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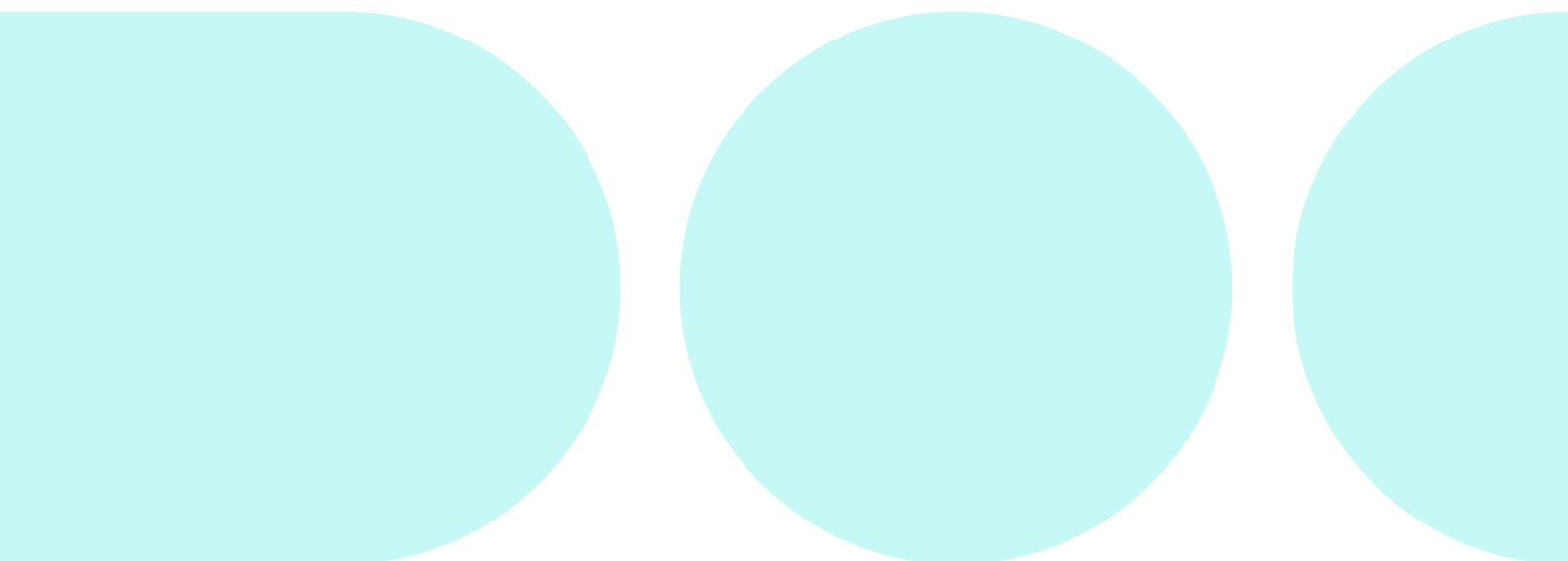
Estimating government spending shocks in a VAR model

Anders F. Kronborg

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Preface

In this working paper, the effects of and adjustment to government spending shocks for the Danish economy are estimated and identified in a structural VAR model using quarterly data. The identification of government spending shocks centers around the commonly used approach in Blanchard and Perotti [2002].

This is combined with an assumption of Denmark as a small open economy as well as sign restrictions to control for generic domestic shocks. This approach leads to results, which are broadly in line with previous empirical findings, albeit they are associated with non-negligible uncertainty.

1 Introduction

Since Sims [1980] vector autoregressive (VAR) models have been one of the main tools in empirical macroeconomics. Specifically, the resulting impulse response functions have been a popular way to examine the monetary policy transmission mechanism (Eichenbaum and Evans, 1995), the effects of fiscal policy (Blanchard and Perotti, 2002), and later supply shocks such as changes in technology (Dedola and Neri, 2007) and labor supply (Feroni et al., 2018). For smaller economies, the framework has been applied to examine the effects of monetary and economic activity spillovers, e.g. from the US or Euro Area (Vasishtha and Maier, 2013). Further, VAR models have been used to estimate the structural parameters of DSGE models by minimizing the distance between the model’s impulse responses and those found in the data (for example Christiano et al. [2005], Christiano et al. [2016], and Aursland et al. [2019]). In the work with MAKRO, a similar approach has been taken to parameterize a key set of parameters that govern the frictions in the model system, i.e. the estimated impulse responses are used to calibrate the model’s adjustment to shocks.

This note describes how a VAR model is used to find the effects on the Danish economy to government spending shocks. Due to Denmark’s fixed exchange rate policy, fiscal policy is left as an important macroeconomic stabilization tool. The benchmark specification shows the impulse response of GDP, private consumption, the GDP deflator, wages, total taxes, and government spending and investment. Further, foreign demand is controlled for by including the total market for Danish exports.

Identification of structural shocks in multivariate time series models such as VAR models is not possible without imposing further restrictions in the estimated reduced-form of the VAR model. In the benchmark model, government spending shocks are identified by combining two types of identifying restrictions, often used in the literature, namely sign and zero (short-term) restrictions, which lend themselves naturally to the present application. Thus, identification of government spending shocks is achieved by combining the widely applied identification from Blanchard and Perotti [2002] while »controlling« for generic shocks in the spirit of Mountford and Uhlig [2009]. The consequence is of course that it implies a causality structure from government spending to the domestic economy from which government spending shocks can be identified from

the contemporaneous correlation of the variables included in the model.

As the number of parameters to be estimated in a VAR model increases rapidly as more variables are included, the variables included in the estimated model will necessarily be a subset of the total variables in a large-scale macroeconomic model such as MAKRO. This naturally raises the question whether the model includes sufficient information or whether relevant and crucial outside information is available to the real world agents that is not used by the econometrician (i.e. that is included in the VAR model's information set). This is addressed specifically by formal testing of the orthogonality condition of the structural shocks, using principal components of a large macroeconomic dataset in the spirit of Forni and Gambetti [2014]. In the benchmark specification, additional information is needed for this condition to be satisfied. Consequently, the model is augmented by a factor a la Bernanke et al. [2005].

The rest of this note is organized as follows: Section 2 describes the model as well as the data used in the estimation. Section 3 shows the results of the benchmark model. Section 4 concludes.

2 The VAR model and the data

The analysis is based on the estimation of the VAR model in the so-called reduced form:

$$y_t = \Gamma_0 + \Gamma_1 t + \Gamma_2 Z_t + \tilde{y}_t, \quad \tilde{y}_t = \Pi_1 \tilde{y}_{t-1} + \dots + \Pi_p \tilde{y}_{t-p} + u_t, \quad u_t \sim N(0, \Sigma) \quad (1)$$

where y_t is a $K \times 1$ -vector of endogenous variables at time t while Z_t is a $n_Z \times 1$ -vector of exogenous variables (such as dummy-variables). The model includes p lags of its own endogenous variables. The matrices and vectors $(\Gamma_0, \Gamma_1, \Gamma_2, \Pi_1, \dots, \Pi_p, \Sigma)$ contain the model coefficients that we want to estimate. Alternatively, the model in (1) can be written as:

$$\Pi(L)(y_t - \Gamma d_t) = u_t, \quad (2)$$

where $\Pi(L) = I_K - \Pi_1 L - \Pi_2 L^2 - \dots - \Pi_p L^p$ (L is the lag-operator), $\Gamma = (\Gamma_0, \Gamma_1, \Gamma_2)$ and $y_t - \Gamma d_t = \tilde{y}_t$ (where d_t is appropriately defined to contain the deterministic components of the model). Writing the VAR model as in (2) follows Villani [2009] which allows for explicit priors on the steady state. The parameters can then be estimated by a Bayesian approach using a so-called Gibbs-sampler by iterating over the conditional distributions of the parameter matrices (see for example Del Negro and Schorfheide [2011] for further details). Villani [2009] shows that the convergence of the Markov-chain in the specification in (1) happens relatively quickly as long as the priors for Γ are not too diffuse. All results presented below are based on 1,000 accepted draws.

The data series used are quarterly series where the benchmark specification uses data from 1983Q1 to 2017Q3. The choice of estimation sample reflects a compromise of conflicting wishes to include as many observations as possible and to obtain a model based on stable relationships without severe breaks. Even though data is available for earlier periods, several related VAR studies on Danish data have preferred to start in 1983 at the earliest when estimating the effects of government spending shocks (e.g. Ravn and Spange, 2014 and Troelsen, 2018). Since this is the time where the fixed exchange rate was implemented and since it is well-known that the type of exchange rate regime is important for the effects of fiscal policy, estimating the model with an earlier starting point than used in the benchmark specification would make it hard to argue that the relations considered are stable. For example, a number of VAR studies who consider the effects of monetary policy prefer to start the estimation in 1994 to avoid a potential break during the ERM crisis in the early 1990s (Beier and Storgaard, 2006 and Jensen and Pedersen, 2019). All variables have been log-transformed and have been appropriately seasonally adjusted prior to estimation. All variables come from the database of the macroeconometric model used by the Danish central bank (see Danmarks Nationalbank [2003] (in Danish)).

The domestic block of the economy in the benchmark specification includes the following 5 variables: Real GDP, real private consumption, domestic prices (measured as the output deflator), wages, total taxes deflated by the consumer price index, and total real government spending and investment. All variables have been log-transformed and are appropriately seasonally adjusted when relevant prior to estimation. To achieve sta-

tionarity, prices and wages have been filtered using the approach suggested in Hamilton [2018]. All variables come from the database of the macroeconometric model used by the Danish central bank (see Danmarks Nationalbank [2003] (in Danish)). The choice of domestic variables in the benchmark specification is meant to capture the main effects of the propagation mechanism of government spending shocks. For example GDP is included as a measure of total economic activity whereas private consumption is the most important component of domestic aggregate demand. Prices and wages are included both to infer aggregate supply effects of demand shocks as well as to give an indication of the level of nominal rigidity («sticky prices»). Besides the domestic variables, the model controls for foreign demand by inclusion of an index for the total export market, relevant for Danish exporters.

The fact that the model is estimated in levels merits a comment: While in theory it is clear which type of specification to use (i.e. a VAR in levels or differences and whether to use a VECM-specification, based on the number of unit roots and cointegrating relations), in practice this is less clear. One reason for this is that pre-testing the data before specifying the model type has the problem that the associated tests have notoriously low power. Further, structural breaks in (trend-) stationary series might make the test falsely conclude that there is a unit root (Lai, 2004). Since the true data generating process is unknown, one concern is how model misspecification affects the estimated impulses. Gospodinov et al. [2013] examine the robustness of the impulse responses from estimated VAR models and find that the level specification is generally more robust than the VECM and VAR in differences in terms of impulse response estimation when the true data generation process is unknown. This echoes Ashley and Verbrugge [2009] who find that overdifferencing of the model yields poor estimation of the impulse response functions, including confidence interval coverage.¹ Perhaps as a result, most studies that match impulse responses to theoretical models include real variables in levels instead of differences (some of the more well-known and recent examples include Rotemberg and Woodford [1997], Iacoviello [2005], Altig et al. [2011], Christiano et al. [2016] and Castelnuovo and Pellegrino [2018]). Further, modelling the real variables in

¹As noted in Kilian and Lütkepohl [2017], the consequences of imposing a unit root are asymmetric: Incorrectly imposing an I(1)-assumption implies overdifferencing while failing to impose a unit root preserves consistency, albeit with less precise parameter estimates.

levels with a deterministic trend corresponds to the constant growth corrections made in the equilibrium conditions in MAKRO, both in the baseline forecast and when conducting shock analysis on the model. Finally, since the motivation for estimating the impulse responses is to have a set of data-driven moments to match against the model's short-run properties (given its long-run structure and parametrization) in face of shocks this motivates the choice to focus on short-run instead of long-run identification. Hence, this contributes to consistency between the empirical impulse responses and those of the model as well as the intended use of the empirical application.

Determining the lag order p is based on information criteria. Data favours a model with a limited lag-length and as a result is estimated with two lags (the robustness of the results to this choice is examined later). A constant and a linear trend is included in the model. Finally, the benchmark specification includes a dummy for the financial crisis, which takes on the value 1 during 2008Q4-2010Q4 and 0 otherwise as well as a few impulse dummies to account for extreme outliers (periods 1986Q2, 1988Q1, 2009Q1, and 2015Q1).

2.1 Identification of structural shocks

The residuals, u_t , in (2) can be interpreted as one-period-ahead forecast errors and do not lend themselves to any economic interpretation per se. Instead, they might be seen as linear combinations of the structural shocks that hit the economy simultaneously. Hence, identification of a particular structural shock (which can then be compared with a theoretical model) cannot be obtained by the VAR model's reduced form, i.e. without imposing further identifying restrictions. Such restrictions lead to the structural VAR (SVAR) representation of the model:

$$B_0 y_t = B_1 y_{t-1} + \dots + B_p y_{t-p} + \varepsilon_t, \quad \varepsilon_t \sim N(0, I_K) \quad (3)$$

where B_0 is a non-singular $K \times K$ -matrix, $B_1 = B_0 \Pi_1$, $B_2 = B_0 \Pi_2$, etc. and $\varepsilon_t = B_0 u_t$. The key difference between (2) and (3) is that the covariance-matrix of the error term in (3) is now diagonal: Since the shocks in ε_t are uncorrelated at time t they are said to be »structural«. While it is potentially possible to assign an economic

interpretation to all elements in ε_t , this need not be the case. Hence, the error term can simultaneously contain the structural shocks considered while remaining elements can be measurement errors or unidentified shocks (see for example Kilian and Lütkepohl [2017] for a discussion hereof). Since Sims [1980], the most widely used identification strategy has been to obtain the structural parameters in B_0 from a Cholesky decomposition of the covariance matrix of the reduced form residuals, Σ . Since the estimate of $\mathbb{E}(u_t u_t') = B_0^{-1} I_K (B_0^{-1})' = B_0^{-1} (B_0^{-1})'$ has $K(K+1)/2$ free parameters but B_0 contains K^2 parameters, $K^2 - K(K+1)/2$ further restrictions on B_0 are necessary for exact identification (which is exactly what is obtained by the Cholesky decomposition). This identification strategy has often been used for example to identify a monetary policy shock in the seminal paper by Christiano et al. [2005]. The disadvantage of this approach is that it implies a full recursive ordering of the variables in terms of weak exogeneity which might have a weak theoretical basis.

Identification of shocks to public consumption and investment is obtained by combining short-term restrictions with sign restrictions. First - due to various policy lags - government spending cannot respond *discretionarily* within same period to other shocks. The assumption is probably reasonable when models are estimated on quarterly data, but this might not be the case with annual data frequency. Furthermore, it is assumed that the output elasticity with respect to public consumption is zero, which means that the automatic feedback from the business cycle to public consumption is also zero within-quarter (this approach is also taken in Blanchard and Perotti [2002], Ilzetzki et al. [2013] as well as many others and for Danish data most prominently Ravn and Spange [2014]). Finally, it is assumed that foreign output does not respond to domestic shocks, i.e. it is assumed that Denmark is a small open economy. Besides these short-run restrictions, the model »controls« for two generic domestic shocks, inspired by Mountford and Uhlig [2009] (which is based on a similar strategy for identifying monetary policy shocks in Uhlig [2005]). Specifically, in addition to the shock to government spending and investment as well as foreign demand, two generic shocks which are orthogonal to the shock to public consumption are added: A domestic demand shock is assumed to increase GDP and prices in Denmark and a supply shock which increases GDP but decreases prices. These sign restrictions are universal across different clas-

ses of macroeconomic models (so-called robust sign restrictions in the terminology of Peersman and Straub [2009]). This approach avoids having to specify a full recursive ordering of the domestic variables as in the Cholesky decomposition. All sign restrictions are assumed to apply in the quarter of the shock and the subsequent three quarters.² Finally, note that no sign restrictions are imposed on the endogenous response of the other variables to public consumption. The sign and zero restrictions are summarized in Table 1. The specific algorithm used is the one proposed in Arias et al. [2018] which allows the combination of sign and zero- (or short-term) restrictions (this was originally implemented in a DREAM master’s thesis by Lund-Thomsen, 2016). The impulse responses below are found as follows: First, a candidate identification matrix is drawn which satisfies the short-run restrictions. Second, the signs of the resulting impulses are compared to the imposed restrictions. If they satisfy the identification restrictions, the draw is kept, otherwise it is discarded. Third, the estimation is continued until 1,000 accepted draws are obtained. The impulse response function of this SVAR model is the median response of all accepted draws.

2.2 Are the identified shocks structural?

An inherent disadvantage of VAR models is that the number of parameters increase rapidly as more variables are included. Further, due to structural breaks, the model has to be estimated on a limited number of observations. This necessitates that the empirical model contains fewer variables than those used by consumers and firms in their decision-making process. Omitting important variables can introduce slack in the estimation, since the true state of the economy is inaccurately observed. That agents and policy makers may have more information than the econometrician has been considered

²We abstain from imposing long-run restrictions a’ la’ Blanchard and Quah [1989] (for example, Souki [2008] identifies a foreign demand shock as the only shock allowed to have a permanent effect on the Canadian economy). The reason for this is that identifying assumptions on the long-run structure of the data are highly sensitive to the trend specification of the empirical model (and the true data generating process is of course unknown as discussed above). A prominent example is in the estimation of hours to technology shocks: While Gali [1999] finds that hours worked decline in face of a positive technology shock (thus questioning RBC-type models) when using a difference specification, Christiano et al. [2003] come to the opposite conclusion using the same identification scheme but using a model estimated in levels. The severe lack of robustness of long run restrictions combined with model misspecification is also highlighted in Ravenna [2007] and Gospodinov et al. [2013].

in terms of VAR models at least since Sims [1992] who argue that part of the »price puzzle« he observes in terms of monetary policy may be due to the fact that the central bank incorporates inflation expectations in their decision making proces.³ Later, this has been discussed in terms of news shocks (Sims [2012]) and fiscal foresight (Leeper et al., 2013).

To investigate whether the identified shocks are in fact structural, the approach in Forni and Gambetti [2014] is followed. The approach has two steps: First, the information from more than 70 macroeconomic and financial variables at quarterly frequency from the database described in Section 2 is summarized using principal components. As suggested in Stock and Watson [2002], in this way one can pool the information in all possible predictor variables in a large macroeconomic data set while discarding idiosyncratic variation in one particular series. Second, we test the orthogonality condition that implicitly underpins the SVAR-representation of the empirical model: All relevant information used to identify the shock of interest must be contained in the information set of the empirical model. In other words, the structural shock must be orthogonal to the lagged values of the principal components. In the benchmark specification, the data suggests that the third principal component should be added in the spirit of Factor-Augmented VAR (FAVAR) models (Bernanke et al., 2005) and it is subsequently included in the final estimation.

3 Results

The impulse responses to the shock to government spending and investment are shown in Figure 1. The shock is scaled so that the graphs show the endogenous reaction to a 1% increase in spending (due to the linearity of the model this has no effect on the results besides scaling the graphs). The persistency of the shock itself is estimated as well and so one can think of the effects in Figure 1 as the average historical effect of government spending, where the shock is of average persistency. This implies that the

³This insight led Fernandez-Villaverde et al. [2007] to propose the “poor man’s invertibility condition” that must hold for all the residuals in the VAR model to have a structural mapping. However, as noted in Forni et al. [2016], one or more structural shock may well be identified even though the condition in Fernandez-Villaverde et al. [2007] is not satisfied.

shock, when compared to a model, should be thought of as a shock from its steady state and the effects as those that are associated with approximately neutral (or »average«) business cycle conditions. Since the variables of the model are log-transformed, the impulse responses show the percentage deviation from this steady state or baseline scenario.

The expansionary fiscal policy stimulates total domestic demand and increases GDP. Both the effects on economic activity and the shock itself are fairly persistent, although the positive effect on GDP is no longer significant after around 2-3 years. The complete crowding out time on GDP (a relatively uncertain moment) is found to be around 5 years in the benchmark specification (consistens with related literature, see below), with half of the effect gone after around 3 years.

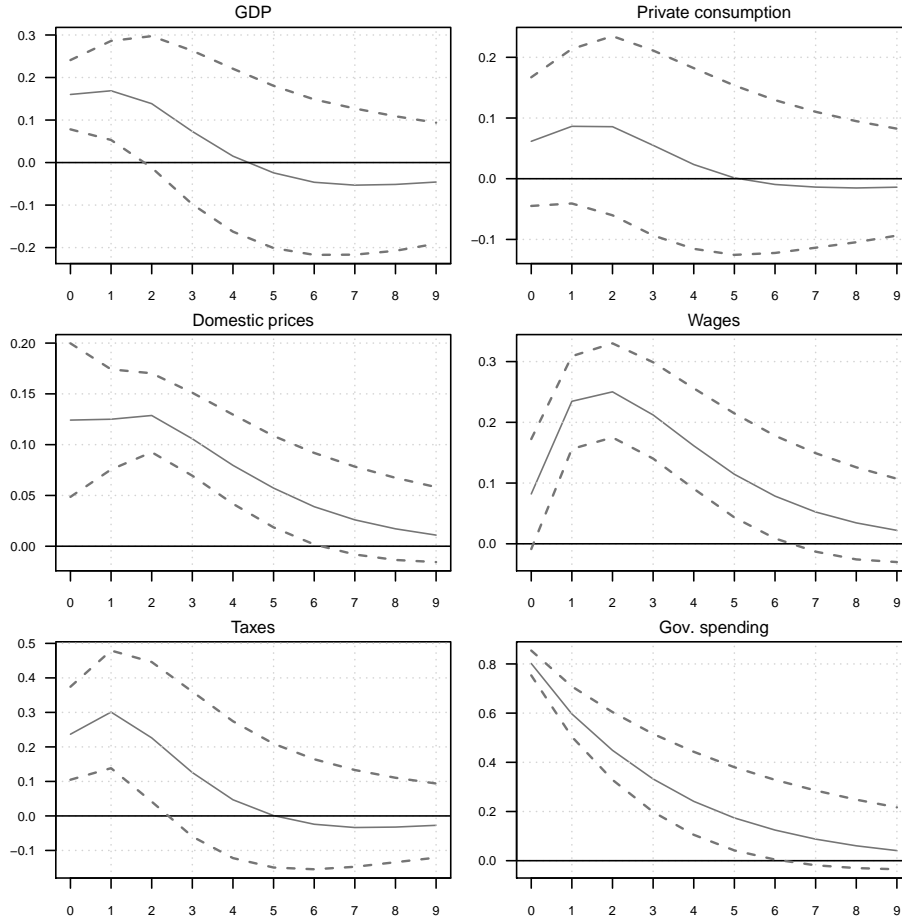
For private consumption, it is found that the effect of increased government spending and the resulting expanding economy is a positive response - a result that this note shares with Lund-Thomsen [2016] and Troelsen [2018], but opposite that what is found in Ravn and Spange [2014]. Hence, in the aggregate, consumers seem to act more »keynesian« than »neoclassical«, although this result is associated with non-negligible uncertainty as indicated by the confidence bands. The central estimate, however indicate that there might be a need for hand-to-mouth or liquidity constrained consumers in MAKRO such that the marginal propensity to consume, conditional on government spending, is not 0 (or negative) due to dominating Richardian equivalence effects.⁴ The »hump-shaped« response in consumption - the effect peaks after around 2 years - might be consistent with some degree of habit formation.

Domestic prices peak slightly later than GDP (and thus also with a delay in relation to the shock) and show much more persistency too. This indicates the presense of nominal rigidities in the price formation. Wages are moving more sluggishly than prices and peak later. This seems to imply that the nominal rigidities in the wage formation are greater. This result is also found in Abildgren [2010] and in the estimation of the DSGE model in Pedersen and Ravn [2013]. As a result, the real wages are insignificant or mildly countercyclical immediately after the government spending shock (consistent

⁴A positive consumption response to a temporary increase in income is consistent with a number of recent studies using Danish microeconomic data or surveys, see for example Crawley and Kuchler [2018] and Kreiner et al. [2019].

with the findings in Messina et al. [2009]), after which the effect reverses and real wages grow.⁵

Figur 1: Impulse responses to a shock to government spending and investment, benchmark model. The identification scheme is based on 1. The impulses are shown including their numerical 68% confidence bands.



It is common in the literature to show the effects of government spending shock via the so-called fiscal multiplier. The multiplier expresses the effect (typically on GDP) in domestic currency (DKK) per unit spent. In the benchmark specification, this multiplier

⁵Of course, a counter cyclical average wage does not imply that the wage for a giver worker is counter cyclical. It has been known at least since Solon et al. [1994] that this result might be due to a composition effect in aggregate time series. For example, the employment of high wage-earners may be less cyclical than that of low wage-earners, which makes the average real wage less procyclical.

is found to be around 0.7 at impact (at quarterly frequency) and close to this level for the average effect in the first year as well. According to the survey in IMF [2014] this implies that the fiscal multiplier in Denmark can be characterized as being in the range of »medium« to »high«. Elements which we would expect to contribute to a higher multiplier are a relatively low debt-to-GDP ratio for most of the sample period (implying that fiscal policy has limited second-order effects on risk premia) and Denmark’s fixed exchange rate, since this implies that there is no endogenous monetary policy reaction following the increase in output and prices (the real interest rate decreases). Factors expected to lead to a lower multiplier are, in particular, high automatic stabilizers in the overall fiscal policy as well as a very high degree of openness to trade (leakage-effect through higher imports). How does this compare to related studies? Ravn and Spange [2014] find a multiplier for Denmark of a little more than 1 in the initial quarter and around 0.6 after 1 year. This is a larger initial effect which is less persistent (although the decay rate of the shock itself is less persistent as well). However, their confidence interval of the multiplier is between 0.33 and 1.93, meaning that the central estimate in this paper is not statistically significantly different. Estimating a larger VAR model, Lund-Thomsen [2016] finds the multiplier to be around 0.5 with a more persistent effect.⁶ In a multi-country study, Ilzetzi et al. [2013] find an impact multiplier of 0.2 for high-income countries with fixed exchange rates, which is somewhat lower than what is found in this note. For high-income countries they report an average multiplier of 0.4, although they find that fiscal multipliers in open economies (imports plus exports as a share of GDP of more than 60%) may even be negative. Several papers estimate the fiscal multiplier in the US using VAR models. Here, the first year estimate ranges from around 0.7 ([Mountford and Uhlig, 2009]) to around or slightly above 1 (Blanchard and Perotti, 2002 and Caldara and Kamps [2017]). Finally, one could compare the estimate with other macroeconomic models: ECB [2015] collects different model simulations (primarily from Euro Area countries) based on country-specific models (calibrated as well as estimated) and report a first year GDP multiplier between around 0.5 (Spain and Germany) and around 0.9 (Belgium, France and Greece). In ADAM, the first year government spending multiplier for spending is between 0.8

⁶Troelsen [2018] who also estimates a VAR model on Danish data includes the unemployment rate instead of GDP.

and 1, depending on the instrument used (Troelsen, 2018). Broadly speaking, the fiscal multiplier found in this paper is in line with existing literature, especially when taking estimation uncertainty into account, perhaps with the exception of the low multipliers found in Ilzetzki et al. [2013].

Another moment for government spending shocks that one could focus on is the crowding out time, i.e. when the positive effect on GDP relative to the baseline level is completely gone, according to the model. As mentioned, this is around 5 years in the benchmark specification used in this paper. Looking at other Danish studies, this is broadly comparable with Ravn and Spange [2014] where the positive effect on GDP is almost gone after 5 years and a little faster than Lund-Thomsen [2016] where the crowding out time is approximately 6 years. As mentioned, Troelsen [2018] does not include GDP as an endogenous variable but considers the impulse response of unemployment instead, the crowding out time is somewhat slower, almost 10 years. It should be emphasized however, that this moment can only be estimated with non-negligible uncertainty as emphasized by the results across Danish and international empirical studies.

Figure 2 makes the same impulses as the benchmark specification with the following changes: Estimating the model with 1 and 3 lags, respectively. Estimating the model with government consumption without investment and reinvestment and government employment, respectively.

4 Conclusion

In this working paper, the effects of government spending shocks to the Danish economy are assessed and analyzed. This is done through an estimated VAR model with domestic variables as well as a measure of foreign demand. The identification of government spending shocks centers around the commonly used approach in Blanchard and Perotti [2002]. This is combined with an assumption of Denmark as a small open economy as well as sign restrictions to control for generic domestic shocks. This approach leads to results which are broadly in line with previous empirical findings, albeit they are associated with non-negligible uncertainty.

Appendix A: Overview of identifying restrictions

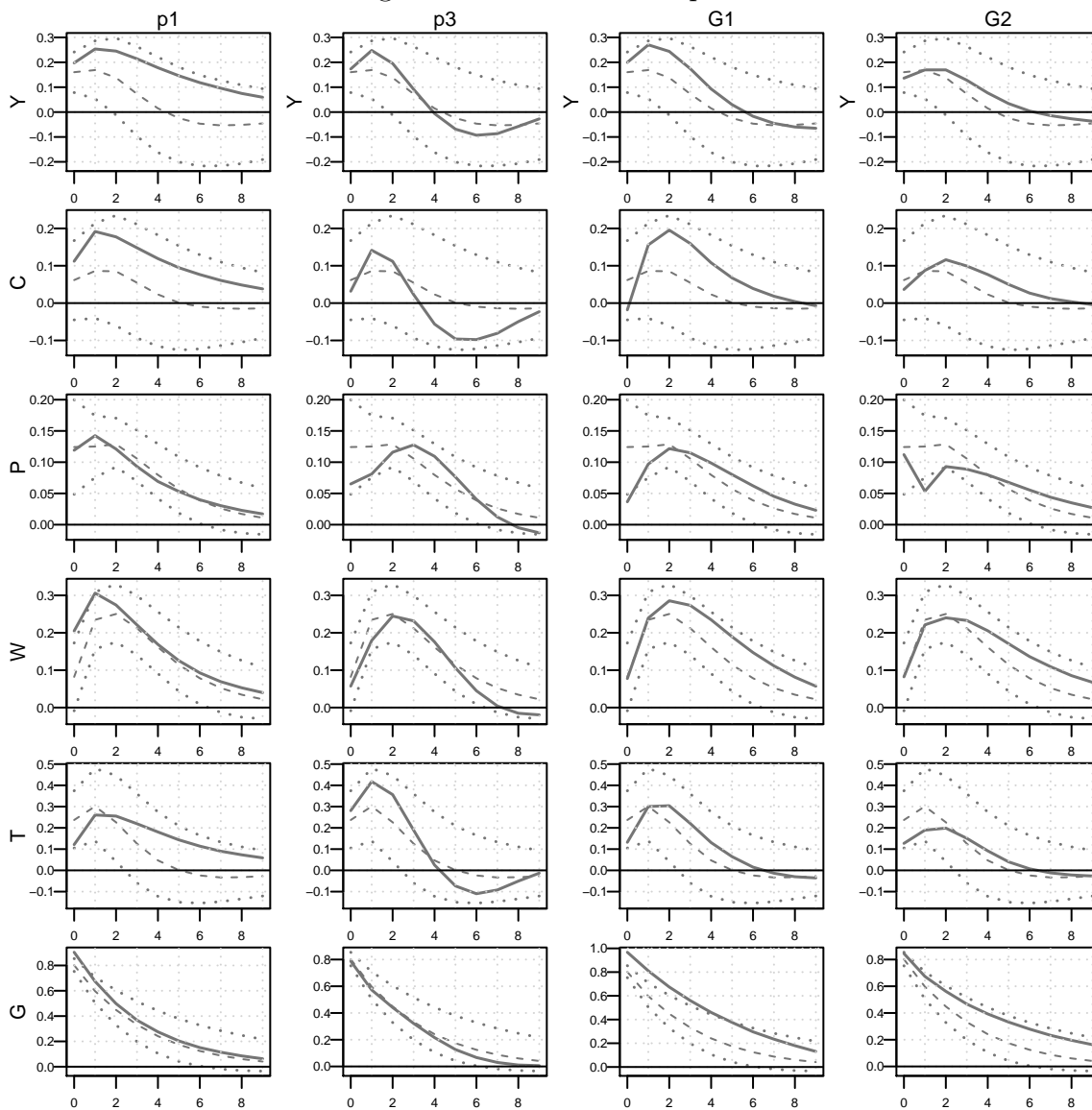
Tabel 1: Identification, benchmark model

	Domestic demand	Domestic supply	Government spending	Foreign demand
GDP	+	+		
Consumption	+			
Prices	+	-		
Wages				
Taxes	0	0		
Government spending	0	0	+	
Foreign output	0	0	0	+

Note: A "0" indicates that this variable cannot move contemporaneously in response to the particular shock. A "+"("-") indicates that this variable must respond positively (negatively) to the particular shock. Signs in () indicate that this is not imposed contemporaneously. All sign restrictions are imposed for a total of 4 quarters in total. The impulse responses are based on 1,000 accepted draws.

Appendix B: Additional graphs

Figure 2: Robustness of impulses



Note: p1 and p3 are lag length 1 and 3, respectively ($p = 2$ in the benchmark model). G1 and G2 are government consumption without investment and reinvestment and government employment, respectively.

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