate the UK recessionary phases (1955:I-2009:IV) identified by applying the BBQ algorithm, whereas the red lines refers to the tax shock measure of Cloyne (2013).

Figure 2: Transition variable versus Business Cycle Dates



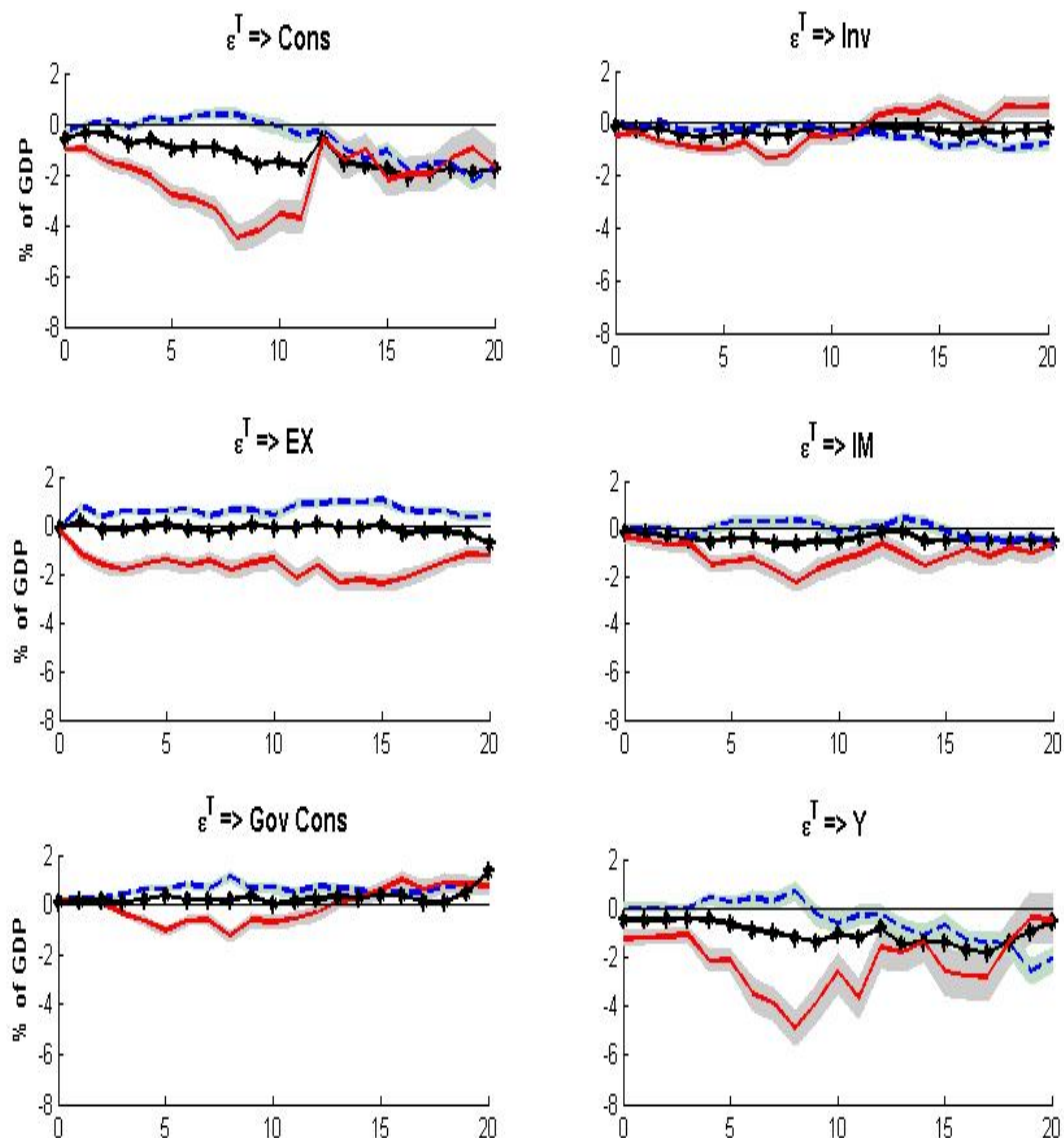
Notes: the transition variable is the standardized backward-looking moving average constructed with two realizations of the quarter-on-quarter real GDP growth rate. Shaded area refers to the recessionary phase identified applying the BBQ algorithm (Harding and Pagan, 2002)

Figure 3: Probability of being in a recessionary phase



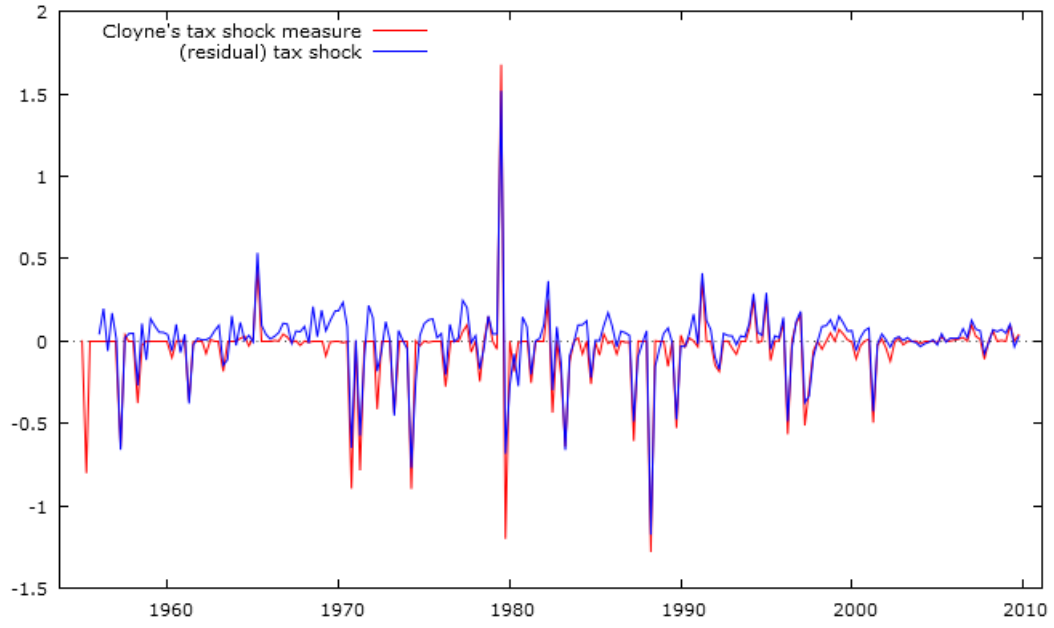
Notes: $F(z_t)$ computed according to the logistic function presented in the text. The transition variable is the standardized backward-looking moving average constructed with two realizations of the quarter-on-quarter real GDP growth rate. The value of the slope parameter is 1.7.

Figure 4: Response of GDP components to an exogenous tax shock in recessions and expansions



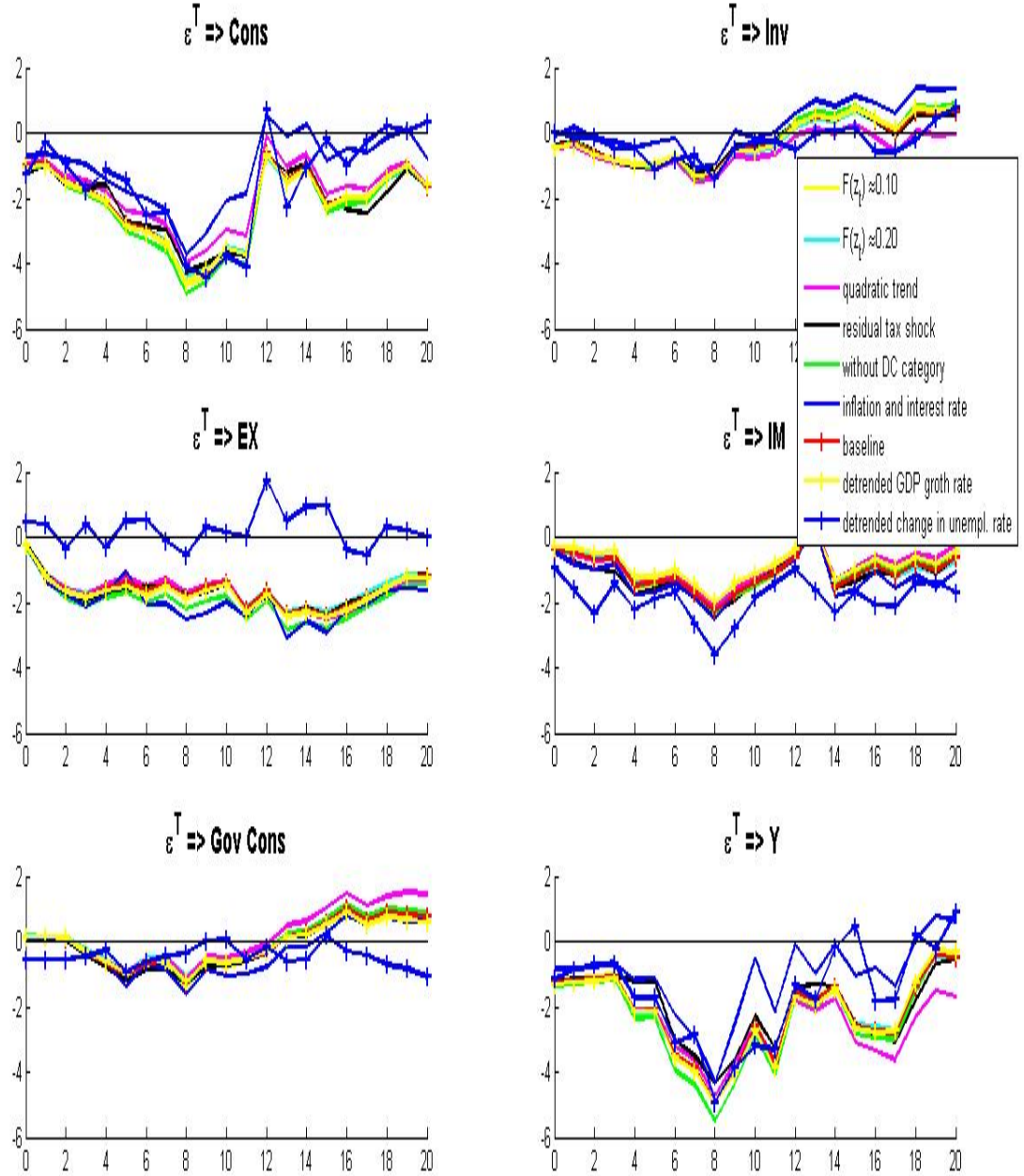
Notes: Figure shows the response of private consumption, investments, exports, imports, government consumption and output to a tax shock corresponding to 1% of GDP. Black dotted lines refer to IRFs computed in a linear specification, whereas the pink and the blue dotted ones to IRFs in recessions and expansions, respectively. The dark and light shaded area refer to the 68% and 90% confidence intervals, respectively.

Figure 5: Cloyne shocks and its exogeneity



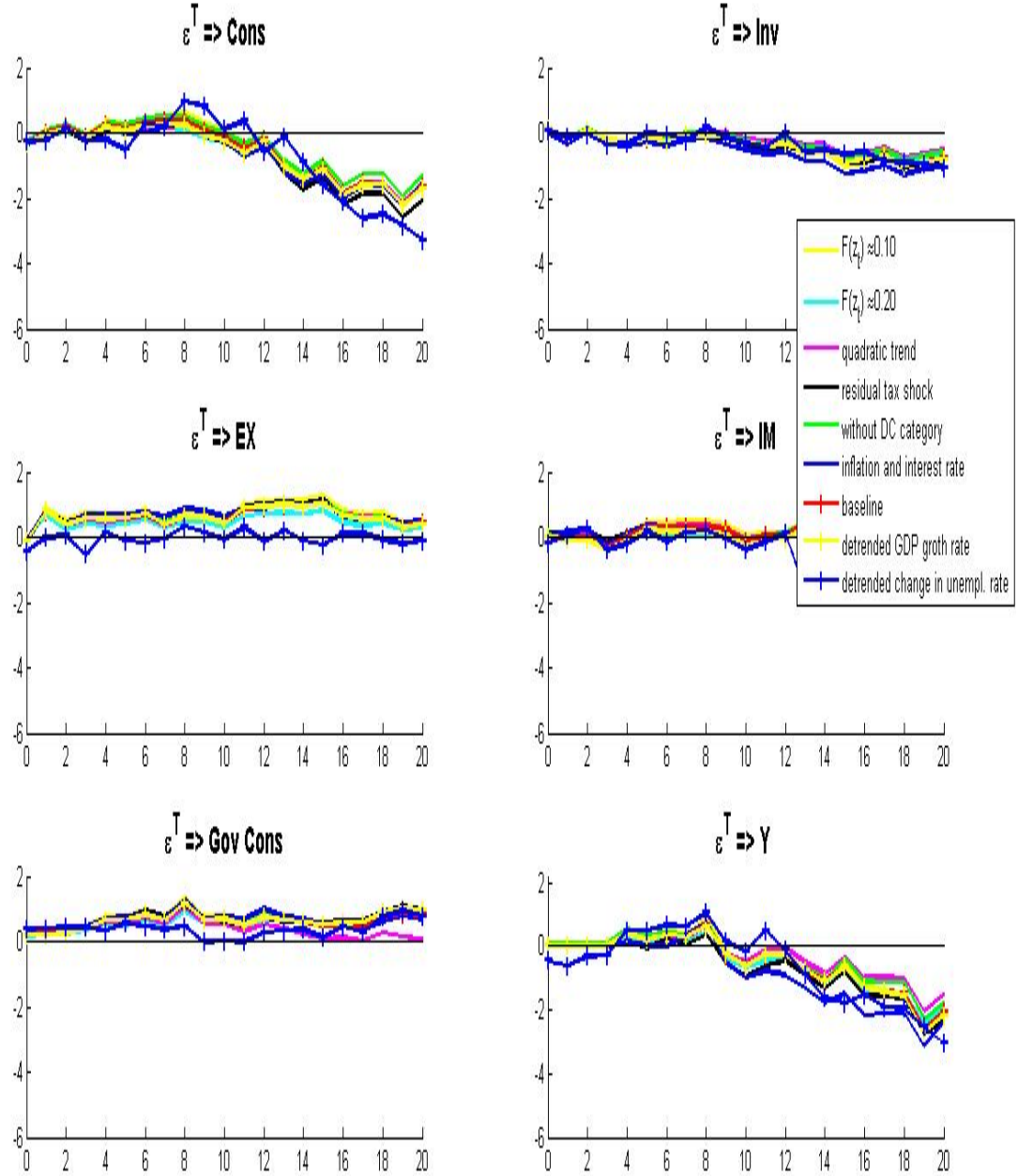
Notes: The figure plots the tax shock series constructed by Cloyne (2013), in our notation ϵ_t^{Cloyne} , versus the (residual) tax shock series obtained regressing the ϵ_t^{Cloyne} on its own four lags and four lags of the log real GDP, revenues and government consumption.

Figure 6: Robustness checks: response of GDP and its components to an exogenous tax change in recessions



Notes: Figures show the impulse responses of private consumption, investments, exports, imports, government consumption and output to a tax shock corresponding to 1% of GDP under alternative specifications.

Figure 7: Robustness checks: response of GDP and its components to an exogenous tax change in expansions



Notes: Figures show the impulse responses of private consumption, investments, exports, imports, government consumption and output to a tax shock corresponding to 1% of GDP under alternative specifications.

A Appendix

Output Elasticity of Revenues and conversion factors of elasticity into multiplier: Do they matter for the Tax Multiplier?

The main challenge in estimating the tax multiplier is to disentangle a tax change due to a discretionary fiscal policy from a nondiscretionary component, e.g. the change in taxes due to a change in output. Two methods have been proposed in the literature. The first one relies on the SVAR model and based mainly on the identification assumption scheme pioneered by Blanchard and Perotti (2002). The second one identifies an exogenous tax change using a narrative method (Romer and Romer, 2010; Mertens and Ravn, 2014; Cloyne, 2013). Despite several studies investigating tax multipliers there is not a shared view. Perotti (2005), identifying a tax shock via coefficient restrictions, finds that following a tax shock the UK GDP decrease. Cloyne (2013) identify a tax shock through the narrative approach and finds that a tax cut stimulates the economy. In general, the size and duration of a tax shock vary across studies and the estimated tax multiplier via a SVAR model tend to be lower than the narrative approach.

Caldara and Kamps (2008) show that contrasting US fiscal multiplier estimations are likely due to different assumptions on the size of the elasticity of tax revenues to GDP. The first question addressed in this section is whether the UK output tax multiplier is "output elasticity of taxes dependent". To do that we employ in very basic (linear) SVARs two measure of the UK automatic stabilizer proposed in the literature by Perotti (2005) and Cloyne (2013).

Consider a simple three-variate VAR as in Blanchard and Perotti (2002)²³ of the form:

$$X_t = C(L)X_{t-1} + u_t \quad t = 1, \dots, T \quad (\text{A.1})$$

where X_t includes four lags of the log real per capita government consumption, tax revenues and GDP and u_t is a three-dimensional vector of residuals. Equation (A.1) includes also a constant and a linear time trend. Following the approach

²³Notice that Perotti (2005) estimates for the UK a five-variable VAR. Caldara and Kamps (2008) show that the different results in the literature about the US fiscal multipliers are not due to difference in the specification of the reduced-form models but to the different identification strategies. We stress that the exercise provided in this section is not aimed at choosing the best specification for our analysis but to understand whether the Caldara and Kamps' result is valid also for the UK economy. Hence, we estimate a more parsimonious VAR, as in Blanchard and Perotti (2002).

proposed by Perotti (2005), the reduced form innovations of vector u_t is expressed as a linear combination of the structural shocks such that:

$$u_t^G = \alpha_Y^G u_t^Y + \beta_T^G \epsilon_t^T + \epsilon_t^G \quad (\text{A.2})$$

$$u_t^T = \alpha_Y^T u_t^Y + \beta_G^T \epsilon_t^G + \epsilon_t^T \quad (\text{A.3})$$

$$u_t^Y = \alpha_G^Y u_t^G + \alpha_T^Y u_t^T + \epsilon_t^Y \quad (\text{A.4})$$

Since the aim is estimating the effect of a tax shock ϵ_t^T on the GDP, let us focus on equation (A.3). It states that unexpected movement in taxes at time t may be due to output innovations (u_t^Y), structural shocks to government consumption (ϵ_t^G) or to taxes (ϵ_t^T). Hence, the coefficients α_j^i capture the elasticity of variable i to the variable j , while coefficients β_j^i capture possible link between structural shocks to fiscal variable which may arise whether, for instance, government consumption instantaneously responds to revenues change with government consumption adjustment. The identification of a tax shock is based on the $Au_t = B\epsilon_t$ scheme and on some restrictions on the matrix A and B to map from innovations u_t^T to the structural shocks ϵ_t^T . Expressed in matrix notation:

$$\begin{bmatrix} 1 & 0 & -\alpha_Y^G \\ 0 & 1 & -\alpha_Y^T \\ -\alpha_Y^G & -\alpha_T^Y & 1 \end{bmatrix} \begin{bmatrix} u_t^G \\ u_t^T \\ u_t^Y \end{bmatrix} = \begin{bmatrix} \sigma^G & \beta_T^G & 0 \\ \beta_G^T & \sigma^T & 0 \\ 0 & 0 & \sigma^Y \end{bmatrix} \begin{bmatrix} \epsilon_t^G \\ \epsilon_t^T \\ \epsilon_t^Y \end{bmatrix} \quad (\text{A.5})$$

The identification of fiscal shock in Blanchard and Perotti (2002) relies on some assumptions about the reaction lags and the structural elasticity. Suppose that there is a negative output shock. To offset such shock a fiscal policy action should be planned, approved by the House of Commons and then implemented. It should take more than one quarter to apply a discretionary fiscal policy. With quarterly data the contemporaneous response of the government spending to an output shock can be set to zero. Also, the implementation lags imply that coefficient α_Y^T captures only the automatic elasticity of the tax revenues to GDP due to a fluctuation in the tax base. Thus, the cyclically-adjusted tax innovation, u_t^{CAT} , is given by the difference between the tax innovation (u_t^T) and the output elasticity of revenues (α_Y^T). Notice that the restricted value of the coefficient α_Y^T is obtained by an out-of-model information.²⁴ Hence, the cyclical adjusted

²⁴Perotti (2005) calibrates the value of the automatic stabilizer for the UK economy through the OECD method and assumptions proposed by Giorno, Richardson, Roseveare, and van den Noord (1995) and van den Noord (2002). The output elasticity of output is calibrated

tax innovation derives from an instrumental variable estimation. The structural shock ϵ_t^T is recovered imposing a recursive order on matrix A, on which we assume that tax shock "comes first" than government spending one. Thus, we set $\beta_G^T=0$.²⁵

Estimated impulse response functions obtained via the estimation of (A.5) allow us to address a second problem, the *ex post* conversion factor's, raised by Owyang, Ramey, and Zubairy (2013). It is related to the estimation of fiscal multipliers. In general, it is common practice in the fiscal multiplier literature to run SVARs using log-transformed variables, and then to convert estimated elasticities into multipliers via (*ex post*) conversion factors, e.g. the average of the ratio GDP/(fiscal variable). However, Owyang, Ramey, and Zubairy (2013) highlight that different sample size may rend different conversion factor values, which may lead to biased fiscal multiplier estimates.

Output Elasticity of Revenues and conversion factors of elasticity into multiplier: Do they matter for the Tax Multiplier? This paper address the two problems through simple exercises. We consider two sample sizes spanning one from 1963:I to 2001:II, and the other one from 1955:I to 2009:IV. For each sample size, we estimate two SVARs including the quarterly log of the real government consumption, tax revenues and GDP,²⁶ and imposing the implementation lag coefficient restrictions discussed above. Notice that for each sample size two alternative coefficient restrictions of output elasticity of taxes (α_Y^T) are set. On the one hand, we set $\alpha_Y^T=0.76$ as in Perotti (2005). On the other hand, we fix $\alpha_Y^T=1.61$ as estimated by Cloyne (2013) using narrative data on tax changes.²⁷ To obtain tax multipliers from (four) estimated SVARs, we convert estimated elasticities (since our variables are expressed in logarithm terms) into multipliers via *ex post* conversion factors. For each sample size and value of α_Y^T , we convert the elasticity into multipliers using the minimum, the mean and the maximum value of the average of the ratio GDP/T of the sample size under analysis.²⁸ The

combining the estimation of elasticity of tax revenues to their tax base with the elasticity of tax base to output. The corporate and indirect taxes is equal to 1 by assumption. Moreover, the computation of the automatic stabilizer excludes output elasticity to GDP cyclical effects on tax expenditure, income of self-employed, capital gains, for example. See Perotti (2005) and Mertens and Ravn (2014) in depth analysis.

²⁵Our results are robust to the alternative specification that government spending "comes first" than taxes shock. The results are available upon request.

²⁶All SVARs are estimated including a constant and a linear time trend.

²⁷The exercises on two samples are justified because the Perotti's output elasticity of taxes is calibrated for the period 1963:I to 2001:II, whereas the estimation of Cloyne is related to the sample 1955:I-2009:IV.

²⁸For the sample size 1963:I-2001:II the mean, minimum and maximum of the ratio GDP/T

90% confidence intervals are computed using 10,000 bootstrapping replications. Figure A.1 depicts the IRFs. The top panels show the response of output to a tax shock for the period 1963:I to 2001:II, whereas the bottom ones for the period spanning from 1955:I to 2009:IV. The left hand side panels depict the results for the two different sample when $\alpha_Y^T = 0.76$ (Perotti), whereas the right ones when $\alpha_Y^T = 1.61$ (Cloyne). Each plot reports the point estimates multiplied by different conversion factors: the mean (blue diamond line), the minimum (red line), and the maximum (dotted red line). Figure A.1 show that, for each sample size, increasing the value of α_Y^T the impact of tax shock on output increases. Moreover, the value of α_Y^T has an impact on the persistence of the shock. That is evident whether we consider table A.1 which reports the cumulative multipliers, for the different sample size, coefficient restrictions, and conversion factors. Let us focus on the sample size A (1963:I -2001:II) and on the row reporting tax multipliers using as conversion factor the mean of GDP/T, mean (A). The estimated 1-year integral multiplier (4Q) is -0.3 setting $\alpha_Y^T = 0.76$, whereas doubles setting $\alpha_Y^T = 1.61$. Moreover, the value of α_Y^T has effects on the persistence of the shock. Indeed, whereas the 2-year integral multiplier (8Q) tax multiplier is not statistically significant for $\alpha_Y^T = 0.76$, it is for $\alpha_Y^T = 1.61$. Turning on panel B, the 1-year integral tax multiplier (4Q) is statistically significant only when $\alpha_Y^T = 1.61$. Further, using different value of conversion factors affects the size of output tax multipliers. For example, this bias is evidence focusing on the 2-year integral multipliers (8Q) of panel A, for which tax multipliers range below and above one.

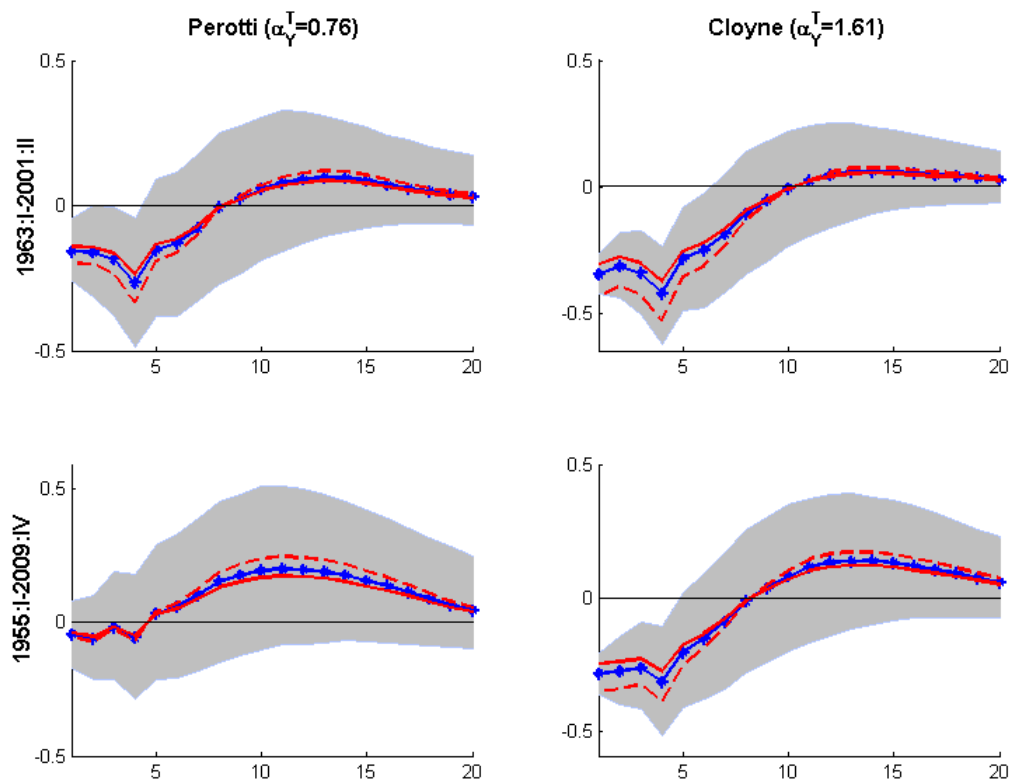
The results show that using the same dataset, the same estimation's method but different coefficient restrictions on the output stabilizer yield different results. This is consistent with Caldara and Kamps (2008): the fiscal multipliers change according to the calibration of the output elasticity of taxes. Moreover, the combination of coefficient restrictions with the value of *ex post* conversion factors may lead other bias on tax multiplier estimates.

An exogenous tax change measure based on the narrative method does not require imposing restrictions on the output elasticity of taxes. A solution to avoid *ex post* conversion problem is to convert GDP and taxes to the same units *ex ante* the estimation. Hence, we identify the tax shock via the tax shock measure proposed by proposed by Cloyne (2013), and to avoid bias on tax multipliers we transform the variables as in Hall (2009), Barro and Redlick (2011) and Owyang,

are 3.19, 2.83 and 3.9, respectively. Regard to the sample size 1955:I to 2009:IV, the mean, minimum and maximum of the above ratio are 3.25, 2.83 and 4.02, respectively.

Ramey, and Zubairy (2013).

Figure A.1: Perotti and Cloyne's output elasticity of revenues in a SVAR specification



Notes: Top panels show the response of output to a tax shock for the period 1963:I to 2001:II, whereas the bottom panels the one for the period 1955:I-2009:IV. The left panels refer to the case in which the output elasticity is set to 0.76 Perotti (2005), whereas the right ones refer to an automatic stabilizer set to 1.61 Cloyne (2013). The blue, red and dotted red lines depict the IRFs obtained using as *ex post* conversion factor the average, the minimum and the maximum of the ratio of GDP to revenues, respectively.

Table A.1: Multipliers estimated relying on different sample size, coefficient restrictions, and conversion factors

Sample size	CF	Perotti ($\alpha_Y^T = 0.76$)		Cloyne ($\alpha_Y^T = 1.61$)	
		4Q	8Q	4Q	8Q
(A) 1963:I-2001:II	min (A)	-0.22	-0.39	-0.56	-0.88
	mean (A)	-0.30	-0.44	-0.62	-1.00
	max (A)	-0.37	-0.55	-0.79	-1.24
(B) 1955:I-2009:IV	min (B)	-0.06	0.05	-0.40	-0.59
	mean (B)	-0.07	0.06	-0.48	-0.67
	max (B)	-0.09	0.07	-0.60	-0.83

Notes: Top rows show the response of output to a tax shock for the period 1963:I to 2001:II, whereas the bottom rows the one for the period 1955:I-2009:IV. The left column refers to the case in which the output elasticity is set to 0.76 Perotti (2005), whereas the right ones refers to an automatic stabilizer set to 1.61 Cloyne (2013). Bold numbers indicate the coefficients statistically significant at 90%.

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B Appendix

Business cycle identification via BQQ

There is not in the UK an official dating Committee, as the NBER, which has established an expansion and recession chronology and which has been recognized as an authoritative dating of the cycle.²⁹ The NBER (2001) defines a recession as "a significant decline in activity spread across the economy, lasting more than few months, visible in industrial production, employment, real income, and wholesale-retail trade. A recession begins just after the economy reaches a peak of activity and ends as the economy reaches its trough". According to the literature turning points can be defined in terms of absolute decline in output (classical cycle) or in terms of deviation of GDP growth rate from its trend (deviation cycle). The deviation-from-trend approach, as in Cooley and Prescott (1995) and Stock and Watson (2008), requires detrending a series. However, several detrending methods exist. For example, the NBER uses the phase-average trend method (PAT), the macroeconomists use Hodrick-Prescott filter or the "band pass" to remove deterministic/stochastic trend. According to Canova (1998) the identified business cycle may depend on the filter used. Moreover, Harding and Pagan (2002) highlight that smoothing methods are aimed at simplifying turning point identification removing idiosyncratic variation. Thus, if turning points are detected using quarterly data series the utility of smoothing methods decreases with such frequency data. Hence, we identify turning points relying on the classical cycle approach. We use the dating algorithm proposed by Harding and Pagan (2002) which is the quarterly version of the well-known monthly Bry and Boschan (1971) algorithm.³⁰

The BQQ algorithm isolates local minimum and maximum points in a quarterly series, via some constraints. First of all, a local peak (trough) occurs at time t when

$$y_t > (<)y_{t \pm k} \quad (\text{B.1})$$

where $k=1,2,...K$. K allows y_t to be a local local peak (trough) to two quar-

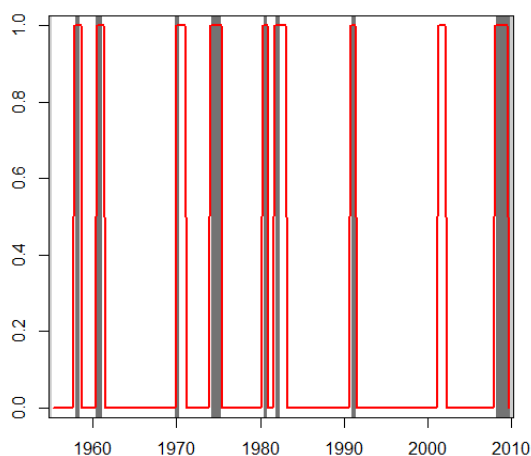
²⁹In 2002 CEPR established a Business Cycle Dating Committee for the euro area.

³⁰The BQQ is one of the most widespread algorithm in detecting turning points. For example, Artis, Marcellino, and Proietti (2002) rely on the BQQ to analyse the characteristic of the business cycle. However, there are other algorithm that we may use to date turning points, for example a Markov Switching model Hamilton (1998). As point out by Harding and Pagan (2002) the Markov Switching model depends on the relative statistical framework.

ters on either side.³¹ Secondly, the phases alternate between peak and trough. This because whether the phases alternate, then it is possible to distinguish the phase of recession (from peak to trough) from the expansion one (from trough to peak).³² Thirdly, a complete cycle (from peak to peak or from trough to trough) lasts at least n quarters. The last two rules are known as censoring rule.

To verify the validity of the BBQ a natural exercise is to apply the algorithm to the US for which exists an official chronology. We set for the US $k=2$ and the duration of the complete cycle to five quarters, as in Harding and Pagan (2002), and we apply the algorithm to the log-real GDP. Then, the turning points are compared with the NBER data. Figure B.1 plots the NBER turning points (red lines) versus the turning point identified by the BBQ ones (shaded area).

Figure B.1: US Business Cycle Chronology (NBER vs BBQ algorithm)



Notes: The shaded area indicate the recession phases identified by the BBQ algorithm, whereas the red lines show the NBER business cycle chronology. The sample size spans from 1955:I to 2009:IV

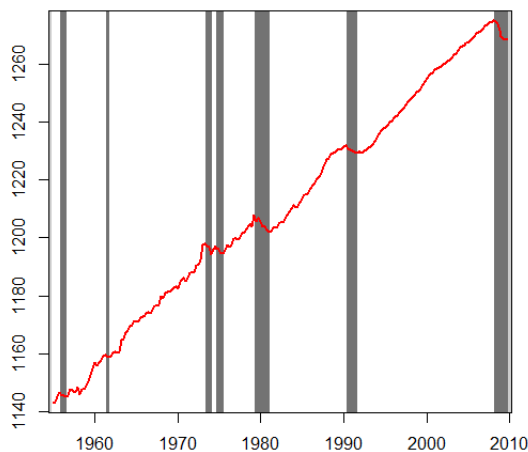
Since 1955 to 2009 the NBER has recorded 9 recessions, whereas the algorithm does not capture the turning points of 2001. Stock and Watson (2010)

³¹Notice that larger is the value of K the more restrictive is the definition of the turning points (Harding (2008)).

³²Harding (2008) show that in UK the frequency of non-alternating turning points is four times higher than the US

report that the NBER committee for dating relies on the quarterly real GDP and on four monthly variables, such as real personal income less transfer, real manufacturing and wholesaleretail trade sales, industrial production, and non-farm employment. They highlight that those series do not receive same weight in the dating procedure. Moreover, Harding (2003) shows that the procedure and variables used by the NBER for the business cycle chronology has changed over time. Also, Harding (2008) report that in detecting the turning points the NBER uses not only committee's procedure but also a voting procedure that can complicate the perfect matching of the BBQ dating turning points with the NBER one. Thus, some difference between the two procedures mat be due to such reasons. Apart of turning point of 2001 that is not captured because it does not exhibit two quarters of negative growth (Harding (2008)) and keeping in mind the above problems, our exercise reproduces the turning points from the NBER. Overall, the BBQ algorithm performs well on the US. After having run the above test, we apply the BBQ algorithm to the UK.

Figure B.2: UK Turning Points



Notes: The shaded area indicate the UK recession phases (1955:I-2009:IV) identified by the application of the BBQ algorithm on the log-real UK GDP (red line).

We apply the BBQ algorithm to log-real GDP and we set $k=2$ and fix the duration of the business cycle to four quarters differently from the US exercise.

This because Harding and Pagan (2002) find difficulties to identify for the UK the strong downturn of 1974 with a complete cycle of five quarter. The recession of 1974 was characterized by a complete cycle of 4. Hence, for the UK a duration of the complete cycle of four can be applied. Figure B.2 shows the identified turnings points for the UK via the application of BBQ algorithm to the log-real GDP. From 1955 to 2009 we identify seven recessions. The number of UK recessions identified via the BBQ matches that ones reported from the Bank of England in the Inflation Report (Bank of England (2014)). The only exception concerns the recessions of 1970s that are treated as a single recession by the BoE. The turning points identified by the BBQ algorithm is going to be used as benchmark for studying the state-dependent tax multiplier.

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