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Fiscal Policy Multipliers and Spillovers in a Multi-Regional Macroeconomic Input-Output Model

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Abstract:

The recent macroeconomic literature dealing with fiscal policy multipliers is dominated by applications of aggregate DSGE (Dynamic Stochastic General Equilibrium) models, whereas multi-sectoral models (econometric IO or CGE) are absent. This paper contributes to the debate from a multi-regional, multi-sectoral perspective. The macroeconomic IO model applied covers 67 countries (plus a statistical RoW) and incorporates model blocks for private consumption, production, the labour market and the public sector. Household consumption follows the permanent income hypothesis, but with important liquidity constraints.

This study calculates macroeconomic and sectoral impacts of fiscal policy in one peripheral EU economy (Spain) as well as their inter-regional spillovers to the rest of Europe. Multipliers are about 1.9 (1.6) for public consumption and 1,2 (0.9) for household taxes or transfers in the case of high (low) liquidity constraints. Partially endogenous public spending produces additional domestic effects as well as relatively large spillovers for some highly indebted European countries.

Key words: Input-output modelling, fiscal policy multiplier, consumption theory

JEL Codes: C54, C67, H60

1.Introduction

During the last decade an intensive debate has emerged in macroeconomics about the role of fiscal policy in the aftermath of the financial crisis and – more specifically – about the stability and magnitude of fiscal policy multipliers. One line of the theoretical literature emphasized the point that at the zero lower bound of the interest rate monetary policy cannot be effective and fiscal policy might be recommended. For example, Eggertson and Krugman (2012) describe a state of the economy where households need to reduce their debt burden (deleveraging) and the interest rate is stuck at the zero lower bound and show the similarities to the original Keynesian liquidity trap.

One important starting point of the recent empirical debate on the magnitude of fiscal policy multipliers was the underestimation of growth dampening impacts of austerity in heavily indebted Euro area countries, leading to errors in GDP growth forecasts. Several studies (IMF, 2012; Blanchard and Leigh, 2013) have shown that significant underestimation (by a factor of 2 to 3) of the effects of fiscal consolidation had contributed to these errors. This led to a re-examination of former studies on fiscal policy multipliers with contributions from VAR approaches and different specifications of standard DSGE (Dynamic Stochastic General Equilibrium), especially of the work by Blanchard and Perotti (2002). One general point of the debate was about the stability of fiscal policy multipliers and their dependency upon the state of the economy (Auerbach and Gorodnichenko, 2012; Bilbao-Ubillos and Fernández-Sainz, 2014; Canzoneri, et al., 2015; and Oywang, et al., 2013). One part of the literature approaches this question in an *ad hoc* empirical way by simply comparing fiscal policy impacts in different historical periods. The other part attempts to explain and specify the economic significance of behavior in booms and busts for fiscal policy multipliers. The core of this explanation is the reaction of private consumption to public spending (Gali et al., 2004), i.e. whether private and public consumption are complements or substitutes. One main mechanism behind that is the magnitude of the reaction of consumption to transitory income shocks. Liquidity requirements as binding constraints for otherwise dynamically optimizing households play a major role in this literature. Households react to liquidity constraints (also due to debt deleveraging) by higher reactions of spending to transitory income shocks. The same change in spending reaction can be achieved in a model with perfect foresight by introducing a share of households for which 'Ricardian equivalence' does not hold (i.e. they do not expect lower permanent income due to higher taxes, when current government spending increases their current income). We follow this strain of the literature by introducing down payments for durable (houses, vehicles) as the binding liquidity constraint in a consumption model that is otherwise specified according to the permanent income hypothesis, as suggested by Luengo-Prado (2006). The consumption model block is integrated into a multi-regional macroeconomic input-output (IO) model. The model produces some heterogeneity in fiscal policy multipliers for liquidity constraints of different stringency. In our sensitivity analysis, the multiplier of public consumption varies between 1.6 and 1.9. This variance of the multiplier is smaller than in the existing macroeconomic literature. That refers especially to the lower bound of the multipliers: now values below or close to unity are found. The basic reason for these differences in results are that this analysis integrates fiscal policy endogeneity and that private consumption as well as gross fixed capital formation react more strongly to the fiscal policy shock.

The DSGE model and reduced-form macroeconomic models based on VAR (Vector Autoregressive Regression) econometrics are the main tools applied in the fiscal policy multiplier literature. Several studies compare model results or undertake meta-analysis (Coenen, et al., 2012; Feve and Sahuc, 2015; and Gechert, 2015), others add features to the standard DSGE to test sensitivity (Chahrour, et al., 2012; and Zubairy, 2014) and another group of researchers engages in analyzing the differences in impacts of fiscal policy instruments (taxes, transfers, public consumption, see for example: Gechert, 2015). Almost no contribution from CGE and macroeconomic IO models can be found. We think that this is due to the specification of private consumption in this type of static models. According to the SAM framework, consumption in these models is specified as a fixed share of income or as a simple Keynesian consumption function. Both do not allow for variety and dynamics in household behavior. There is, though, a difference with respect to fiscal policy multipliers between macroeconomic IO and CGE models, which is due to the macroeconomic constraints in the closure rule. Fixed investment, determined by the level of domestic plus foreign savings prevent multipliers of fiscal policy in CGE models, though the consumption function is a linear function of income (see: Kratena and Streicher, 2009). Due to this treatment of private consumption, the IO literature has not entered in this recent multiplier debate, though it has questioned the traditional concept of static IO or SAM multipliers by introducing 'net multiplier' (Oosterhaven et al., 2003; Miller and Blair, 2009) concepts. A recent example is Guerra and Sancho (2011), who assume that the positive demand shock needs to be compensated by some negative impact that represents, for example, the financing of public expenditure. Only a few approaches introduce more dynamics or heterogeneity in consumption modelling in IO models, mostly in the part of allocation of commodities within total consumption (Mongelli et al., 2010; Kim et al., 2015). To our knowledge there has only been one attempt of integrating a non-Keynesian consumption model block into an IO model (Chen, et al., 2010). We expand this approach by introducing liquidity constraints into a permanent income hypothesis-model and fully integrating the household accounts (stocks and flows) into the IO model structure. The down payment parameter is exogenous (determined in financial markets not covered by the model) and is fixed in a way that a long-run target of the debt to durable stock[1] ratio is achieved. The latter can be interpreted as the long-run down payment restriction in a model of dynamic optimization. Fixing a lower debt-to-durable ratio than the actual one for European households results in the need of debt deleveraging and lower long-run growth of private spending as well as more pronounced reactions of consumption to transitory income shocks and, thus, higher fiscal policy multipliers. Such a scenario is the base case in the analysis presented here for Europe and is confronted with sensitivity analysis for the debt-to-durable ratio and different fiscal policy shocks. This paper also deals explicitly with two other issues in the fiscal policy multiplier debate: (i) partial endogeneity of fiscal policy, and (ii) inter-regional spillovers of fiscal policy between heavily interlinked regions (like the European countries). Regarding (i) most empirical studies which use models with partially endogenous government spending or taxes simply allow that the *ex post* result – for example in the case of fiscal consolidation – is different from the *ex ante*

[1] This relationship is termed as the 'loan to value' ratio in the financial literature.

policy target. This has been an important point in the debate about 'self defeating' fiscal consolidation. If macroeconomic impacts of austerity have been underestimated (as among others suggested by Blanchard and Leigh, 2013), deficit targets have not been achieved, if components of the deficit are endogenous and anticyclical (automatic stabilizers). In this paper, we apply an *ex post* concept to fiscal policy targets. The endogenous reactions of spending and tax revenues therefore further contribute to the total multiplier impact, and the total impact can be decomposed into an *ex ante* and an *endogeneity* effect. Inter-regional spillovers for Europe have been presented by Cwik and Wieland (2009) as well as by in't Veld (2013). Our results directly compare to their work. In general, this study explores macroeconomic as well as industry results beyond the macroeconomic studies, both for national impacts as well as for spillover effects. It can be shown that the industry structure of impacts of fiscal policy has important consequences for some macroeconomic variables, especially employment.

The paper is organized as follows: section 2 describes the multi-regional macroeconomic IO model with special emphasis on private consumption, trade, and the public sector. Section 3 reports the results for fiscal policy experiments in Spain on the economy of all EU countries. Section 4 discusses the results and puts them in perspective with respect to the literature. In section 5 some conclusions are drawn and the shortcomings as well as the need for future research are lined out. A more detailed model description can be found in the Appendix.

2. A Multi-Regional Macroeconomic IO Model

The model approach applied in this study is a hybrid between an econometric IO and a CGE model and is characterized by the integration of rigidities and institutional frictions; it might be called "DYNK" (Dynamic New-Keynesian), to highlight the "theoretical foundation" of this hybrid type of model. It is an extended version of the FIDELIO model (see: Kratena et al., 2013; and Kratena, et al., 2017), with the extensions mainly referring to wider geographical coverage, additional data integration and the inclusion of non-EU countries in the production block . The rigidities that differentiate this model from a pure CGE model include liquidity constraints for consumers (deviation from the permanent income hypothesis), and wage bargaining (deviation from the competitive labor market). In the long-run the model works similarly to a CGE model, and explicitly describes an adjustment path towards a long-run equilibrium. The two main differences to a static CGE model are (i) equilibrium is achieved in a long lasting dynamic adjustment process and not instantaneously, and (ii) not all markets are stabilized via adjustments in the price mechanism. As far as (ii) is concerned, prices have an impact on all quantities demanded (intermediate, final), both on the level of demand (real income effect) as well as on its commodity structure (substitution effect). For the supply side, constant returns to scale and perfect competition inhibit that quantities react to prices. The only feedback from quantities to prices works via the wage curve in the labour market. This mechanism causes price effects, but is not equivalent to a balancing of labour supply and demand in competitive labour markets as in most CGE models.

Macroeconomic closure in this macroeconomic MRIO model works via fixing (i) an equilibrium value for the household debt/durables ratio in the long-run and (ii) an equilibrium path for the public deficit/GDP ratio. Again, this is not equivalent to the fixed savings assumption in macroeconomic closures of CGE models, but still establishes some long-run equilibrium restrictions.

2.1 The General Structure of the Macroeconomic MRIO Model FIDELIO

The model is based on supply and use tables describing the inter-linkages between 59 NACE Rev. 1 industries and commodities in 2007, as well as the consumption of five household income groups by 47 consumption categories. Geographic coverage is based on the WIOD data base: EU27 (members in 2007, FIDELIO’s base year) plus AUS, BRA, CAN, CHN, IDN, IND, JPN, KOR, MEX, RUS, TUR, TWN, USA. To reduce the “Eurocentric aspect” of WIOD, however, the coverage was expanded to include the following countries and regions: UKR, MDA, YUG, HRV, NOR, CHE, ISL, BLR, GEO, ALB, BIH, MKD (Europe); COL, CHL, ARG, Rest_SOUTHAMERICA (South America); Rest_NORTHAMERICA; ZAF, TigerofAfrica, SubSahara, NorthAfrica (Africa); STAN, MiddleEast, ISR, NZL, Rest_Oceania, Rest_ASIA (Asia&Oceania).

The supply-and use tables of the additional countries were constructed using a variety of data sources: National accounts data from UNSD[2] and OECD[3] were used as boundary values, with commodity structures being mostly based in GTAP[4]. The SUTs for all regions distinguish between 59 commodities; the number of industries, however, is not uniform: for the EU27, the WIOD SUTs were replaced by ERUROSTAT tables, allowing for 59 industries (up from 35 for the WIOD countries). The additional 27 regions follow WIOD's 35 industry classification.

The trade matrix was derived from COMTRADE for commodities; trade in services is based on BoP data as well as trade structures taken from GTAP. Special attention was reserved for the consistent treatment of international trade and transport margins (TIR), and the cif-fob correction. Following Streicher and Stehrer (2015), these transport margins are explicitly taken into account, both on the demand side as well as on the production side.

Figure 1 shows how the core of a traditional IO model is expanded by the explicitly modelled demand categories in the model. Aggregate consumption is split into demand for 2 types of durables (Vehicles, Housing) and total non-durables, depending on income, wealth, and liquidity constraints. Total non-durable consumption is then disaggregated into 14 commodities using an AIDS model based on relative prices. The distribution between imported and domestic goods is modelled using an Arnington assumption. Production is modeled via a Translog model (determining output prices p^Q as well as $KLEM^dM^m$ factors shares: Labour, Capital, Energy, imported and domestically produced materials) that is fully integrated into the IO structure. Besides that, the model also comprises a block for the labor market (incorporating wage bargaining). For the EU27, the public sector is modelled in a detailed bottom-up fashion, with endogenous revenue (mostly from taxes and social security contributions) and expenditure (public investment, payment on interest and debt, unemployment benefits among the most important ones[5]). The public sector closes the model via one of two conceptually different rules: public consumption can be exogenous, which

[2] see http://unstats.un.org/unsd/snaama/introduction.asp

[3] http://www.oecd.org/trade/input-outputtables.htm

[4] www.gtap.org

[5] other important expenditures, like transfers and pesnions, are treated exogenously

results in the budget deficit being endogenous; or an exogenous path for the budget deficit can be specified, which results in endogenous public consumption.

So, the IO core of the model is based on Supply-Use tables and intermediate demand is split into domestic and imported commodities. Instead of deriving a technical coefficient matrix (inputs of intermediate commodities per unit of industry output) from the use matrix, this modelling step is split into two parts in the FIDELIO model. First, vectors of total input coefficients per unit of industry output for domestic and imported commodities ($\mathbf{v}_D$ and $\mathbf{v}_M$) are defined. In a second step, the commodity structure below this level is defined by use structure matrices $\mathbf{S}^m$ and $\mathbf{S}^d$ with column sums equal to unity. A further distinction within the use matrix is between non-energy and energy commodities. The commodity balance for non-energy commodities is then defined by applying the use structure matrices $\mathbf{S}^m_{NE}$ and $\mathbf{S}^d_{NE}$ as well as the diagonal matrices of the factor shares defined above, $\hat{\mathbf{V}}_D$ and $\hat{\mathbf{V}}_M$. Multiplying the use structure matrix with the corresponding factor share matrix and with the column vector of output in current prices gives the sum of intermediate demand by commodity. The procedure for energy commodities is the same, with use structure matrices $\mathbf{S}^m_E$ and $\mathbf{S}^d_E$ (where the column sum over both matrices yields one), and diagonal matrix $\hat{\mathbf{V}}_E$. The full commodity balance is given by adding the column vectors of domestic consumption ($\mathbf{c}^d$), capital formation ($\mathbf{cf}^d$) and public consumption ($\mathbf{cg}^d$). Capital formation is endogenous as well and derived from capital demand by industry in the Translog model, applying the capital formation matrix (for details see the Appendix). The (column vector of) domestic output of goods in current prices, $\mathbf{p}^G\mathbf{q}^G$, is transformed into the (column vector) of output in current prices, $\mathbf{p}^Q\mathbf{q}$, by applying the market shares matrix, $\mathbf{C}$ (industries * commodities) with column sum equal to one:

$$\mathbf{p}^G\mathbf{q}^G = \left[\hat{\mathbf{V}}_D\mathbf{S}^d_{NE}\right]\mathbf{p}_Q\mathbf{q} + \left[\hat{\mathbf{V}}_E\mathbf{S}^d_E\right]\mathbf{p}_Q\mathbf{q} + \mathbf{c}^d + \mathbf{cf}^d + \mathbf{ex}^d + \mathbf{st}^d + \mathbf{cg}^d \tag{1}$$

$$\mathbf{p}^Q\mathbf{q} = \mathbf{C}\mathbf{p}^G\mathbf{q}^G \tag{2}$$

These two equations describe the core IO model of the system. The final demand categories ($\mathbf{c}^d$, $\mathbf{cf}^d$, $\mathbf{ex}^d$, $\mathbf{st}^d$ and $\mathbf{cg}^d$) comprise energy and non-energy commodities, are all in current prices and are all – except for changes in stocks ($\mathbf{st}^d$) – endogenous. The export vector $\mathbf{ex}^d$ is determined via the import demand of all trading partners (after cif/fob-correction). The vector of public consumption $\mathbf{cg}^d$ is determined in the public sector-block of the model.

2.2 Aggregate household demand

Including household accounts and linking them in a SAM (Social Accounting Matrix) framework to an IO table still represents the main workhorse in IO as well as CGE modelling. In both model types this methodology simply consists of adding Keynesian income-expenditure loops to the IO framework and thereby relating consumption to current disposable income (Miyazawa, 1976). In the CGE modelling context, the macroeconomic closure rules impede Keynesian multiplier effects, though consumption is simply linked to current income (Kratena and Streicher, 2009).

This linear coefficient-treatment of consumption neglects the macroeconomic debate since the 1950s of whether and how consumption reacts to transitory income shocks. The life-cycle/permanent income hypothesis assumes that consumers optimize dynamically and only react to changes in their permanent (= long-run expected) income. This has been challenged mainly by empirical puzzles, the most relevant being 'excess sensitivity'. This property refers to the empirical observation that consumption significantly depends on lagged income. This should not be the case, as information about past variables should be completely irrelevant according to the permanent income hypothesis (Hall and Mishkin, 1982) and consumption should be a martingale (Hall, 1978). As an alternative model to integrate the empirical puzzles into the permanent income hypothesis, the buffer-stock model (Deaton, 1991, and Carroll, 1997) emerged, introducing income uncertainty (risk of unemployment, etc.). We apply a specification in which buffer-stock saving is not motivated by income uncertainty, but by down payments for purchase of durables, as laid down in Luengo-Prado (2006). Households maximise the present discounted value of the expected utility obtained from consuming nondurable commodities and from the services provided by the stock of durables subject to a budget constraint. At the first stage, the demand for durables (housing and vehicles) is modeled and total nondurable demand is also specified in a way consistent with the main properties of the buffer stock model (excessive smoothing). All model parameters are based on dynamic estimation of panel data for Europe (1995-2011), in the first stage for 14 EU countries (Belgium, Czech Republic, Denmark, Germany, France, Italy, Cyprus, Lithuania, Austria, Poland, Portugal, Romania, Slovakia, Finland). The data for the estimation of consumption demand functions are mainly taken from EUROSTAT's National Accounts. The capital stock of housing property was constructed by combining data of the Household Financial and Consumption Survey (HFCS) of the ECB (European Central Bank) with property price data from BIS (Bank of International Settlement). A crucial variable at this first stage of consumers' demand is the down payment for durable purchases (see the Appendix for details).

The model distinguishes between 5 types of households (defined as income quintiles). For each type of household, demand functions are specified that are consistent with the model properties. These comprise non-linear consumption functions for durables, which are based on the concave shape of the policy functions for consumption in Luengo-Prado (2006), and where, with higher levels of durables per households (K_t/h_t), the marginal propensity of investment in durables, C_{Kt} with respect to X_t decreases. The down payment parameter in Luengo-Prado (2006) represents a long-term constraint between the debt stock and the durable stock of households and is specified here by imposing limits to the down payment for durable flows. Durables in this model are owner occupied houses (dwelling investment) and vehicles. The long-run demand functions for the two durable categories ($C_{dur,t}$) is a function of 'cash on hand' (X_t), the down payment for durable purchases (θ_{Ct}), as well as static user costs of durables, $p_{dur,t}(r_t + \delta)$

$$\log C_{dur,t} = \log C_{dur,t}\left[\log X_t, \theta_{Ct}, \log\left(p_{dur,t}(r_t + \delta)\right), \log\left(K_{t-1} / h_{t-1}\right)\right] \tag{3}$$

The long-run demand function for total nondurable consumption is a function of 'cash on hand' and down payments for durable purchases ($\theta_{Ct} \log C_{dur,t}$)

$$\log C_{nondur,t} = \log C_{nondur,t}\left[\log X_t, \theta_{Ct} \log C_{dur,t}\right] \tag{4}$$

The latter considers that households need to finance down payments, and will not do so by savings in the same period but will smooth nondurable consumption accordingly (excessive smoothing). The estimation is carried out as error correction panel data estimation and the results are used to calibrate the model at the level of the 5 quintiles of income, which are characterized by different values for the durable stocks per household.

Once the full model is set up, the property of ‘excess sensitivity’ can be tested. The full model presented in the next sections is simulated until 2050, so that endogenous disposable household income is generated. All exogenous variables had to be projected for this baseline scenario (population, number of households, tax rates, world energy prices, labour supply by skill groups, some variables of the public sector, TFP growth by industry, etc.). In the consumption block of the model the crucial exogenous variable that had to be fixed is the relation of the debt to durables stock of households. This is a target variable achieved in the long-run and governed by the down payment for durable purchases. The baseline scenario (‘high θ scenario’) corresponds to debt deleveraging so that the relationship debt-to-durable stock in the long-run decreases to its values before 2002, i.e. before the main expansion of household debt began. Excess sensitivity has been tested by regressing total consumption (durable plus nondurable) and nondurable consumption growth on lagged disposable income growth (without profit income), both extracted from the model’s baseline scenario until 2050. Profit income has been excluded, as this income source is a result of intertemporal optimization of consumers and therefore not affected by transitory income shocks. The parameters for quintile 1 to 4 are significant at the 1% level, those for quintile 5 at the 5% level. The estimated parameters clearly reveal huge differences in the marginal propensity of consumption between quintiles. (Table 1). The quintiles exhibit significant differences in the debt-to-durable stock ratios as well as net asset stocks. Therefore, a general change in liquidity constraints for households affects the income groups in different ways. This, in turn, triggers an aggregate effect on consumption of households. The multiplier of fiscal policy measures that influence income is therefore not constant, but depends on the financial market environment (liquidity constraints) and the income groups that are most affected. This mechanism has been analyzed theoretically by Eggertson and Krugman (2012) and empirically for the US by Mian et al. (2013). Luengo-Prado (2006) also carries out excess sensitivity tests with her calibrated model, based on US household survey data and confronts these results with US stylized macroeconomic facts. The excess sensitivity coefficients found by Luengo-Prado (2006), i.e. the marginal propensity of consumption (MPC) with respect to lagged income change, are 0.16 (nondurables) and 0.26 (durables).

2.3 Household demand by commodity

At the second stage, energy consumption (which is disaggregated into: heating, electricity and fuels for transport), is modeled as a service demand in terms of utilization of the capital (durable) stock. Therefore, it links energy demand (in monetary and physical units) to the durable stock (houses, vehicles, appliances). The econometric estimation has been carried out for an EU 27 country panel (1995 – 2011) from EUROSTAT National Accounts, as well as for data from the household survey 2004/2005 for six EU countries: Austria, France, Italy, Slovakia, Spain and UK (Salotti, et al., 2015). For the cross section model no price variance across time is available and therefore the model only estimates the expenditure term. The price elasticity values (Table 2) found here for heating, transport fuel and electricity (around -0.8) are outside the range established by the existing literature for the energy price elasticity. That can be explained by two factors. First, the elasticity values presented here measure the service price elasticity and the reaction of service demand to both price changes and improvements of energy efficiency in the durable stock. Service prices have been almost constant in the sample period used for estimation due to energy efficiency improvements, whereas demand has increased considerably. This is consistent with part of the literature on the (price) rebound effect that finds rebound effects of 100% in some cases. Second, the elasticity values calculated here are conditional on the stock of durables, thereby implicitly assuming a unitary elasticity of energy demand to the durable stock as a strong driving force of demand (Table 2).

Finally, the third stage contains the model of non-energy nondurable consumption, modeled in a flexible demand system (AIDS model). This third step is again split into two nests: (i) an aggregate level of eight categories, described in an AIDS model, and (ii) a detailed model of 47 COICOP categories, explained by sub-shares of the aggregate categories that change over time and can be changed exogenously for model simulation purposes. The econometric estimation also has been carried out for the EU 27 country panel and for data from the household survey 2004/2005 for the six EU countries. The main results of the estimation of the demand system for non-energy nondurables are the expenditure elasticity from both models (panel and cross section) and the price elasticity from the panel data model (Table 2). The price elasticity shows considerable heterogeneity across categories. For the expenditure elasticity values the results of both models differ considerably. While the expenditure elasticity of the panel data model is mainly distributed around unity, the expenditure elasticity of the cross-section model differs largely between categories.

The integration of this consumption block into the IO model builds upon the model by Mongelli et al. (2010). The first stage yields (column) vectors of total nondurable consumption $(\mathbf{c}_{\mathrm{nondur}})$ and of investment in owned houses $(\mathbf{c}_{\mathrm{hous}})$ and in vehicles $(\mathbf{c}_{\mathrm{veh}})$ by quintile (q). From the second stage one derives (column) vectors of fuel, heat, and electricity consumption, again by quintile (q): $\mathbf{c}_{\mathrm{fuel}}$, $\mathbf{c}_{\mathrm{heat}}$, and $\mathbf{c}_{\mathrm{el}}$.

Nondurable non-energy consumption (the vector by quintiles) is then given by:

$$\mathbf{c}_{\mathrm{NE}} = \mathbf{c}_{\mathrm{nondur}} - \mathbf{c}_{\mathrm{fuel}} - \mathbf{c}_{\mathrm{heat}} - \mathbf{c}_{\mathrm{el}} \tag{5}$$

The matrix of commodities of non-energy consumption by quintiles ($\mathbf{C}_{\mathrm{j}}$) is in a next step derived from multiplying the matrix of budget shares by quintiles, **W** (for details see the Appendix), with the vector of nondurable non-energy consumption (converted into a diagonal matrix):

$$\mathbf{C}_{\mathrm{j}} = \mathbf{W}[\hat{\mathbf{c}}_{\mathrm{NE}}] \tag{6}$$

where j = 1...8 are the eight non-energy consumption commodities. The final result of this procedure is a matrix of durable, energy and non-energy consumption by quintiles ($\mathbf{C}_{\mathrm{C}}$):

$$\mathbf{C}_{\mathrm{C}} = \begin{bmatrix} c_{hous,1} & . & . & . & c_{hous,5} \\ c_{veh,1} & . & . & . & c_{veh,5} \\ c_{fuel,1} & . & . & . & c_{fuel,5} \\ c_{heat,1} & . & . & . & c_{heat,5} \\ c_{el,1} & . & . & . & c_{el,5} \\ .. & .. & .. & .. & .. \\ c_{j,1} & . & . & . & c_{j,5} \\ .. & .. & .. & .. & .. \end{bmatrix}$$

This matrix is then transformed into a consumption matrix by commodities of the input-output core in the FIDELIO model and by quintiles in purchaser prices, $\mathbf{C}_{\mathrm{pp}}$, by applying the bridge matrix, $\mathbf{B}_{\mathrm{C}}$ (linking COICOP categories to CPA goods of the IO model):

$$\mathbf{C}_{\mathrm{pp}} = \mathbf{B}_{\mathrm{C}}\,\mathbf{C}_{\mathrm{C}} \tag{7}$$

The bridge matrix has the dimension CPA (industry classification of the FIDELIO model) * COICOP (classification of consumption categories) and is a coefficient matrix with column sum equal to unity. It is derived from a bridge matrix in absolute numbers $\mathbf{B}_{\mathrm{CPA}}^{\mathrm{COICOP}}$ that links both classifications. The consumption vector in purchaser prices and industry classification is derived by summing over $\mathbf{C}_{\mathrm{pp}}$: $\mathbf{c}_{\mathrm{pp}} = \mathbf{C}_{\mathrm{pp}}\boldsymbol{e}$ with $\boldsymbol{e}$ as the diagonal matrix (per quintiles) of the unity vector.

This vector is then split into a domestic and imported part for each commodity and converted into producer prices by reallocating trade and transport margins to the corresponding industries and subtracting taxes less subsidies. That yields the vectors of total domestic ($\mathbf{c}^{\mathrm{d}}$) and imported ($\mathbf{c}^{\mathrm{m}}$) consumption, with $\mathbf{c} = \mathbf{c}^{\mathrm{d}} + \mathbf{c}^{\mathrm{m}}$, all valued at producer prices. For this conversion a matrix of net tax rates (with identical tax rates on domestic and imported commodities) is applied.

2.4 Production and factor demand

The model of production links the above described commodity balances of the IO core model (Leontief technologies) of 59 domestic and imported inputs to a Translog model with K, L, E, M^m (imports) and M^d (domestic) factors (for details see the Appendix). The factor energy (E) is further disaggregated into 26 types of energy, from which carbon emissions of production are derived, a part of which constitutes the domestic indirect carbon emissions of households. The imported indirect carbon emissions of households are taken from simulation results with a MRIO model (Arto et al., 2014).

The Translog specification assumes constant returns to scale and perfect competition and incorporates autonomous technical change for all input factors (i.e. the factor biases) as well as TFP (total factor productivity). All data for the production system are derived from the WIOD (World Input Output Database) dataset that contains World Input Output Tables

(WIOT) in current and previous year's prices, Environmental Accounts (EA), and Socioeconomic Accounts (SEA). For energy inputs the data in physical units (TJ) by energy type and user are used. Energy prices by energy type are exogenous, like in the household block of the model. The systems of output price and factor demand equation by industry across the EU 27 have been estimated applying the Seemingly Unrelated Regression (SUR) estimator for the balanced panel under cross section fixed effects. The estimation results yield values for own and cross price elasticities for capital, labour, energy, and imported intermediates respectively. The average (un-weighted) own price elasticity of labour as well as that of energy is about -0.5, while the own price elasticities of imported intermediates (-0.75) and capital (-0.95) are considerably higher (Table 4). For energy-intensive industries the own price elasticity of energy is lower, but the substitution elasticity between energy and capital is slightly higher than on average. In most sectors, capital and energy are also substitutes (in some they are complementary). The rate of factor bias in general is very low, and technical progress is on average slightly energy using and labour saving.

The labor market is characterized by wage bargaining, formalized in wage curves by industry. These wage curves are specified as the employee's gross wage rate per hour by industry. The labor price (index) of the Translog model is then defined by adding the employers' social security contribution. Wage data including hours worked are taken from WIOD Sectoral Accounts and are complemented by labor force data from EUROSTAT. The wage equations have been estimated for the full EU 27 panel. Combining the *meta-analysis* of Folmer (2009) on the empirical wage curve literature with a basic wage bargaining model from Boeters and Savard (2013) gives a specification for the sectoral hourly wages. Table 4 shows the un-weighted average of the long-run unemployment elasticity of wages across industries (0.06). The long-run productivity elasticity of wages is only about 0.3, whereas the consumer price elasticity is closer to unity (0.8).

2.5 The multi-regional IO price system

The model consistently distinguishes between basic prices and purchaser prices. At the heart of the price system are output prices $p^{Q}_{r,i}$, which are derived for industries *i* in region *r* in the Translog production block. Basic prices $p^{G}_{r,g}$ of domestic products *g* (related to the second rectangle of the top row of Figure 1, demand for domestic goods) are obtained as weighted averages of the sectoral gross output prices, where the market shares of sectors are used as weights. These prices, p^Q and p^G, are basic prices and are equal for all users, much like in the standard IO price model. However, demand in purchasers' prices is essentially demand for a composite good consisting of the good itself plus trade and transport margins as well as taxes (less subsidies) on products, all of which (potentially) are different for different users *u*. Therefore, the purchaser prices $p^D_{r,u,g}$ of domestically produced products are ultimately user-specific. The Free-On-Board (FOB) prices of exports ex, $p^D_{r,x,g}$ in each exporter region are comparable to international basic prices, and, once corrected for the exchange rates and augmented by international transport costs and tariffs, give the CIF prices of good *g* from region *rx*, $p^m_{rx,rm,g}$ at the border of each importing region *rm*. Next, the weighted average of the import prices of trading partners gives the total import CIF price $p^{M,cif}_{r,g}$ at the border of each region *r* for each good *g*. The weights of the trading partners are again endogenous, as their import shares are modelled as a function of relative prices. Inside the importers' borders, allowance for domestic margins and taxes on products yields purchaser prices for imports, which, like domestic purchaser prices, can vary by user: $p^M_{r,u,g}$. Evaluated in this way, prices for imports and domestic products can be combined into a composite price $p_{r,u,g}$, which is specific for each commodity and each user, as the weighted average of the purchasers' prices of domestic products $p^D_{r,u,g}$ and import prices $p^M_{r,u,g}$ using the individual import shares as the corresponding weights.

The regional total use price for each user, $p_{r,u}$, is the aggregate price of these individual use prices for that user, and is obtained as the average of the corresponding purchaser prices $p_{r,u,g}$ weighted by each user's individual use structure. For instance, for the factors of production, the aggregate price of energy inputs in the production function is determined using the commodity structure of energy inputs and the corresponding sectoral use prices. Similarly, combining the purchasers' prices of domestic (imported) goods with the commodity structure of domestic (imported) non-energy inputs yields the aggregate prices of domestic (imported) non-energy inputs. By the same principle, the price of investments is determined from the investment products' use prices. As a further example, the total purchaser price for private consumption *CP*, $p_{r,CP}$, that has been constructed in this way, can be interpreted as a consumer price index. To calculate prices for the consumption block, the transpose of the base-year COICOP-CPA bridge matrices $\mathbf{B}_{\mathrm{CPA}}^{\mathrm{COICOP}}$ is converted into a matrix with column sum equal to unity, $\mathbf{B}'_{\mathrm{C}}$ and used to translate CPA products' use prices for private consumption $p_{r,CP,g}$ into the prices of durable and nondurable consumption COICOP commodities $p_{r,CP,COICOP}$.

2.6 Inter-regional Linkages

FIDELIO being a demand-driven world model (albeit with a “statistical difference”), exports of each country are determined as the sum of all other countries’ imports (after cif-fob correction). In each country, imports by commodity are determined by the sum of its final and intermediate demand. Imports are determined differently for each user: in the case of intermediate demand, total imports demand by industry constitutes a separate factor of production which is determined in the Translog system. Using (base-year) commodity structures, this factor demand is disaggregated into intermediate demand for imported commodities.

As for the components of final demand, import shares by commodity are assumed constant except for households’ consumption. In the case of NPISH and government consumption CG, this assumption is rather uncontentious, as both these categories predominantly consume services with very low (or even zero) import shares, like public administration, health, education, and other personal services. In the case of exports, which over time show increasing import shares, “imported exports” are to a substantial degree statistical constructs[6]; also, imported goods which are sold second-hand abroad are defined as imported exports (textiles and cars being the most important ones). Assuming constant import shares seems to be the only viable option.

With investment, however, things are different: apart from investment in buildings, investment goods are a very global type of commodities, with corresponding high import shares. However, the market especially for investment goods, much more than for consumer goods, is dominated by highly specialised firms with some monopolistic power, leading to a low or zero elasticity of substitution. In a somewhat ad hoc way, this serves as the justification to assume constant import shares for commodity goods, although this clearly could and should be dealt with differently in future model versions.

In contrast to the other categories of final demand, household consumption features endogenous import shares, determined by the relation of domestic to import prices according to the Armington elasticity.

In the second stage, the vector of total imports by commodity is distributed across sourcing countries. Thus, Armington elasticities enter the model at two stages: first to determine the basic import share, and second to distribute imports to their countries of origin. Table 4 contains the trade elasticities (Armington elasticities) for import demand. These Armington elasticities have been estimated with WIOD data using a panel fixed effects model. The resulting elasticities are close to unity and therefore considerably lower than those from the literature. For the second stage, trade elasticities for import origin are assumed to be double the first stage's Armington elasticities. The logic is the following: in the first stage, substitution between domestic and imported products is less likely to occur since substitution is not as strongly based on relative prices; hence, domestic and imported goods behave more like imperfect substitutes. However, in the second stage, substituting imports among third countries is more sensitive to changes in relative prices. Thus, imports among different countries behave more like perfect substitutes, with correspondingly larger elasticities. The import shares together with the levels of the different demand categories determine inter-regional spillovers. Fiscal policy is supposed to influence both variables: the import shares via changes in prices due to wage feedbacks to labour demand shocks and the demand levels via direct effects of public spending. As in standard multi-regional IO modelling, the imports of each country determine the exports of the other countries. Once a vector of total imports for each commodity is calculated in the first stage, the imported goods collected in this vector have to be allocated to their specific origins (i.e. export regions). This is done by means of a trade matrix of trading partners **TM** where, for every region, the trading partners' shares are accounted for each imported good. Though in principle, this matrix could be defined for each user, the current model version assumes a constant **TM** for all users[7]. The calculation of trade flows by country is done separately for the services used in international trade and transport (TIR services) and the other goods (non-TIR goods and services).

2.7 Public Sector

The public sector-balances close the model and show the main interactions between households, firms and the general government. Taxes from households and firms are endogenized via tax rates. In the main version, the EU stability program is included as a restriction on the path of the deficit relative to GDP . Alternatively, public consumption can also be set exogenous and the development path of the deficit, then, becomes endogenous. Wage income of households is taxed with social security contributions (tax rates t_{wL} and t_L) and wage income plus operating surplus accruing to households are taxed with income taxes (tax rate t_Y). Additionally, households' gross profit income is taxed with tax rate t_r. Taxes less subsidies are not only levied on private consumption, but also on the other final demand components in purchaser prices ($\mathbf{f_{pp}}$, comprising capital formation, changes in stocks, exports, and public consumption), as well as on intermediate inputs (where appropriate). The expenditure side of government is made up of transfers to households (Tr), public investment (cf_{gov}) and public consumption (cg). Additionally, the government pays interest with interest rate r_{gov} on the stock of public debt, D_{gov}.

In the main version of the model the closure by fixing the public budget constraint defines the future path of government net lending, relative to GDP ($p_Y Y$). Linking public investment with a fixed ratio (w_{cf}) to public consumption and introducing the net lending-to-GDP constraint, public consumption is then derived as the endogenous variable that closes the model:

$$
\begin{aligned}
& cg\left(1+w_{cf}\right)=\Delta D_{gov,t} / p_y Y - r_{gov,t} D_{gov,t-1} - Tr + \left(t_{wL}+t_L\right) w_t H_t \\
& + t_Y\left(w_t H_t + \Pi_{h,t}\right) + t_r r_t A_{t-1} + \hat{\mathbf{T}}_{\mathrm{N}}\left[\mathbf{c}_{\mathrm{pp,t}} + \mathbf{f}_{\mathrm{pp,t}} + \mathbf{p}_{\mathrm{Q,t}} \mathbf{Q}_{\mathrm{t}}\right]
\end{aligned} \tag{8}
$$

[7] this does not imply that all users exhibit a uniform sourcing pattern, because import shares are different.

Fiscal policy can be carried out in several ways. Tax rates at all levels (t_{wL}, t_L, t_Y , t_r, $\hat{\mathbf{T}}_{\mathrm{N}}$), as well as the level of transfers Tr can be changed exogenously. Targets for these changes (for example in % of GDP) are usually fixed *ex ante*, as the feedback effects of the model lead – for a given deficit target in % of GDP – to the corresponding adjustment in public consumption. Another option is a change in the target value of the deficit/GDP share ($\Delta D_{gov,t} / p_y Y$), which similarly leads to an adjustment in public consumption. A third option is to expand equation (9) on the right hand-side by an additional term for 'extra' public consumption. This means that on top of the level of public consumption that guarantees achieving the deficit/GDP target, more expenditure is added.

3. Fiscal Policy Simulation Results

The fiscal policy simulations undertaken with the model are similar to those carried out in in't Veld (2013), as far as the regional dimension of the shock is concerned. This is due to our interest in quantifying the inter-regional spillovers of fiscal consolidation in Europe. The general nature of the fiscal policy shock introduced is a normalized 1% of GDP fiscal consolidation in Spain. This general shock is introduced with different policy instruments that refer to variables in (9) above and from different perspectives concerning the definition of the magnitude (1% of GDP). The latter refers to the concepts of *ex ante* vs. *ex post* measurement of shocks due to partial endogeneity of fiscal policy according to (9). The following four different fiscal policy scenarios have been simulated with the model and the impacts after 10 years of model simulations are presented:

FISCAL: the target value of the deficit/GDP share ($\Delta D_{gov,t} / p_y Y$) is decreased by one percentage point, which is sustained for the full period, and public consumption adjusts accordingly (equation (9)).

FISCALEXP: an additional negative term of one percentage point of GDP is added at the right hand-side of equation (9) in terms of a sustained decrease in public consumption. The target value of the deficit/GDP share is kept in equation (9), but is not relevant anymore.

CAPTAX: the net capital taxes for households are permanently increased by one percentage point of GDP.

TRANSF: the transfers to households are permanently increased by one percentage point of GDP.

The two scenarios where public expenditure is cut (**FISCAL** and **FISCALEXP**) contain additional shocks to variables, which actually materialize in a negative fiscal policy shock. In the other two scenarios (**CAPTAX** and **TRANSF**) the model closure via public consumption is upheld, so that public consumption adjusts and the scenarios represent revenue-neutral fiscal policy shocks, yielding net multipliers. The difference between **FISCAL** and **FISCALEXP** is that the former uses the automatic adjustment of public consumption to the new target, including all endogenous effects that need to be compensated. In the second scenario, the *ex ante* fiscal shock to public consumption is fixed and all endogenous effects (which are compensated as well according to (9)) are a direct consequence of this shock. In any case the differences between these two scenarios are expected to be rather small and only reflect different ways of summing up endogenous fiscal policy effects.

Figure 2 reveals the impact on the final demand components in Spain of the four scenarios, compared to the baseline scenario after 10 years of a sustained shock. These results show how the model reacts with respect to some of the crucial issues identified in the literature on fiscal policy multipliers. The first issue is the reaction of private consumption in the case of a fiscal policy shock. If private consumption is in general complementary to public consumption ('Edgeworth complementarity' as in Fève and Sahuc, 2015) and/or consumers exhibit Keynesian consumption function behavior due to the absence of Ricardian equivalence or due to binding liquidity constraints, then private consumption decreases with fiscal consolidation. Figure 2 shows that this is the case for Spain: in the model simulations presented here, private consumption decreases between 1 and 2% in the scenarios **FISCAL** and **FISCALEXP**. In the **CAPTAX** scenario almost no private consumption reaction is observed, as this tax rate (t_r) only has indirect effects on private consumption (via 'cash on hand') and directly only affects asset accumulation (see equation (A2)). The scenario, where transfers to Spanish households are reduced (scenario **TRANSF**) also shows only small private consumption reactions. Gross fixed capital formation reacts to the general output decrease and slightly changes more than private consumption in all scenarios. All fiscal policy scenarios exhibit significant price effects, which in turn directly have an impact on inter-regional trade. The GDP deflator is about 2% below the level of the baseline in the scenarios **FISCAL** and **FISCALEXP**. Exports of Spain increase due to these price effects to the tune of about 0.7%. The price effect on exports is determined by the Armington elasticities (Table 4), which – as already mentioned – are considerably lower than in the standard CGE literature. The quantity effect on Spanish exports is negative, as the negative GDP impact in Spain has inter-regional spillovers on the GDP of the other (mainly) European trading partners and their demand for imports from Spain.

Investment demand (gross fixed capital formation) also reacts significantly to fiscal policy in FIDELIO (Figure 2 and 3). This is partly a consequence of output effects, that stimulate investment demand for a given capital input coefficient. Additionally, this capital input per unit of output is also influenced by price changes. The price of capital in the Translog cost function (section 2.4) is an index of static user costs, based on the investment goods' prices, the interest rate, and the industry-specific depreciation rate. The change in output prices changes the prices in all countries via the trade spillovers and therefore, the investment goods price is lower in the fiscal consolidation scenarios (**FISCAL** and **FISCALEXP**) than in the baseline. This price effect stimulates investment demand. Wages are depressed more than output prices in the fiscal consolidation scenarios via the wage curve mechanism. That drives a substitution process between capital and labour, which has a decreasing impact on investment demand. Obviously, the positive influence on investment dominates the total effect.

The interest rate is exogenous in FIDELIO and therefore crowding out effects, depending on the accompanying monetary policy, are not accounted for in the simulations presented here. This mechanism is important for the investment impact in the studies that apply macroeconomic models (DSGE and other).

The final demand component that exhibits the largest changes in all scenarios is public consumption. In the scenario **FISCAL**, this change just measures the adjustment necessary to reduce public deficit one additional % of GDP *ex post*. The endogenous impact of public consumption cut backs (on tax revenues) therefore is accounted for and *ex post* leads to higher reductions in public consumption than *ex ante*. The potentially 'self-defeating' effect of fiscal consolidation that has led to surprises concerning the final outcome of the deficit share in GDP in Europe (Blanchard and Leigh, 2013) is therefore avoided in the scenarios presented here. The same holds for the scenario **FISCALEXP**, where some additional expenditure is added, that creates endogenous effects on the public sector-variables which in turn need to be adjusted for by public consumption cut backs. Table 5 shows the contribution to the change in GDP of the public consumption component (share of public consumption * change in public consumption). For both scenarios (**FISCAL** and **FISCALEXP**) this is larger than 1% of GDP, which should be the original shock. This difference can be seen as the policy endogeneity effect and amounts to around 0.4 to 0.5% of GDP for the 1% of GDP shock. The original GDP multiplier of the fiscal consolidation scenarios – measured as GDP impact in relation to the *ex ante* fiscal shock - is 1.7 and 1.9 respectively in Spain. Taking into account that due to policy endogeneity the public consumption shocks increase from 1% of GDP to 1.37% and 1.53% respectively, the *ex post* multiplier in both scenarios decreases to 1.2. Fixing the public consumption ex ante therefore produces a slightly larger (0.15% of GDP) policy endogeneity effect than allowing for automatic adjustment (scenario **FISCAL**).

In the scenarios **CAPTAX** and **TRANSF**, public consumption can be expanded due to higher tax revenues and the impact on private consumption spending is almost negligible (Table 5). Therefore, the effect of higher revenues that allows for higher spending dominates the macroeconomic outcome. This in turn leads to higher investment spending (crowding in) and the increase in prices leads to lower exports of Spain. The GDP impact is positive, but considerably smaller than the negative impact of public consumption cuts. The multiplier measured as the GDP impact is about 1.2, and the expansive effect stems from the possible increase in public consumption. These two scenarios, therefore, are not fiscal consolidation scenarios, but balanced budget fiscal shocks. According to the simple 'Haavelmo theorem' of standard textbooks, the multiplier of such a shock is unity. Having in mind that without policy endogeneity public consumption could only rise by 1% of GDP (*ex ante*), we can calculate a policy endogeneity effect of about 0.65%. Relating the *ex post* public consumption increase to the GDP effect, gives an effective multiplier of about 0.7.

One crucial issue for all fiscal policy scenarios is the reaction of private consumption to the shocks in transitory income, triggered by the fiscal shocks. In our model that depends on the general lending constraints, defined by the long-run target of debt to durable stocks and implemented by down payments of durables. The baseline scenario, on top of which the fiscal shocks have been implemented, corresponds to a 'high θ scenario', where the debt-to-durable relationship decreases to values before the debt increase (before 2002). For the sake of sensitivity analysis, an alternative 'low θ scenario' has been designed, that corresponds to a financial regime, where the relationship debt to durable stock does not significantly decrease, i.e. no major debt deleveraging by households occurs. As a first step, a new baseline needed to be constructed based on these input data. On top of this alternative baseline scenario, the same fiscal shocks as before had then been implemented.

As Table 6 shows, the impacts on public consumption itself, as well as on private consumption and investment spending, are considerably smaller than in the scenario with debt deleveraging of households. The Spanish economy is closer to full employment in the baseline scenario with loose liquidity constraints. Therefore, fiscal consolidation leads to higher wage reactions and price effects (decreases compared to the baseline), which results in higher impacts on exports in the scenarios **FISCAL** and **FISCALEXP**. The original GDP multiplier of the fiscal consolidation scenarios (GDP impact/ *ex ante* fiscal shock) in Spain is now reduced to about 1.6. Due to policy endogeneity, the public consumption shocks increase from 1% of GDP only to about 1.3%. The *ex post* multiplier in both scenarios is equal to the values in the 'high θ scenario', i.e. 1.2. In general, fiscal consolidation leads to higher multipliers in the 'high θ scenario', i.e. with binding liquidity constraints. The differences are not large, though, as the liquidity constraint variable (θ) is the same for all household income groups and there is no full heterogeneity of marginal propensities of consumption by income and wealth types of different income groups in this simple version of the buffer stock model. Splitting up these different variables (given data availability) and allowing for different consumption propensities is supposed to yield more pronounced differences of consumption reactions to income, depending on the liquidity situation of households (see: Muellbauer, 2016, and Mian, et al., 2013).

In the tax scenarios (**CAPTAX** and **TRANSF**), public consumption expands by about 0.4 percentage points of GDP less with loose liquidity constraints and the original GDP multiplier is below unity in Spain. The policy endogeneity effect drops to about 0.25 percentage points of GDP and the ex post multiplier is almost the same as in the 'high θ scenario'. Due to higher wage and therefore price reactions, exports are lower compared to the baseline than in the 'high θ scenario'

The fiscal policy shocks in Spain have important inter-regional spillovers, which are driven by lower import demand in Spain and changes in the relative prices of exports from Spain. Table 7 presents the real GDP impact across EU countries induced by the fiscal policy shocks in Spain. It can be observed that in the fiscal consolidation scenarios the negative impact is around 0.5 % of GDP for a large group of European countries, compared to the 1,7 to 1,9% of GDP for Spain in these scenarios (**FISCAL** and **FISCALEXP**). The impacts are slightly higher for the two large economies Germany and Italy and somewhat smaller for the UK. The neighbor country Portugal is even more affected than Spain itself. This is only partly triggered by the important trade linkages between the countries. The direct negative effect via trade linkages in other countries is magnified by additional adjustment that is necessary for these countries to stay at their path for the public deficit/GDP ratio. This mechanism makes further cuts in public consumption necessary, leading in the case of some countries to non-linear level shifts effect. That can be observed in Table 7 for the two highly indebted economies of Portugal and Greece, and is an important spillover effect mechanism in the case of several highly indebted countries that simultaneously apply ambitious fiscal consolidation plans.

One significant result in the FIDELIO model applied here is that demand shocks like the fiscal policy shocks analyzed also bring about important changes in the whole price system, even though the output price equations represent simple marginal cost pricing with constant returns to scale and do not contain any reaction of prices to demand conditions and/or capacity utilization. The price effects are a consequence of the wage effects, driven by changes in the unemployment rate. The specification of the wage curve produces accelerating wage inflation when the economy approaches full employment. The wage changes therefore are larger than the price changes and therefore, in some industries, employment reacts positively, although output almost does not change.

The detailed modelling of price pass-through in FIDELIO magnifies the output price effect and induces price changes at all levels. The import prices of all countries change, and with them the input prices of intermediate inputs and capital. This full modelling of multi-regional IO price spillovers is the main explanation for the relatively large price effects in FIDELIO, although output prices do not directly react to demand and supply.

Output is heavily reduced in the public sectors (public administration, health, education), but is almost unchanged in export intensive industries, where the positive impact from export demand compensates for the negative impact of domestic intermediate demand. This, together with the wage dampening of fiscal consolidation, leads to positive employment effects in some of these industries, compared to the baseline (Figure 4). These industries are: Fabricated metals, basic metals, rubber and plastic products, chemicals, and – to a lesser extent – textile and wearing apparel.

The inter-regional spillovers effectuate negative output effects in export intensive industries of the European trading partners. This can be seen for the case of Germany (Figure 5) where the negative GDP impact from spillovers is above the European average of -0.5%. Export intensive industries in the metal processing sectors all show above average decreases in gross output (compared to the baseline). Consumer goods industries are hit less severely. Nevertheless, in Germany the necessary adjustment in public consumption has the most pronounced industry effects compared to the baseline: public administration, health and education are the industries that most reduce their output.

4. Discussion of Results for Multipliers

The results presented in the last section can be compared with DSGE model results from the recent literature that has adopted a critical view about pre-crisis DSGE studies presenting very low fiscal policy multipliers. The first candidate for such a comparison is the study by in't Veld (2013), as the simulation design chosen here very much resembles the one in his analysis. From the vast body of recent literature that incorporates sensitivity analysis with DSGE models we chose the following studies for a comparison with the results presented here: Canzoneri et al. (2015), Coenen et al. (2012), and Fève and Sahuc (2015).

The QUEST model applied in in't Veld (2013) has important characteristics that differentiate it from the FIDELIO model applied in this analysis. First of all, the specification and the parameterization allow for more variance in variables as a consequence of shocks. The interaction between prices and quantities should be stronger as well, as demand conditions directly influence price setting. The most important difference is that the DSGE model QUEST comprises an explicit modelling of monetary variables and financial markets. This is completely absent in the FIDELIO model and is only introduced in terms of exogenous variables (liquidity constraints, interest rates). The FIDELIO model exceeds the QUEST model in the disaggregation by commodities and industries.

The analysis of in't Veld (2013) comprises three different fiscal consolidation scenarios for Spain: a balanced composition (revenues and expenditures) of consolidation measures, an expenditure based, and a revenue based consolidation. The expenditure based consolidation yields the largest negative macroeconomic outcome and can be compared to the **FISCALEXP** scenario in this study. The results presented here are the results after 10 years and the FIDELIO model does not produce large volatility in impacts for a sustained fiscal shock. This is not the case in the results with the QUEST model. The multiplier in in't Veld almost completely disappears after 7 years of a sustained fiscal shock. The shock starts off with 1% of GDP in the first year and then adds 1% of GDP until the third year (after which the shock reminas constant). Therefore, we take the first year as the point of comparison with our results.

Figure 6 shows that the impact on private consumption is the one with the smallest difference between the two studies. The difference in the impact on gross fixed capital formation and on exports is much more pronounced. In the FIDELIO model, the impact of fiscal consolidation on prices is higher, though it only works indirectly via the wage increase, whereas demand conditions directly influence prices in the QUEST model. This is a strong indication that the full multi-regional IO price system applied in the FIDELIO model captures channels of price pass-through that cannot be specified in one simple output price equation typically applied in DSGE models. The detailed and explicit modelling of the different prices in an economy is a typical characteristic of multi-sectoral models, like the one used in this study or the CGE model (see: Jorgenson, et al., 2013). The GDP impact in the QUEST simulations (1^{st} year) is almost unity, whereas in the case of FIDELIO amounts to -1.7%.

The inter-regional spillovers in Europe in in’t Veld (2013) from a 1% of GDP expenditure based fiscal consolidation in Spain are about -0.05% for most Euro area countries (the impact on Spain is -1.11%). The spillovers are insignificantly higher for Greece and France (-0.06%), and more than double for Portugal (-0.12%). The higher price effects in Spain in this model lead to higher trade effects for Spain, which magnify through the trade matrix in terms of spillovers. Another important difference is endogeneity of fiscal policy: larger spillovers together with endogenous fiscal policy induce larger adjustments in public consumption, especially in debt-ridden economies (Greece and Portugal). This mechanism is absent in QUEST.

Comparing our results with other recent studies generally reveals that the sensitivity of the multiplier on the conditions identified as critical is generally larger in other studies than in the case of this model. Canzoneri et al. (2015) distinguish between household behaviour in recessions and expansions and accordingly derive a short term (first quarter) multiplier of government expenditure between the maximum value in a recession of 2.04 and the minimum value in an expansion of 1.07. This result coincides with the multiplier range identified in Auerbach and Gorodnichenko (2012).

Coenen et al. (2012) deal with different regions (US and EU) and different categories of public expenditure that are common across the models applied in their study. The magnitude of the multiplier mainly depends on the accommodation of fiscal policy by monetary policy, a characteristic that can be analysed with the help of the models used. The average short-run (1 year) value for the output multiplier of public consumption is 0.9 (when monetary policy is accommodating). This value rises to 1.5 with two years of accommodating monetary policy. The multiplier of public investment is 1.48 and much smaller for tax and transfer measures (between 0.3 and 0.6).

Fève and Sahuc (2015) derive a first quarter multiplier of government spending of 1.618 in their benchmark model that considers Edgeworth complementarity between public and private consumption, endogeneity of fiscal policy, as well as habit formation and durability in private consumption. Their model builds, as far as many other parameters and specifications are concerned, on the Smet and Wouters (2003) DSGE model, which – without this specific characteristics – only yields an output multiplier of 1.065. Sensitivity analysis without Edgeworth complementarity reduces the benchmark output multiplier of 1.618 to a value of 1.011; omitting fiscal policy endogeneity results in a mulitplier of 1.279.

5. Conclusions

The objective of this study is to contribute to the recent debate on fiscal policy multipliers by applying a multi-regional macroeconomic IO model (FIDELIO). This recent debate is dominated by macroeconomic model-methodology, mostly DSGE models. The lack of contribution from CGE and macroeconomic IO models is most probably due to the static and simple specification of private consumption that does not allow for variety and dynamics in household behavior. One main issue in the fiscal policy multiplier debate is exactly about different reactions of consumption behavior of different households or in different states of the economy. In the context of fiscal policy analysis, the question is, whether private and public consumption are complements or substitutes and how private consumption reacts to transitory income shocks. This reaction depends on the type of household analysed and on the economic situation of households. Liquidity constraints due to debt deleveraging increase the reaction of spending to transitory income shocks. The contribution of this study is to introduce liquidity constraints into a permanent income hypothesis-model with full household accounts (stocks and flows) and to integrate this consumption block into a multi-regional macroeconomic input-output (IO) model. Liquidity constraints are specified as a medium-run target of the debt to durable stock ratio of households. A lower debt-to-durable ratio leads to higher debt deleveraging of households and higher reactions of consumption to transitory income shocks (and higher fiscal policy multipliers).

The fiscal policy simulation is defined as a 1% shock of GDP to public expenditure and to capital taxes and transfer payments in Spain over a ten years period. One important specification integrated into the model used is partial endogeneity of fiscal policy. That has several important consequences for the impacts. In the case of public expenditure cuts, it leads to further spending cuts due to lower tax revenues, thereby compensating the *self-defeating* effects of fiscal consolidation. In the case of tax increases it leads to an increase in public spending. The expenditure cuts induce multipliers between 1.6 and 1.9, where the lower value corresponds to the absence of binding liquidity constraints. The part of this multiplier value that can be attributed to endogenous fiscal adjustment corresponds to 0.36 to 0.64 in the case of the higher multiplier values. The tax increase scenarios lead to multiplier values around unity, as the restrictive impact is compensated by higher public expenditure for a given deficit target.

Compared to the existing literature and especially to In't Veld (2013), who applies an European multi-regional model, we find relatively higher impacts on private consumption, investment, and output prices. One important result is the relatively high GDP deflator impact, though the FIDELIO model does not directly include feedbacks from demand and supply to prices. Only the labour market reacts according to a wage curve mechanism. The price effects induced by this mechanism are magnified by the detailed multi-regional IO cost-push effects of the FIDELIO model. These multi-regional spillovers reduce prices in all countries and for all demand categories in the case of fiscal consolidation. These relatively high price effects also drive the relatively high impacts on investment and export demand.

The mix of final demand effects together with the wage and price changes lead to significant differences in output and especially employment effects by industry. This is the case for the consolidating country (Spain) as well as for other European countries (e.g.: Germany).

The simulations also show relatively high inter-regional spillovers of fiscal policy. Fiscal policy endogeneity in other European countries leads to fiscal adjustments in these countries, magnifying the first-round spillovers. Heavily indebted European countries with high liquidity constraints can be hit significantly by this indirect effect.

The sensitivity analysis for different degrees of liquidity constraints of private households does not produce huge differences in fiscal multipliers. This is due to a simple specification of the buffer stock-model of consumption in FIDELIO, without large heterogeneity in marginal propensities of consumption for different household types and different states of the economy.

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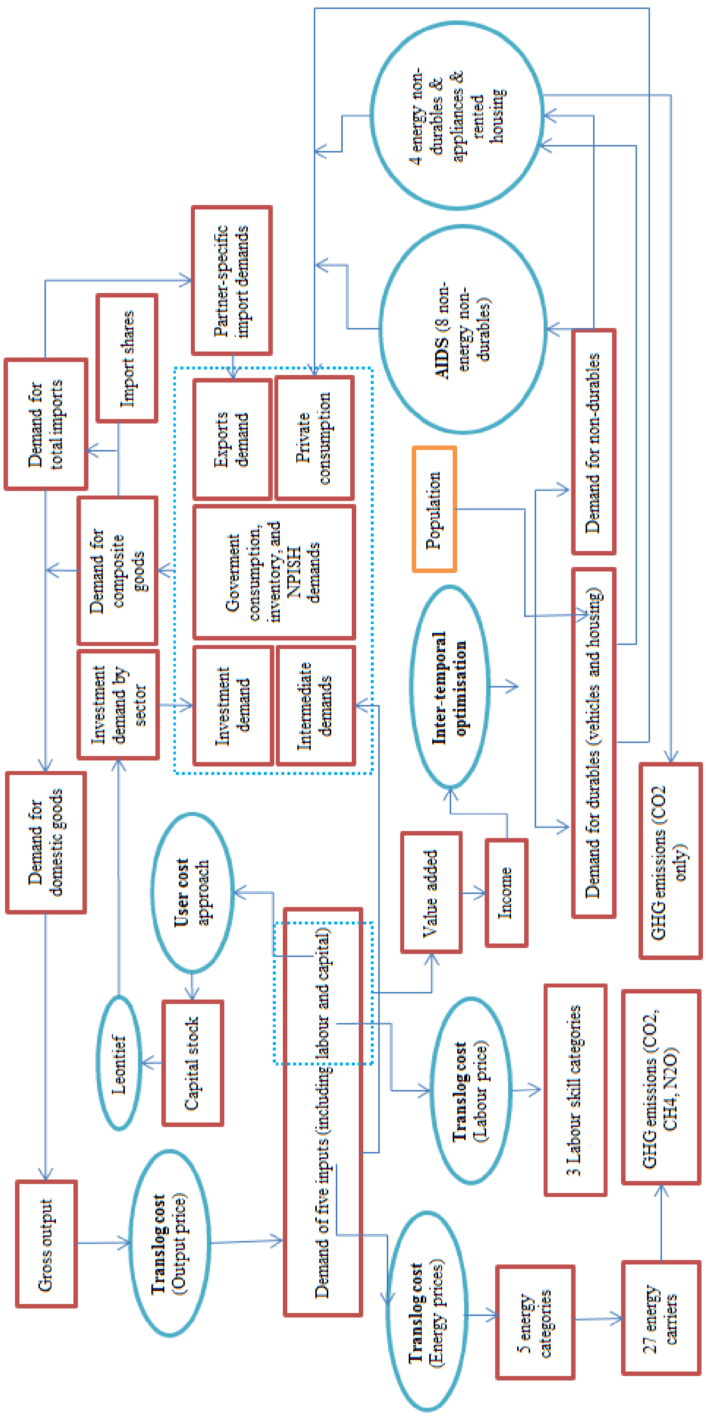
Figure 1: Commodity demand and supply in the FIDELIO 2 model



Source: Kratena, et al. (2017)

Table 1: Excess sensitivity of consumption growth to lagged income growth, EU 27, 2009 - 2050

	Q1	Q2	Q3	Q4	Q5
$(C_{dur,t} + C_t)$	0.6100	0.2381	0.1092	0.0803	0.0424
S.E.	0.1618	0.0668	0.0322	0.0210	0.0183
C_t	0.6283	0.2919	0.1654	0.1248	0.0911
S.E.	0.1939	0.0801	0.0009	0.0008	0.0200

Table 2: Price and expenditure elasticity of energy and non-energy demand of households (EU 27 panel 1995-2011, EU 6 cross section, 2004/2005)

Nondurable	own price	expenditure elasticity	
Consumption	elasticity	Time series	Cross section
Food	-0.14	0.85	0.61
Clothing	-0.64	1.04	1.28
Furniture/equipment	-1.06	1.11	1.46
Health	-0.83	0.98	1.20
Communication	-0.89	0.96	0.68
Recreation/accomodation	-0.50	1.08	1.27
Financial Services	-0.94	1.33	1.00
Other	-0.68	1.09	1.00
Energy	own price	durable stock	
Consumption	elasticity	elasticity	
Transport fuel	-0.77	1.00	
Heating	-0.87	1.00	
Electricity	-0.81	1.00	

Table 3: Parameters for factor demand (price elasticity, factor bias) and wage function

	own price	cross price	rate of
Production	elasticity	elasticity, E/K	factor bias
K, all industries	-0.95		0.00
L, all industries	-0.51		-0.01
E, all industries	-0.53		0.02
E, energy intensive	-0.37	0.20	0.00
all industries		0.15	
M(m)	-0.75		0.02
	long-run		
Wage curve	elasticity		
Consumer price	0.82		
Productivity	0.27		
Unemployment rate	-0.06		

Table 4: Armington elasticity (first nest), private consumption and intermediate demand

	Private Consumption	Intermediate Demand
Agriculture, forestry, fishing products	1.11	0.97
Mining products	0.79	0.64
Food products and beverages	1.21	0.80
Tobacco products	1.21	0.80
Textiles	1.39	1.53
Wearing apparel; furs	1.39	1.53
Leather and leather products	0.00	0.81
Wood and products of wood and cork	1.22	0.78
Pulp, paper and paper products	0.74	0.67
Printed matter and recorded media	0.74	0.67
Coke, refined petroleum products and nuclear fuels	0.00	0.36
Chemicals, chemical products and man-made fibres	0.76	0.70
Rubber and plastic products	0.28	0.41
Other non-metallic mineral products	0.96	0.66
Basic metals	0.67	0.81
Fabricated metal products, except machinery and equipment	0.67	0.81
Machinery and equipment n.e.c.	0.00	0.00
Office machinery and computers	0.75	0.57
Electrical machinery and apparatus n.e.c.	0.75	0.57
Radio, television and communication equipment and apparatus	0.75	0.57
Medical, precision and optical instruments, watches	0.75	0.57
Motor vehicles, trailers and semi-trailers	0.99	1.30
Other transport equipment	0.99	1.30
Furniture; other manufactured goods n.e.c.	0.00	0.00
Secondary raw materials	0.00	0.00
Electrical energy, gas, steam and hot water	0.45	0.60
Collected and purified water, distribution services of water	0.45	0.60
Construction work	0.00	0.27
Trade, maintenance and repair services of motor vehicles	0.43	0.68
Wholesale trade and commission trade services	0.84	0.30
Retail trade services	0.56	0.41
Hotel and restaurant services	0.93	1.02
Other services	0.69	0.54

Figure 2: Impact of fiscal policy (Spain) on final demand (const. prices), difference to baseline in %

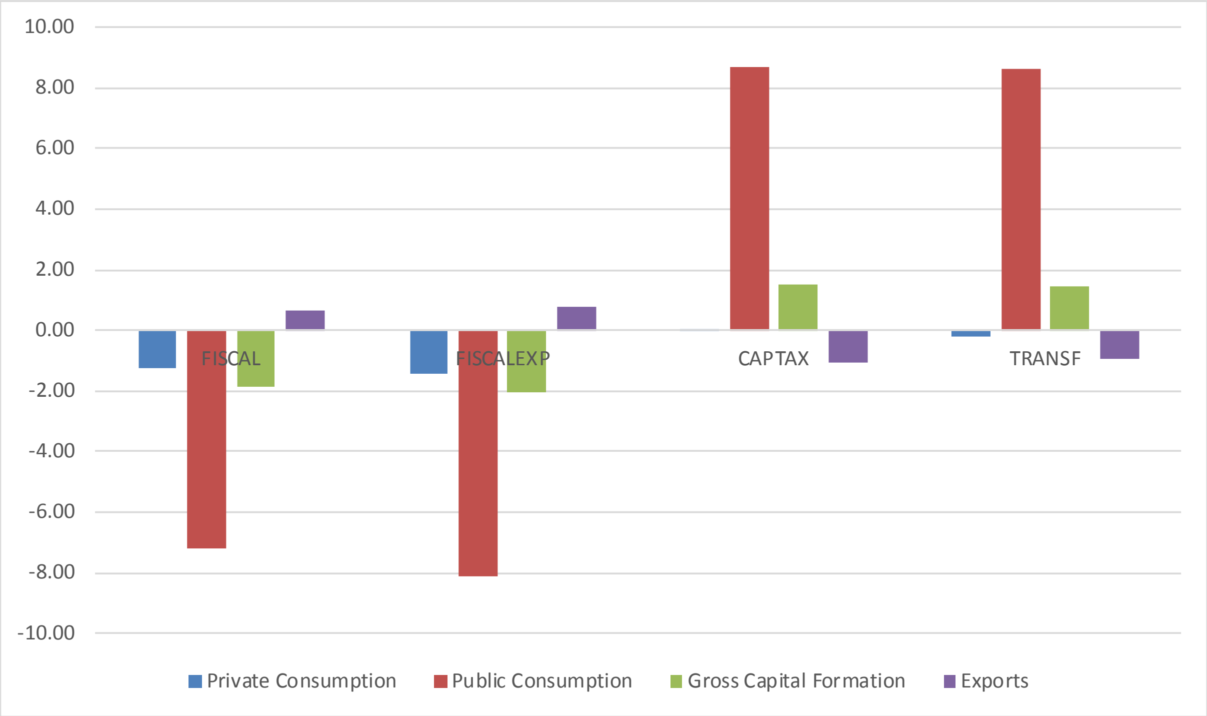


Table 5: Multipliers of fiscal policy and policy endogeneity (Spain)

	FISCAL	**FISCALEXP**	**CAPTAX**	**TRANSF**
Real GDP Impact	-1.70	-1.91	1.23	1.17
Contribution of Pub. Consumption	-1.37	-1.53	1.65	1.64
Policy Endogeneity Effect	-0.37	-0.53	0.65	0.64
GDP Multiplier, *ex post*	1.2	1.2	0.7	0.7

Figure 3: Impact of fiscal policy (Spain) on final demand (const. prices) with loose liquidity constraints (difference to baseline in %)

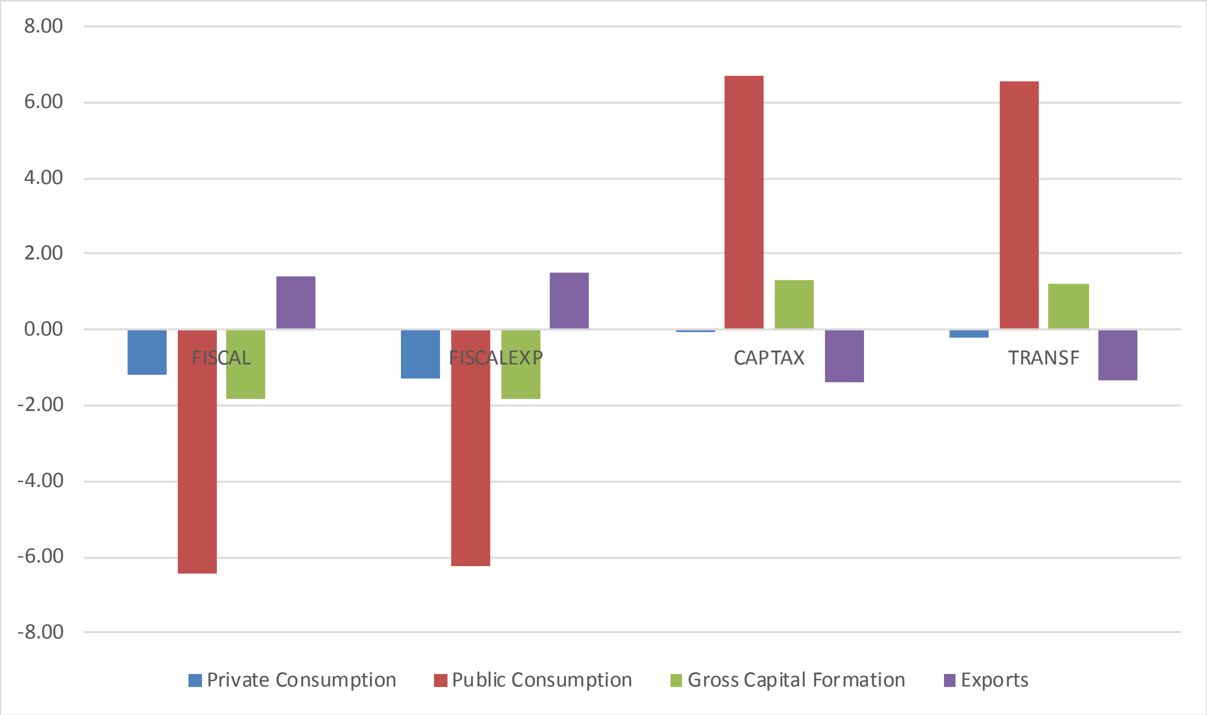


Table 6: Multipliers of fiscal policy and policy endogeneity, loose liquidity constraints (Spain)

	FISCAL	**FISCALEXP**	**CAPTAX**	**TRANSF**
Real GDP Impact	-1.59	-1.58	0.99	0.89
Contribution of Pub. Consumption	-1.36	-1.32	1.27	1.25
Policy Endogeneity Effect	-0.36	-0.32	0.27	0.25
GDP Multiplier, *ex post*	1.2	1.2	0.8	0.7

Table 7: GDP impact (const. prices) of fiscal policy in Spain (difference to baseline in %)

	FISCAL	FISCALEXP	CAPTAX	TRANSF
Germany	-0.73	-0.80	0.61	0.63
Spain	**-1.70**	**-1.91**	**1.23**	**1.17**
France	-0.46	-0.51	0.38	0.39
UK	-0.29	-0.32	0.24	0.25
Greece	-0.99	-2.45	0.49	0.97
Italy	-0.63	-0.70	0.53	0.55
Portugal	-2.15	-2.35	1.27	1.38
Rest of EU	-0.47	-0.51	0.39	0.41

*Figure 4: Impact of fiscal policy (Spain), scenario **FISCALEXP** on employment (difference to baseline in %)*

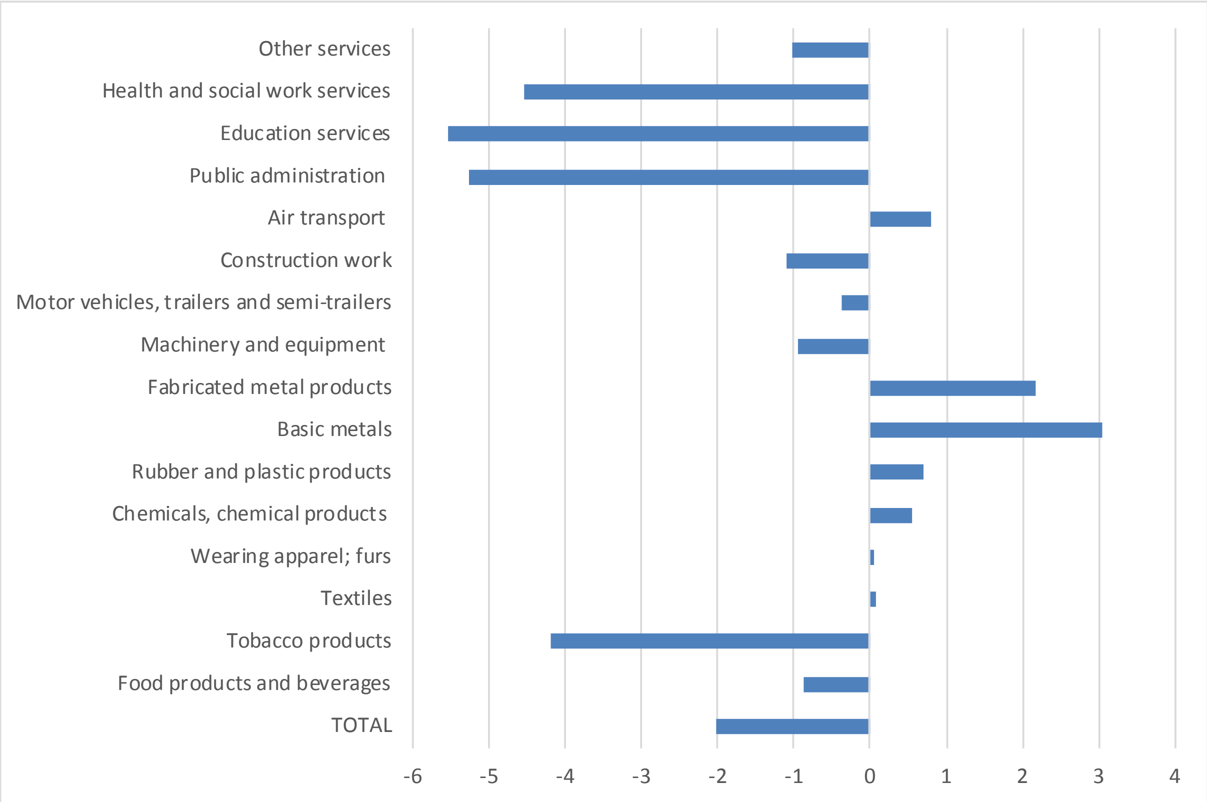


Figure 5: Impact of fiscal policy (Spain), scenario ***FISCALEXP*** *on gross output (const. prices) in Germany (difference to baseline in %)*

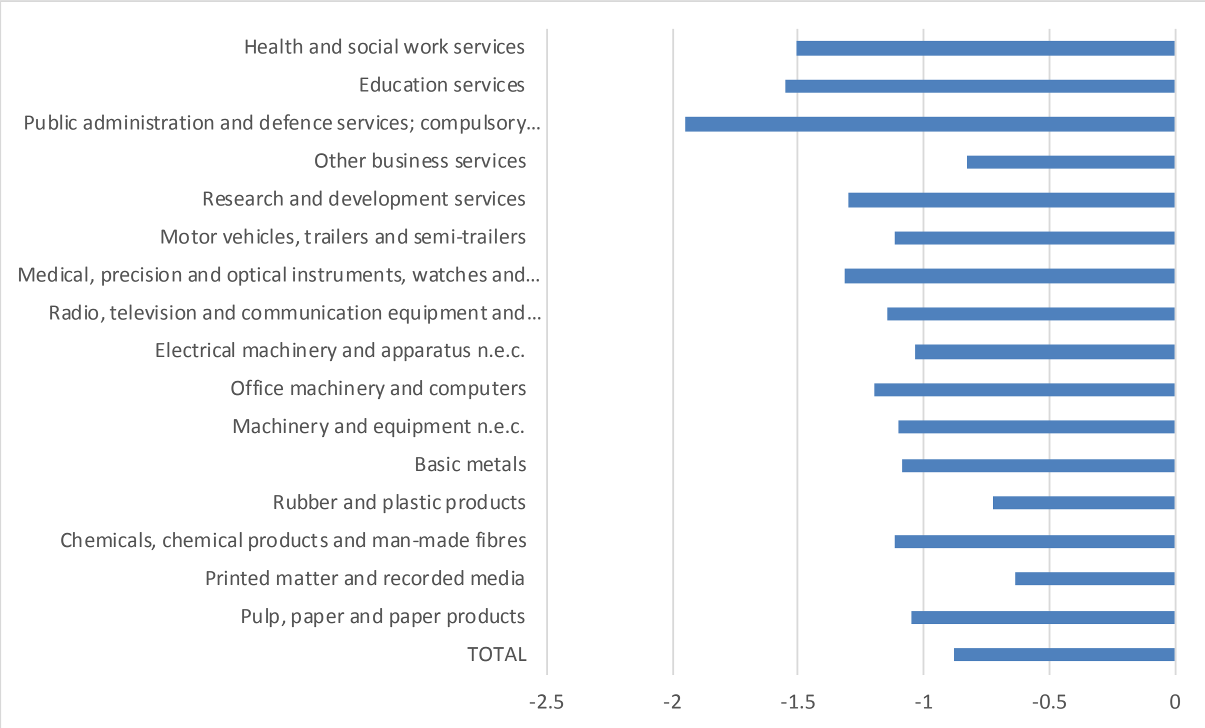
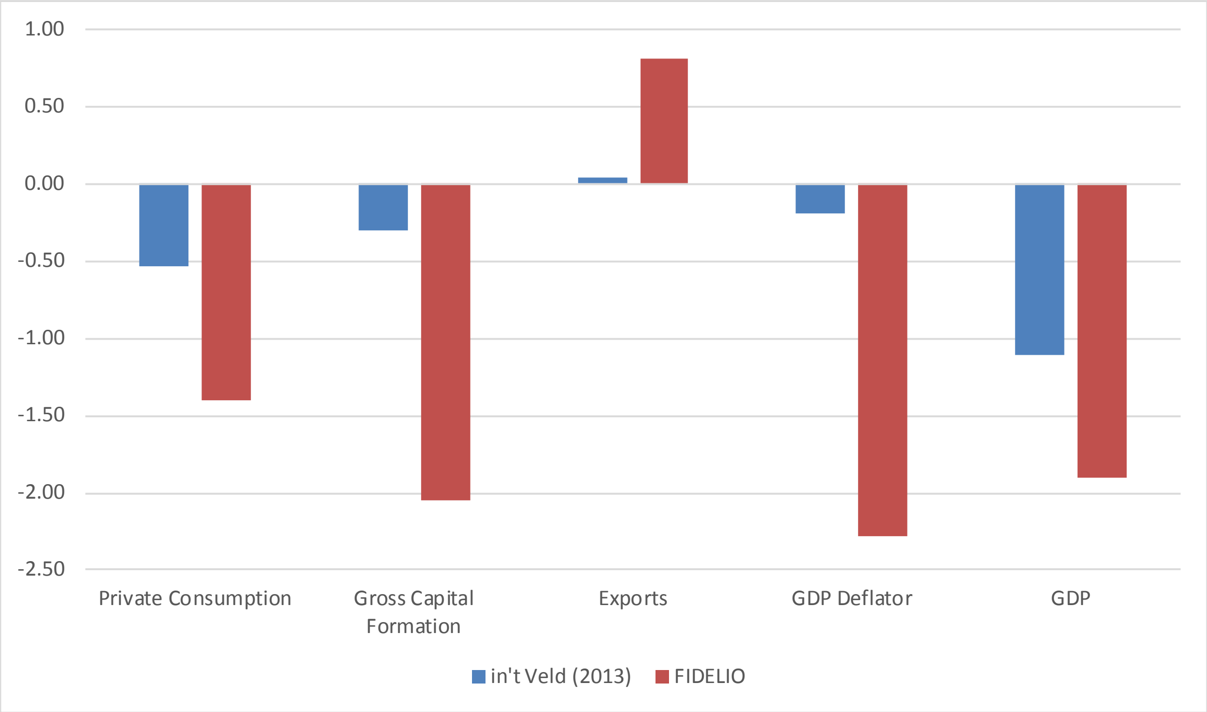


Figure 6: Impact of fiscal policy (Spain) on final demand (const. prices), difference to baseline in %: in't Veld (2013) vs. FIDELIO



Note: in't Veld: scenario results from "Expenditure based consolidations", 1st year of results; FIDELIO: **FISCALEXP** scenario (all results are average effects of 10 years). Source: own calculations, in't Veld (2013), p.4

Appendix: The DYNK Model

A.1 Household behaviour and private consumption

Durable demand and total nondurables

Consumers maximize the present discounted value of expected utility from consumption of nondurable commodity and from the service provided by the stocks of durable commodity:

$$\max_{(C_t, K_t)} V = E_0 \left\{ \sum_{t=0}^{\infty} \beta^t U(C_t, K_t) \right\} \tag{A1}$$

Specifying a CRRA (constant rate of risk aversion) utility function and a budget constraint the model can be solved in terms of first order conditions, but not in terms of explicit demand functions. The budget constraint in this model without adjustment costs for the durables stock is given by the definition of assets, A_t:

$$A_t = (1+r)(1-t_r)A_{t-1} + YD_t - C_t - (K_t - (1-\delta)K_{t-1}) \tag{A2}$$

In (A2) the sum of C_t and $(K_t - (1-\delta)K_{t-1})$ represents total consumption, i.e. the sum of nondurable and durable expenditure (with depreciation rate of the durable stock, δ). The gross profit income rA_{t-1} (with interest rate r) is taxed with tax rate t_r. Disposable household income excluding profit income, YD_t, is given as the balance of net wages $(1-t_S-t_Y)w_t H_t$ and net operating surplus accruing to households $(1-t_Y)\Pi_{h,t}$, plus transfers Tr_t:

$$YD_t = (1-t_S-t_Y)w_t H_t + (1-t_Y)\Pi_{h,t} + Tr_t \tag{A3}$$

The following taxes are charged on household income: social security contributions with tax rate t_S, which can be further decomposed into an employee and an employer's tax rate ($t_{wL}$and t_L) and income taxes with tax rate t_Y. The wage rate w_t is the wage per hour and H_t are total hours demanded by firms. Wage bargaining between firms and unions takes place over the employee's gross wage, i.e. w_t (1 - t_L).

All the income categories are modelled at the level of quintiles q of household incomes (q = 1…5):

$$YD_t = \sum_q \left[(1-t_{S,q}-t_{Y,q})w_{t,q}H_{t,q} + (1-t_{Y,q})\Pi_{t,q} + Tr_{t,q} \right] \tag{A4}$$

Financial assets of households are built up by saving after durable purchasing has been financed, and the constraint for lending is:

$$A_t + (1-\theta)K_t \geq 0 \tag{A5}$$

This term represents voluntary equity holding, as the equivalent of the other part of the durable stock (θK_t) needs to be held as equity. The consideration of the collateralized constraint is operationalized in a down payment requirement parameter θ, which represents the fraction of durables purchases that a household is not allowed to finance. One main variable in the buffer stock-model of consumption is 'cash on hand', X_t, measuring the household's total resources: $X_t = (1 + r_t)(1 - t_r)A_{t-1} + (1 - \delta)K_{t-1} + YD_t$.

Energy demand

The energy demand of households comprises fuel for transport, electricity and heating. These demands are part of total nondurable consumption and separability from non-energy nondurable consumption is assumed. In line with the literature on the rebound effect (e.g.: Khazzoom, 1989), the energy demand is modeled as (nominal) service demand and the service aspect is dealt with via service prices. The durable stock of households (vehicles, houses, appliances) embodies the efficiency of converting an energy flow into a service level $S = \eta_{ES} E$, where E is the energy demand for a certain fuel and S is the demand for a service inversely linked by the efficiency parameter (η_{ES}) of converting the corresponding fuel into a certain service. For a given conversion efficiency, a service price, p_S, (marginal cost of service) can be derived, which is a function of the energy price and the efficiency parameter: $p_S = p_E/\eta_{ES}$. Any increase in efficiency leads to a decrease in the service price and thereby to an increase in service demand ('rebound effect').

For transport demand of private households we take substitution between public (C_{pub}) and private transport (C_{fuel}) into account. The price for fuels, $pc_{S,fuel}$, is defined as a service price. Total transport demand of households depends on the composite price of private and public transport, as well as on total nondurable expenditure. The demand for transport fuels is linked to the vehicle stock and depends on the service price of fuels as well as on the endowment of vehicles of the population. The latter term is important because the second car of the household usually is used less in terms of miles driven than the first.

$$\log\left(\frac{C_{fuel,t}}{K_{veh,t}}\right) = \mu_{fuel} + \gamma_{fuel} \log\left(\frac{p_{fuel,t}}{\eta_{fuel,t}}\right) + \xi_{fuel} \log\left(\frac{K_{veh,t}}{h_t}\right) \tag{A8}$$

In (A8) μ_{fuel} is a constant or a cross section fixed effect and γ_{fuel} is the price elasticity under the condition that there is a unitary elasticity of fuel demand to the vehicle stock.

The equations for heating and electricity demand are analogous to equation (A8) and have the following form:

$$\log\left(\frac{C_{heat,t}}{K_{hous,t}}\right) = \mu_{heat} + \gamma_{heat} \log\left(\frac{p_{heat,t}}{\eta_{heat,t}}\right) + \xi_{heat} \log(dd_{heat}) \tag{A9}$$

$$\log\left(\frac{C_{el,t}}{K_{app,t}}\right) = \mu_{el} + \gamma_{el} \log\left(\frac{p_{el,t}}{\eta_{el,t}}\right) + \xi_{el} \log(dd_{heat}) \tag{A10}$$

In both equations the variable heating degree days dd_{heat} is added. The durable stocks used are the total housing stock ($K_{hous,t}$) and the appliance stock ($K_{app,t}$). The latter is accumulated from consumption of appliances, C_{app}, which in turn is explained in a log linear specification like total transport demand.

Nondurable (non-energy) demand

The non-energy demand of nondurables is treated in a demand system. The one applied in this DYNK model is the Almost Ideal Demand System (AIDS), starting from the cost function for $C(u, p_i)$, describing the expenditure function (for C) as a function of a given level of utility u and prices of consumer goods, p_i (see: Deaton and Muellbauer, 1980) . The AIDS model is represented by the budget share equations for the i nondurable goods in each period:

$$w_i = \alpha_i + \sum_j \gamma_{ij} \log p_j + \beta_i \log\left(\frac{C}{P}\right) \quad ; \quad i = 1...n, 1...k \tag{A11}$$

with price index, P_t, defined by $\log P_t = \alpha_0 + \sum_i \alpha_i \log p_{it} + 0.5 \sum_i \sum_j \gamma_{ij} \log p_{it} \log p_{jt}$, often approached by the Stone price index: $\log P_t^* = \sum_k w_{it} \log p_{it}$ .The expressions for expenditure

(η_i) and compensated price elasticities (ε_{ij}^{C}) within the AIDS model for the quantity of each consumption category C_i can be written as (the details of the derivation can be found in Green, and Alston, 1990)[8]:

$$\eta_i = \frac{\partial \log C_i}{\partial \log C} = \frac{\beta_i}{w_i} + 1 \tag{A12}$$

$$\varepsilon_{ij}^{C} = \frac{\partial \log C_i}{\partial \log p_j} = \frac{\gamma_{ij} - \beta_i w_j}{w_i} - \delta_{ij} + \varepsilon_i w_j \tag{A13}$$

In (13) δ_{ij} is the Kronecker delta with $\delta_{ij} = 0$ for i ≠ j and $\delta_{ij} = 1$ for i = j.

The commodity classification $i = 1...n$ in this model comprises the n non-energy nondurables: (i) food, and beverages, tobacco, (ii) clothing, and footwear, (iii) furniture and household equipment, (iv) health, (v) communication, (vi) recreation and accomodation, (vii) financial services, and (viii) other commodities and services.

A.2 Firm behaviour and production structure

Substitution in a K,L,E,M^m,M^d model

The model is set up with inputs of capital (K), labor (L), energy (E), imported (M^m) and domestic non-energy materials (M^d), and their corresponding input prices p_K , p_L , p_E , p_{Mm} and p_{Md} . Each industry faces a unit cost function for the price (p_Q) of output Q, with constant returns to scale

$$\log p_Q = \alpha_0 + \sum_i \alpha_i \log(p_i) + \frac{1}{2}\sum_i \gamma_{ii} \left(\log(p_i)\right)^2 + \sum_{i,j} \gamma_{ij} \log(p_i)\log(p_j) + \alpha_t t + \frac{1}{2}\alpha_{tt} t^2 + \sum_i \rho_{ti} t \log(p_i) \tag{A14}$$

, where p_Q is the output price (unit cost), p_i, p_j are the input prices for input quantities x_i, x_j, and t is the deterministic time trend, TFP is measured by α_t, and α_{tt}. Shepard's Lemma yields the cost share equations in the Translog case, which in this case of five inputs can be written as:

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[8] The derivation of the budget share w_i with respect to log (C) and log (p_j) is given by β_i and $\gamma_{ij} - \beta_i$ (log(P)) respectively. Applying Shephard's Lemma and using the Stone price approximation, the elasticity formulae can then be derived.

$$
\begin{aligned}
v_K &= \left[\alpha_K + \gamma_{KK} \log(p_K / p_{Md}) + \gamma_{KL} \log(p_L / p_{Md}) + \gamma_{KE} \log(p_E / p_{Md}) + \gamma_{KM} \log(p_{Mm} / p_{Md}) + \rho_{tK} t\right] \\
v_L &= \left[\alpha_L + \gamma_{LL} \log(p_L / p_{Md}) + \gamma_{KL} \log(p_K / p_{Md}) + \gamma_{LE} \log(p_E / p_{Md}) + \gamma_{LM} \log(p_{Mm} / p_{Md}) + \rho_{tL} t\right] \\
v_E &= \left[\alpha_E + \gamma_{EE} \log(p_E / p_{Md}) + \gamma_{KE} \log(p_K / p_{Md}) + \gamma_{LE} \log(p_L / p_{Md}) + \gamma_{EM} \log(p_{Mm} / p_{Md}) + \rho_{tE} t\right] \\
v_M &= \left[\alpha_M + \gamma_{MM} \log(p_{Mm} / p_{Md}) + \gamma_{KM} \log(p_K / p_{Md}) + \gamma_{LM} \log(p_L / p_{Md}) + \gamma_{EM} \log(p_E / p_{Md}) + \rho_{tM} t\right]
\end{aligned} \tag{A15}
$$

The homogeneity restriction for the price parameters $\sum_i \gamma_{ij} = 0$, $\sum_j \gamma_{ij} = 0$ has already been imposed in (A15), so that the terms for the price of domestic intermediates p_{Md} have been omitted. The immediate *ceteris paribus* reaction to price changes is given by the own and cross price elasticity. These own- and cross- price elasticities for changes in input quantity x_i are given as:

$$\varepsilon_{ii} = \frac{\partial \log x_i}{\partial \log p_i} = \frac{v_i^2 - v_i + \gamma_{ii}}{v_i} \tag{A16}$$

$$\varepsilon_{ij} = \frac{\partial \log x_i}{\partial \log p_j} = \frac{v_i v_j + \gamma_{ij}}{v_i} \tag{A17}$$

Here, the v_i represent the factor shares in equation (A15), and the γ_{ij} the cross-price parameters. The rate of factor bias, i.e. the impact of t on factor x_i without considering TFP is given by:

$$\frac{d \log x_i}{dt} = \frac{\rho_{ti}}{v_i} \tag{A18}$$

Factor prices are exogenous for the derivation of factor demand, but are endogenous in the system of supply and demand. Some factor prices are directly linked to the output prices p_Q which are determined in the same system. All user prices are the weighted sum of the domestic price p^d and the import price, p^m. The import price of commodity i in country s is given as the weighted sum of the commodity prices of the k sending countries ($p^{d,k}$). Once the (user specific) import prices for intermediate goods are given, the price vectors of total domestic ($\mathbf{p}_{\mathrm{Md}}$) and imported ($\mathbf{p}_{\mathrm{Mm}}$) intermediate inputs by industry can be calculated. Within the bundle of intermediate inputs (M^m and M^d), which comprises 55 non-energy industries/commodities, Leontief technology is assumed. These bundles are defined by the 'use structure matrices' ($\mathbf{S}_{\mathrm{NE}}^{\mathrm{m}}$ and $\mathbf{S}_{\mathrm{NE}}^{\mathrm{d}}$) with column sum of unity.

$$\mathbf{p}_{\mathrm{Mm}} = \mathbf{p}^{\mathrm{m}}\mathbf{S}_{\mathrm{NE}}^{\mathrm{m}} \qquad \mathbf{p}_{\mathrm{Md}} = \mathbf{p}^{\mathrm{d}}\mathbf{S}_{\mathrm{NE}}^{\mathrm{d}} \tag{A19}$$

The price of capital is based on the user cost of capital: $u_K = p_{CF}(r+\delta)$ with p_{CF} as the price of investment goods an industry is buying, r as the deflated benchmark interest rate and δ as the aggregate depreciation rate of the capital stock K. The investment goods price p_{CF} can be defined as a function of the domestic commodity prices and import prices, given the input structures for investment, derived from the capital formation matrix for domestic ($\mathbf{B}_{\mathrm{K}}^{\mathrm{d}}$) and imported ($\mathbf{B}_{\mathrm{K}}^{\mathrm{m}}$) investment demand:

$$\mathbf{p}_{\mathrm{CF}} = \mathbf{p}^{\mathrm{m}}\mathbf{B}_{\mathrm{K}}^{\mathrm{m}} + \mathbf{p}^{\mathrm{d}}\mathbf{B}_{\mathrm{K}}^{\mathrm{d}} \tag{A20}$$

The price of labor is endogenous as well and determined in the labor market. The prices of energy types are assumed to be determined at world markets for energy and are therefore treated as exogenous. A specific feature of capital is that two prices of this input can be formulated: (i) the *ex post* rate of return to K (derived from operating surplus) and (ii) the *ex ante* rate of return to K, i.e. the user cost. In economic terms, that represents an imperfect capital market, which can be in disequilibrium (see: Jorgenson, et al., 2013). It is assumed that after the base year, this adjustment takes place instantaneously.

Energy inputs in production and the domestic indirect Carbon footprint of households

The aggregate E comprises four energy industries/commodities. In a second nest, the factor E is split up into aggregate categories of energy (coal, oil, gas, renewable, electricity/heat) in a Translog model. The unit cost function of this model determines the bundle price of energy, p_E, and the cost shares of the five aggregate energy types:

$$\log p_E = \alpha_0 + \sum_i \alpha_{E,i}\log(p_{E,i}) + \frac{1}{2}\sum_i \gamma_{E,ii}\left(\log(p_{E,i})\right)^2 + \sum_{i,j}\gamma_{E,ij}\log(p_i)\log(p_j) + \sum_i \rho_{tE,i}t\log(p_{E,i}) \tag{A21}$$

$$v_{E,i} = \left[\alpha_{E,i} + \sum_{i,j}\gamma_{E,ij}\log(p_{E,i}) + \rho_{tE,i}t\right] \tag{A22}$$

In some cases the elasticity of inter-fuel substitution is very close to zero, but most industries show a value of straying around -0.5. The cross price elasticity also show negative signs in a large number of industries, indicating complementarity between fuels.