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Revisiting the effect of VAT changes on output: The importance of pass-through dynamics

Simon Voigts*

* Humboldt-Universität zu Berlin, Germany

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Abstract

Standard models used in academic and institutional research implement the value-added tax (VAT) as a simple consumption tax levied on consumers, implying that tax changes instantaneously translate into consumer price changes. This corresponds to immediate tax pass-though, which is, however, inconsistent with a wealth of empirical evidence for gradual pass-through. I investigate how empirically plausible pass-through dynamics affect VAT multipliers in a New-Keynesian DSGE model relative to instantaneous pass-through under the conventional modeling strategy. To this end, I propose an approach to reconcile pass-through in the model with empirical estimates, and find that short-run multipliers decline by about 50% once we account for empirically observed pass-through dynamics. Standard models thus dramatically overestimate the short-run impact of VAT changes.

1 Introduction

The "New View" of fiscal policy (Furman, 2016) refers to the emerging consensus that discretionary fiscal policy is indispensable and can be effective in a world of persistently low interest rates. The renewed emphasis on fiscal policy is accompanied by a surge in academic and institutional interest (for surveys, see Ramey, 2011; Parker, 2011; Fatás & Mihov, 2009; Hebous, 2011; Leeper et al., 2015). For fiscal stimulus design and macroeconomic consolidation packages, it is crucial to have a precise understanding of the size of multipliers associated with different fiscal instruments. In the context of fiscal stimulus, the relative magnitudes of multipliers tell us which instrument provides the most "bang for the buck", and in the context of consolidation they tell us how a given improvement in the primary balance can be achieved with the smallest possible reduction in aggregate demand. Among fiscal instruments, the value-added tax (VAT) plays a prominent role: between 2007 and 2013, 15 EU countries increased the VAT in order to improve public finances (see Benedek et al., 2015). Japan plans to increase the VAT by 2% in 2019. This gives VAT multipliers a central political relevance, especially in light of high levels of public debt in many developed countries. VAT reductions are also used to stimulate spending, as was done with the 2.5% reduction in the UK in 2010. As of 2014, 160 countries employ a VAT, including all OECD member countries except the US.[1]

As an indirect tax, the VAT on final products is not paid to the government by consumers but by the respective sellers, as e.g. retail stores or service providers. Since consumer prices in countries with a European-style VAT are typically quoted inclusive of the VAT liability, tax changes affect consumers only to the extent that they are passed on via price adjustments. Consistent with the notion of nominal rigidity, there is a wealth of empirical evidence reporting that pass-through of changes in the VAT is only gradual. For example, the comprehensive IMF study of Benedek et al. (2015) strongly rejects full contemporaneous pass-through in a sample of all VAT reforms in the Eurozone between 1999 and 2013: "*The null of full pass-through is firmly rejected, with the point estimates implying that only around one-third of a VAT change is passed forward to consumer prices*". They conclude "*[s]imply assuming full pass-through of all VAT reforms is, it seems, a significant mistake*".

The conventional way of implementing the VAT in macroeconomic models is to use a simple ad valorem consumption tax levied on consumers, which implicitly assumes instantaneous tax pass-through. Consider IMF's workhorse DSGE model GIMF as an example. The household's consumption tax liability is given by $P_t^C c_t \tau_{c,t}$, with P_t^C denoting the price index, c_t consumption and $\tau_{c,t}$ the tax rate (see Kumhof et al., 2010, p. 9). The tax liability per unit of consumption $P_t^C \tau_{c,t}$ moves contemporaneously and proportionally with $\tau_{c,t}$, so if P_t^C was constant, a change in the tax liability would be fully paid by consumers. Sellers only pay a share of a tax change to the extent that there is a general equilibrium adjustment in P_t^C, i.e. that prices decline (increase) in the face of higher (lower) taxes. However, P_t^C is virtually constant in the short-run after a tax change, because standard models feature price and wage rigidity that delay general equilibrium price adjustments.[2] Changes in the tax liability are thus effectively paid by consumers in the short run, which corresponds to full instantaneous pass-through of VAT changes.

Despite the inconsistency between gradual pass-through in the data and instantaneous model

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[1] Source: OECD Consumption Tax Trends, 2014.

[2] Anderson et al. (2013a) p.27 shows price adjustments in GIMF to a permanent fiscal consolidation in the size of 1% of GDP, implemented by higher consumption taxes. Prices decline by about 0.03% in the first year and by roughly 0.06% (0.08%) in the second (third) year after the tax hike started. Coenen et al. (2010) study the impact of fiscal stimulus in four different structural models. Without monetary accommodation, annual inflation in response to a two-year 1%-GDP decrease in consumption taxes is is below 0.05% in the QUEST model, in the GIMF model, and in ECB's NAWM model (p.106).

pass-through under the conventional modeling strategy,[3] the latter is adopted in both academic and institutional research. Examples of academic papers papers include Papageorgiou (2012), Coenen et al. (2013) and Coenen et al. (2012) on fiscal policy in Europe, Lipinska & Von Thadden (2012), Hohberger & Kraus (2016) and Engler et al. (forthcoming) on Fiscal Devaluations, and Eggertsson & Woodford (2004) on the liquidity trap in Japan. Leading policy-making institutions extensively draw on large-scale DSGE models to derive policy advice on the design of discretionary fiscal policy. There is a host of applications of the ECB's New Area-Wide and EAGLE models, the European Commission's QUEST model, the IMF's GIMF and FSGM models and the OECD's Fiscal model[4] which analyze fiscal policy using the respective model's consumption tax to represent a VAT.[5]

To investigate how empirically plausible pass-through dynamics affect VAT multipliers relative to instantaneous pass-through under the conventional modeling approach, I develop a New-Keynesian DSGE model which features a consumption tax as well as a VAT. The consumption tax is levied on households and represents the conventional implementation of the VAT in standard models. For the VAT, I develop a modeling strategy to reconcile tax pass-through in the model with empirical estimates. The impact on output of changes in the two taxes is simulated and the resulting multipliers are compared. Since consumption tax multipliers provide a reference point for the impact of VAT changes under the conventional modeling approach, their differences to VAT multipliers can be interpreted as bias introduced by the conventional VAT-implementation. Short-run multipliers obtained for the consumption tax are dramatically larger than those obtained for the VAT. For example, increasing tax revenues by 1% of GDP for five years causes an average first-year GDP decline of 0.14% (0.06%) if it is achieved by increasing the consumption tax (the VAT). Hence, by neglecting to account for plausible VAT pass-through dynamics, standard models overestimate the short-run impact of VAT changes. Gradual pass-through dampens the impact of tax changes because intertemporal optimization leads agents to cut back spending when consumer prices rise, which happens instantaneously if the VAT is represented by a consumption tax, but only gradually if the tax hike transmits to consumer prices in line with empirical estimates.

The main contribution of this paper is to draw attention to the unsatisfactory implementation of the VAT in standard models. This is especially relevant in the context of institutional research because the results suggest that a substantial body of policy advice suffers from overestimation of short-run VAT multipliers. While this issue is mentioned (but not addressed) in Eggertsson (2011), I propose a modeling strategy to reconcile VAT pass-through with empirical evidence and quantify the bias in VAT multipliers introduced by the conventional implementation. Improving the accuracy of VAT multipliers obtained from theoretical models allows for more meaningful policy advice, especially because it can be crucial for the ordering of different fiscal instruments with regard to their suitability for some discretionary fiscal policy. My results also suggest

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[3]A consumption tax is suitable to represent the US-style sales tax, because pass-through of the sales tax is reported to be swift and comprehensive (see for example Poterba, 1996; Besley & Rosen, 1998). This is compatible with nominal rigidity because retail prices are quoted exclusive of the tax liability in the US.

[4]For model derivations, see Christoffel et al. (2008) for the New Area-Wide model, Gomes et al. (2010) for the EAGLE model, Ratto et al. (2009) for the QUEST model, Kumhof et al. (2010) for the GIMF model, Andrle et al. (2015) for the FSGM model and Furceri & Mourougane (2010) for the OECD Fiscal model.

[5]For papers using GIMF, see IMF (2014b) (on fiscal devaluation in Spain), IMF (2014a) (on fiscal multipliers in Denmark), IMF (2013) (on fiscal consolidation in Hungary), Snudden & Klyuev (2011) (on fiscal consolidation in the Czech Republic), Anderson et al. (2013b) (on fiscal consolidation in various Euro Area countries) and IMF (2015) (on the impact of VAT hikes in Iceland). Arbatli et al. (2016) apply the recent FSGM model for Japan (that has a VAT). For ECB publications see Coenen et al. (2008) (monthly bulletin on fiscal consolation), and Barrell et al. (2014) as well as ECB (2014) on multipliers. For the European Commission's QUEST model, see for example in't Veld (2013), Roeger & in't Veld (2010), and Giudice et al. (2003). Furceri & Mourougane (2010) applies OECD Fiscal to analyze the effects of fiscal policy in the euro area.

that the introduction of realistic VAT pass-through dynamics could overturn the findings of the theoretical literature on the effectiveness of Fiscal Devaluations, in which the VAT is also represented by a consumption tax. This paper's results are also policy-relevant to the extent that policymakers can influence VAT pass-through dynamics. Benedek et al. (2015) report that pass-through for reduced VAT rates is considerably slower than for the standard rate. The latter rate thus appears more suitable for fiscal stimulus, as faster pass-through leads to a quicker consumption increase. By the same token, reduced rates are better suited for fiscal consolidation, as the adverse impact on GDP is delayed.

Section 2 of this paper summarizes empirical evidence on VAT pass-through and Section 3 presents the model and its calibration. Section 4 provides economic intuition for the results presented in Section 5. Section 6 discusses policy implications and Section 7 provides a robustness analysis. The paper concludes with Section 8.

2   Evidence on tax pass-through

The European-style VAT taxes the value added at each stage of the supply chain (see, for example, the textbook Wendler et al. (2008)). Each seller on the chain charges the VAT to the buyer and pays it to the government. At the same time, all buyers other than the end consumer are entitled to refund the VAT liability that accrued for the purchase of intermediate goods used in the production (final goods in the case of retailers). The tax liability for each business on the supply chain is thus a fraction of the difference between its revenues and its expenses for upstream products. Since the end consumer is charged the VAT for the final product but is not entitled for a refund, she or he ends up paying the total VAT liability.[6] For the US-style sales tax, it also holds that ultimately only the end consumer is taxed. However, its collection procedure is simpler. Here, only the business that sells the final product to the end consumer charges the sales tax and pays it to the government.

Empirical evidence on VAT pass-through can be divided into studies that focus on a narrow set of goods and studies that investigate the impact of VAT changes on the CPI. Beginning with the former, Kosonen (2013) reports that a decline in the VAT on hairdressing services in Finland led to price reductions of only half of what full pass-through would imply. Carbonnier (2007) examines a reduction of the VAT on car sales and on housing repair services in France. In both cases, the pass-through was swift (during the first four months) but incomplete. For housing repair services, the consumer share of the tax reduction was estimated to be 77% and 57% for car sales. Politi & Mattos (2011) investigate VAT pass-through for ten different food items in Brazil. In their baseline specification, full pass-through is rejected for all items, with point estimates ranging from 55% for rice to 26% for bread. Regarding the second type of studies, the IMF publication Carare & Danninger (2008) looks at the 3% VAT hike in Germany in 2007. They report a cumulative pass-through of 73% over a time period of two years: one third occurred in the year preceding the reform due to anticipation effects, and the remaining two thirds took place in the implementation year. Various papers study the 13-month VAT reduction starting in December 2008 in the UK. Pike et al. (2009) estimate a pass-through of only a half, while Chirakijja et al. (2009) report substantial and rapid pass-through, with a point estimate of 75%. The Bank of England assumes that around half of the tax cut is passed on to consumers in the course of the 13-month reduction (Bank of England Inflation Reports for February 2009 (p.31) and for August 2010 (p.32)).

The most comprehensive study on VAT pass-through in Europe is the IMF study Benedek

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[6]This paragraph takes a long-run perspective, in which all prices have adjusted such that every firm passes on its tax liability to the respective buyer.

et al. (2015). The authors use a dataset that ranges from 1999 to 2013 and covers monthly price and tax data for 67 consumption items and 1231 VAT changes in total. To isolate the impact of a VAT change on the consumer price of a commodity, the study uses as control variables the prices of the same commodity sold in countries other than the one in which the tax change occurs. Benedek et al. (2015) strongly reject full contemporaneous pass-through for the average VAT change. Because of the high statistical power of the dataset and its unmatched completeness, this study serves as the calibration target for VAT pass-through in the model. It is discussed in more detail in the context of the calibration in Section 3.8.

3 Model

In the following DSGE framework, the small open economy under consideration belongs to a monetary union and represents a typical country of Europe's distressed periphery, in which fiscal consolidation is highly relevant. The home country trades with the rest of the union (henceforth "RoU"), but RoU-countries are not affected by developments in the home country (apart from adjusting imports according to the terms of trade). Domestic households trade non-contingent bonds with RoU-households. In the baseline model, the home country has a negligible weight in the union-wide inflation measure stabilized by the central bank. Intermediate good prices and wages can only be adjusted in a staggered fashion. A government levies taxes and has constant government consumption defined as plain waste. The only non-standard component of the model is a retail firm sector which distributes the final good to households.[7]

We study two versions of the model. In the "European VAT model", the government exclusively levies a VAT whose pass-through dynamics are consistent with empirical evidence. In the "consumption tax model", the government only levies a consumption tax on households, so tax changes directly affect consumer prices. Consumption tax multipliers are broadly in line with the institutions' workhorse models.[8] The purpose of this model version is to provide a reference point for the impact of VAT changes under the conventional modeling approach, when the consumption tax represents a VAT. The two models have identical steady states because they differ only in the speed of pass-through of changes in the tax liability (tax incidence is the same in the long run).[9] Differences between multipliers computed in subsequent sections can thus be fully attributed to different pass-through dynamics.

3.1 Households

Households on the continuum $[0, 1]$ are indexed by j. The index is neglected for the most part to ease notation. A household's lifetime utility is given by

$$U_t = \mathbb{E}_t \sum_{k=0}^{\infty} \beta^k \left(\frac{c_{t+k}^{1-\gamma}}{1-\gamma} - \frac{n_{t+k}^{1+\phi}}{1+\phi} \right) \quad , \tag{1}$$

where n_{t+k} and c_{t+k} are hours worked and consumption in period $t + k$.

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[7]The model shares its basic features with workhorse models used at policy-making institutions. This way, differences between the impact of changes in the two taxes provide an indication for how the introduction of realistic VAT pass-through would affect multipliers in the institutions' workhorse models.

[8]As shown in Section 5, the first-year consumption tax multiplier is 0.15%. In contrast, Coenen et al. (2010) report that the GIMF, QUEST and NAWM models generate multipliers in the range of 0.25%-0.33% for the euro area as a whole. The model at hand produces a smaller multiplier because it represents an individual country and thus has a steady state trade share roughly twice as large as in Coenen et al. (2010). In addition, rule-of-thumb consumers are only considered as a robustness exercise.

[9]Pass-through dynamics in either version are illustrated and explained in Section 3.8.

The household faces the following series of period budget constraints for $t \geq 0$:

$$(1+\tau_t^c)P_t c_t + a_t + b_t \leq (R_{t-1} - RP_{t-1})a_{t-1} + (R_{t-1} - RP_{t-1})b_{t-1} + w_t(j)N_t(j) + \Pi_t - T_t \quad , \quad (2)$$

where P_t denotes the retail price index, and c_t is the final consumption bundle, both introduced below. τ_t^c is the tax rate of the consumption tax, which is implemented as in the institutions' models. It is set to zero in the European VAT model. $R_t - RP_t$ is the gross nominal interest rate (including a risk premium introduced below), and a_t as well as b_t are one-period risk-free nominal bonds. a_t is issued by the domestic government, and b_t denotes bonds traded with RoU-households. Both bonds mature at the beginning of period $t+1$. $w_t(j)N_t(j)$ is nominal labor income, corresponding to the product of the household-specific wage $w_t(j)$ (which it earns for its work at all intermediate good firms $i \in [0,1]$ on the continuum) and its total employment, defined as $N_t(j) = \int_0^1 n_t(i,j)\,di$. T_t are lump-sum taxes levied by the government, and Π_t denotes nominal profits from the ownership of firms (including retail firms introduced below). Intertemporal optimization leads to the following Euler equation:

$$R_t - RP_t = \beta \mathbb{E}_t \left(\frac{c_t}{c_{t+1}} \right)^\gamma \frac{P_t}{P_{t+1}} \frac{1+\tau_t^c}{1+\tau_{t+1}^c} \quad . \tag{3}$$

$RP_t = -\phi^B B_t$ is a risk premium proposed by Schmitt-Grohé & Uribe (2003), with $B_t = \int_0^1 b_t(j)\,dj$ denoting aggregate bond holdings. It forces external debt to return asymptotically to the steady state level of zero after a shock, which ensures stationarity of the model. However, ϕ^B is so small that the risk premium can be neglected in the short and medium term shock adjustment, and thus does not affect the results of this paper.

Hours worked are determined by labor demand. As discussed below, workers reduce their labor supply below the competitive level because they have market power.

The final consumption bundle c_t consists of retail good varieties from all retail firms on the continuum (indexed by $r \in [0,1]$). Varieties of different retail firms $c_t^{ret}(r)$ are imperfect substitutes for households and are bundled with the following Dixit-Stiglitz aggregator:

$$c_t = \left[\int_0^1 \left(c_t^{ret}(r) \right)^{\frac{\epsilon_r - 1}{\epsilon_r}} dr \right]^{\frac{\epsilon_r}{\epsilon_r - 1}} \quad . \tag{4}$$

Cost minimization implies a standard demand schedule for retail firm varieties:

$$c_t^{ret}(r) = \left(\frac{p_t^{ret}(r)}{P_t} \right)^{-\epsilon_r} c_t \quad , \tag{5}$$

where $p_t^{ret}(r)$ is the price of retail variety r and P_t the retail price index, given by

$$P_t = \left(\int_0^1 \left(p_t^{ret}(r) \right)^{1-\epsilon_r} dr \right)^{\frac{1}{1-\epsilon_r}} \quad . \tag{6}$$

3.2 Supply side

Intermediate good firms produce differentiated intermediate good varieties, which are sold domestically and exported to the RoU. A competitive final good firm bundles domestic intermediate goods as well as imports into a final good. In contrast to the standard model, the final good is not sold to households directly, but distributed by a continuum of retail firms. These firms have market power because they repackage the final good into differentiated retail firm varieties that

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are imperfect substitutes in (4). Retail firms pay the European VAT to the government in the respective version of the model.[10] Figure 1 summarizes the supply side (neglecting government consumption). Arrows denote the flow of goods and the respective price levels.
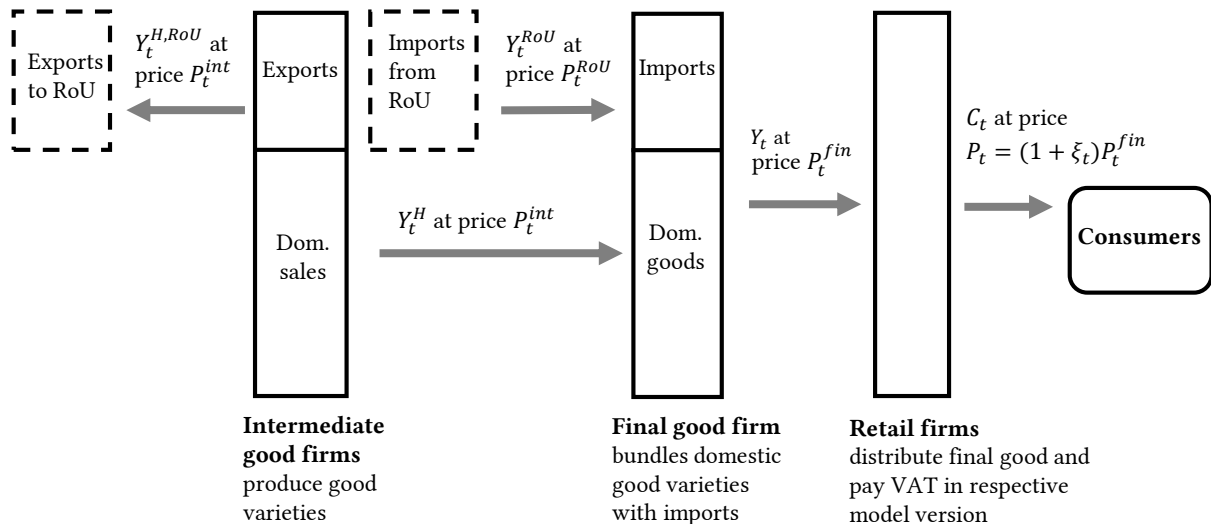

Figure 1: Supply side of the model economy.

3.2.1 Intermediate good producers

Intermediate good firm $i \in [0,1]$ produces its variety $y_t(i)$ with a linear production function:

$$y_t(i) = n_t(i) \quad . \tag{7}$$

The input is a labor composite $n_t(i)$ that contains differentiated labor services $n_t(i,j)$ of all households $j \in [0,1]$:

$$n_t(i) \equiv \left(\int_0^1 n_t(i,j)^{1-\frac{1}{\epsilon_w}} \, dj \right)^{\frac{\epsilon_w}{\epsilon_w - 1}} \quad . \tag{8}$$

Cost-minimizing composition of $n_t(i)$ implies the following demand schedule for type-j labor:

$$n_t(i,j) = \left(\frac{w_t(j)}{W_t} \right)^{-\epsilon_w} n_t(i) \quad , \tag{9}$$

where $w_t(j)$ is the wage for type-j labor and W_t is the aggregate wage index:

$$W_t \equiv \left(\int_0^1 w_t(j)^{1-\epsilon_w} \, dj \right)^{\frac{1}{1-\epsilon_w}} . \tag{10}$$

Using (9) and (10), firm i's total wage bill can be expressed as:

$$\int_0^1 w_t(j) \, n_t(i,j) \, dj = W_t n_t(i) \quad . \tag{11}$$

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[10]The shortcut of levying the VAT only on retailers is discussed in Section 3.2.3.

Demand for firm i's variety stems from domestic private and government consumption and, via exports, from consumption in the RoU. All buyers of the variety use the same aggregation technology as the final good firm (governed by (17) below). Consequently, cost minimization implies the following demand schedule:

$$y_t(i) = \left(\frac{p_t^{int}(i)}{P_t^{int}} \right)^{-\epsilon} Y_t^{total} \quad , \tag{12}$$

where $p_t^{int}(i)$ is the price of firm i's variety, and Y_t^{total} denotes aggregate demand for domestic goods, given by (35) below. P_t^{int} is the price index for intermediate goods, defined by

$$P_t^{int} \equiv \left(\int_0^1 p_t^{int}(i)^{1-\epsilon} \, di \right)^{\frac{1}{1-\epsilon}} \quad . \tag{13}$$

Only a random share $(1-\theta)$ of firms is allowed to re-adjust prices in a given period. A firm that is allowed to re-adjust its price solves the following problem:

$$\max_{p_t^{int}(i)} \mathbb{E}_t \sum_{k=0}^{\infty} Q_{t,t+k} \theta^k \left[y_{t+k|t}(i) \, p_t^{int}(i) - \Psi_{t+k}\left(y_{t+k|t}(i)\right) \right] \quad , \tag{14}$$

where $y_{t+k|t}(i)$ is period $t+k$ output (determined by (12)), given that the price set in t remains valid up to period $t+k$. The stochastic discount factor (SDF) is $Q_{t,t+k} \equiv \beta^k \left(c_{t+k}/c_t\right)^{-\gamma} \left(P_t \left(1+\tau_t^c\right)/P_{t+k}\left(1+\tau_{t+k}^c\right)\right)$. The cost function $\Psi_t(.)$ represents the firm's total wage bill (11), which, using (7), can be written as:

$$\Psi_{t+k}\left(y_{t+k|t}(i)\right) = W_{t+k} y_{t+k|t} \quad . \tag{15}$$

The optimal price $(p_t^{int})^*$ set by re-adjusting firms is governed by the following FOC:

$$\mathbb{E}_t \sum_{k=0}^{\infty} Q_{t,t+k} \theta^k y_{t+k|t} \left[(p_t^{int})^* - \frac{\epsilon}{(\epsilon-1)} W_{t+k} \right] = 0 \quad . \tag{16}$$

$(p_t^{int})^*$ is a markup over a weighted average of expected effective marginal costs, which are equal to the wage rate.

One possible modeling strategy to generate gradual VAT pass-through is to levy the tax on intermediate good firms. In this case, the FOC would schedule that after-tax revenues (price divided by tax factor) are a markup over marginal costs, and a change in the tax liability would affect firm profits until prices can be adjusted in order to pass it on to consumers. However, this modeling strategy is inconsistent with the destination-based nature of the VAT. In reality the VAT is reimbursed on exports, so it is not reasonable to assume that foreign prices are adjusted in order to roll over changes in the domestic VAT liability. Unless the model featured a second pricing equation for the foreign market (i.e. a pricing-to-market strategy), this would nevertheless happen if the FOC accounted for after-tax revenues.

3.2.2 Final good producer

In a first step, the competitive final good firm bundles domestic intermediate goods $\{y_t(i)\}$ into the domestic goods bundle Y_t^H. In a second step, it bundles Y_t^H with the foreign goods bundle Y_t^{RoU} into the final consumption good that is distributed via the retail sector. The aggregation technology for the first step is given by

$$Y_t^H \equiv \left(\int_0^1 y_t(i)^{1-\frac{1}{\epsilon}} \, di \right)^{\frac{\epsilon}{\epsilon-1}} \quad . \tag{17}$$

Bundling of Y_t^H with the foreign goods bundle Y_t^{RoU} is subject to consumption home bias. The final good Y_t is packed with the following technology:

$$Y_t = \left((1-\omega)^{\frac{1}{\sigma}} \left(Y_t^H\right)^{\frac{\sigma-1}{\sigma}} + \omega^{\frac{1}{\sigma}} \left(Y_t^{RoU}\right)^{\frac{\sigma-1}{\sigma}}\right)^{\frac{\sigma}{1-\sigma}} , \qquad (18)$$

where ω reflects home bias in consumption, and σ determines the elasticity of substitution between domestic goods and goods from the RoU.

The price of the final good P_t^{fin} is given by:

$$P_t^{fin} = \left((1-\omega)\left(P_t^{int}\right)^{1-\sigma} + \omega\left(P_t^{RoU}\right)^{1-\sigma}\right)^{\frac{1}{1-\sigma}} , \qquad (19)$$

where P_t^{RoU} is the price index for the foreign goods bundle.[11] Cost-efficient bundling of Y_t implies the following demand schedule for the domestic intermediate goods bundle:[12]

$$Y_t^H = (1-\omega)\left(\frac{P_t^{int}}{P_t^{fin}}\right)^{-\sigma} Y_t . \qquad (20)$$

Since the terms of trade are one in the steady state of the model, the steady state import share is given by ω. Profits made by intermediate firms are discussed in Section 3.2.4.

3.2.3 Retailers

A retail firm $r \in [0,1]$ buys the final good at price P_t^{fin} and sells it to households with a firm-specific markup $\xi_t(r)$, so its price $p_t^{ret}(r)$ is given by

$$p_t^{ret}(r) = (1 + \xi_t(r))P_t^{fin} . \qquad (21)$$

In the European VAT model, retailers pay a tax-inclusive[13] VAT rate of τ_t^v (set to zero in the consumption tax model). They thus only receive after-tax revenues of $p_t^{ret}/(1+\tau_t^v)$ per unit. This accounts for the destination-based nature of the VAT. It is paid on imports, since imports are part of the final good bundle sold by retailers, but not paid on exports, since the VAT exclusively affect retailers who only sell to the domestic market.

Substituting (21) in (6) yields $P_t = \left(\int_0^1 (1+\xi_t(r))^{1-\epsilon_r} dr\right)^{\frac{1}{1-\epsilon_r}} P_t^{fin}$. Defining

$$(1 + \xi_t) \equiv \left(\int_0^1 (1+\xi_t(r))^{1-\epsilon_r} dr\right)^{\frac{1}{1-\epsilon_r}} \qquad (22)$$

as the aggregate markup factor, the retail price index can be written as

$$P_t = (1 + \xi_t) P_t^{fin} . \qquad (23)$$

Retailers choose their markups subject to a Calvo constraint: in each period, they are only allowed to re-adjust $\xi_t(r)$ with a probability $0 < 1-\theta^r < 1$. When deciding on $\xi_t(r)$, re-adjusting retailers solve the following problem:

$$\max_{\xi_t} \mathbb{E}_t \sum_{k=0}^{\infty} (\theta^r)^k Q_{t,t+k} y_{t+k|t}^{ret} \left[\frac{p_{t+k|t}^{ret}}{1+\tau_{t+k}^v} - P_{t+k}^{fin}\right] . \qquad (24)$$

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[11] Foreign prices are constant and assumed to equal domestic prices in the steady state.

[12] Demand for the foreign goods bundle is not shown because it has no relevance in a small open economy model.

[13] For a tax-inclusive rate, the tax liability is included in the tax base.

Because retail firms are owned by households, $Q_{t,t+k}$ discounts future profits.[14] $y_{t+k|t}^{ret}$ is period $t+k$ demand for retailers that have not adjusted their markup since t and therefore still charge the price $p_{t+k|t}^{ret} = (1+\xi_{t+k|t})P_{t+k}^{fin}$. It is determined by demand schedule (5). The square bracket denotes profits, as it subtracts expenses P_{t+k}^{fin} from period $t+k$ after-tax revenues $p_{t+k|t}^{ret}/(1+\tau_{t+k}^v)$.

Using (21) and (23) in (5), $y_{t+k|t}^{ret}$ can be written as $y_{t+k|t}^{ret} = \left(\frac{1+\xi_{t+k|t}}{1+\xi_{t+k}}\right)^{-\epsilon_r} C_{t+k}$, where $C_t \equiv \int_0^1 c_t(j)\,dj$ denotes aggregate consumption. Substituting $y_{t+k|t}^{ret}$ in (24) leads to the following FOC for newly set markups ξ_t^*:

$$\mathbb{E}_t \sum_{k=0}^{\infty} (\theta^r)^k Q_{t,t+k} C_{t+k} P_{t+k}^{fin} (1+\xi_{t+k})^{\epsilon_r} \left[\frac{1+\xi_t^*}{1+\tau_{t+k}^v} - \frac{\epsilon_r}{\epsilon_r - 1}\right] = 0 \quad . \tag{25}$$

The FOC implies that retailers charge a markup over their expenses for the final good, and, in the European VAT model, also roll over the tax liability to consumers in the long run. In the steady state, all firms have adjusted markups and charge ξ^*, so it holds that $(1+\xi^*) = (1+\xi) = \frac{\epsilon_r}{\epsilon_r - 1}(1+\tau^v)$. If retail varieties were perfect substitutes ($\epsilon_r \to \infty$), the aggregate markup would equal the tax rate, so retailers would roll over the full tax liability and thus break even.[15] However, since retailers have market power ($\frac{\epsilon_r}{\epsilon_r - 1} > 1$), they charge a higher price and therefore make profits in the steady state. These profits deviate from their steady state value in the short run when τ_t^v is shocked in the European VAT model. A change in τ_t^v directly affects after-tax revenues, so if a retailer is not allowed to re-adjust its markup, the change in the tax liability fully falls on its profits. It is passed on to consumers only when the retailer is allowed to re-adjust. This means that the aggregate pass-through of a change in the tax liability depends on the share of retailers that adjusted markups in response. Since $\theta^r < 1$, the immediate aggregate pass-through is incomplete, and the value of θ^r determines the delay until full pass-through on the part of retail firms is achieved.

Under $\tau_t^v = 0$ in the consumption tax model, all retailers charge the constant markup $\frac{\epsilon_r}{\epsilon_r - 1}$ reflecting their market power. For fully flexible retail markups $\theta^r = 0$ (a hypothetical case to illustrate the workings of the model), the European VAT model is equivalent to the consumption tax model. In this case retailers instantaneously pass on changes in the tax liability, so the adjustment of consumer prices is equivalent to their adjustment to a consumption tax change (for which changes in the tax liability immediately affect consumer prices).

Relative to the alternative modeling strategy of levying the tax on intermediate good firms that follow a pricing-to-market strategy (see Section 3.2.1), this modeling choice has the advantage that pass-through dynamics can be varied while all other adjustment properties of the model are held constant. Changing θ^r only affects VAT pass-through dynamics, while changing θ under the alternative modeling strategy would at the same time also alter general inflation dynamics.

The evolution of the aggregate markup factor ξ_t over time is determined in a way that is familiar from standard Calvo pricing. The fraction $(1-\theta^r)$ of re-adjusting retailers charge ξ_t^*, while the distribution of markups among non-adjusting retailers is the same as in the previous

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[14]In the baseline calibration, retailers discount future profits in the same way as households, which is consistent with their ownership of these firms. Section 5 also considers different discount factors of retails firms (β^r), in which case the SDF reads as $Q_{t,t+k} \equiv (\beta^r)^k (c_{t+k}/c_t)^{-\gamma} \left(P_t \left(1+\tau_t^c\right)/P_{t+k}\left(1+\tau_{t+k}^c\right)\right)$. This allows to study a broader set of pass-through dynamics, but comes at the cost of the inconsistency that retail firms use a different discount factor than their owners. However, apart from affecting pass-through dynamics, this has no further implications for the model's adjustment properties.

[15]After-tax revenues per unit $\frac{p_t^{ret}(r)}{1+\tau_t^v} = \frac{1+\xi_t(r)}{1+\tau_t^v}P_t^{fin}$ then equal P_t^{fin}, which are the expenses for one unit of the final good.

period. It follows that (22) can be written as

$$1 + \xi_t = \left(\int_{S(t)} \left(1 + \xi_{t-1}(r)\right)^{1-\epsilon_r} dr + (1 - \theta^r)\left(1 + \xi_t^*\right)^{1-\epsilon_r} \right)^{\frac{1}{1-\epsilon_r}} , \qquad (26)$$

where $S(t)$ denotes the set of non-adjusting retailers (which has a mass of θ^r). Using (22) for $t-1$, the equation can be written as

$$1 + \xi_t = \left(\theta^r \left(1 + \xi_{t-1}\right)^{1-\epsilon_r} + (1 - \theta^r)\left(1 + \xi_t^*\right)^{1-\epsilon_r} \right)^{\frac{1}{1-\epsilon_r}} \qquad (27)$$

which (jointly with (25)) governs the evolution of the aggregate retail markup factor $(1 + \xi_t)$.

Discussion of the modeling strategy
Assuming that only retail firms pay VAT is at odds with the collection scheme outlined in Section 2. In a more realistic setup, intermediate good firms would charge VAT to the final good firm, which would charge VAT to retail firms, which in turn would charge the VAT to consumers (the final good firm and retail firms would also receive tax refunds). The model at hand only accounts for taxation at the final link of the supply chain (i.e. retailers charging VAT to consumers), but abstracts from taxation at all other segments of the chain. As argued in the following, the model is nevertheless well suited to study VAT multipliers, because all channels by which VAT changes affect output are either thoroughly calibrated or operate in the same way as under a realistic collection scheme.

First, for the consumption decision of households, only pass-through at the final link of the supply chain matters, because it is only then that tax changes affect consumer prices.[16] Pass-through dynamics at this link are thoroughly calibrated, since the rigidity of the aggregate retail markup ξ_t is chosen such that the "final" pass-through of tax changes to consumer prices corresponds to empirical evidence (see section 3.8 below). Note that empirical studies on VAT pass-through also measure pass-through of tax changes to consumer prices, and thus constitute a valid empirical counterpart to pass-through in the model.

Second, we consider profits and household income. Levying VAT exclusively on retail firms means that only their profits are affected by VAT changes. Under a realistic collection scheme, in contrast, profits of all firms along the supply chain would be affected, since all firms pay VAT.[17] Household income is the same in both cases because the representative household owns all firms (see Section 3.2.4), so her or his income is independent of the distribution of after-tax profits across the different types of firms. A stringent modeling of the collection scheme would thus imply the same household income as the model at hand.[18]

Third, expenditure switching effects only depend on the adjustment of intermediate good prices, because the VAT is destination-based tax[19] and therefore does not matter for the terms

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[16]The household's intertemporal substitution decision depends on the adjustment of the real interest rate via Euler equation (3). The real rate is fully determined by consumer price changes, since they also determine the nominal interest rate in Taylor rule (36). Thus only the impact of VAT changes on consumer prices is relevant in the Euler equation, while the impact of VAT changes on prices of upstream products is of no consequence for the consumption decision.

[17]Under a realistic collection scheme, all types of firms would pay a portion of total VAT revenues to the government. Thus, prior to any price adjustments, a change in the total tax liability would be split among intermediate good firms, the final good firm, and retailers. Price adjustments would then cause the tax liability to be passed on downwards the supply chain to the consumer.

[18]Even if household income was different under a realistic collection scheme, this would not affect the consumption adjustment to VAT changes because Ricardian Equivalence holds.

[19]The domestic VAT applies on imports and on domestic goods, while a foreign VAT applies on exports to the respective country as well as on goods produced and sold in that country. A country's VAT thus applies regardless of a good's origin and does therefore not affect relative prices between imports and domestic goods.

of trade. This is accounted for in the model because VAT plays no role for the quantity of imports relative to domestic goods (see Section 3.2.2 on the final good firm, which bundles foreign and domestic goods), and because VAT does not matter for export demand (see the foreign portion in the total demand equation (35)). Plausible expenditure switching effects thus only require plausible adjustment dynamics of intermediate good prices. The latter are governed by θ, which is has a standard value that is in line with micro-evidence.

3.2.4 Profits

Profits of retailers and intermediate good firms are pooled and paid out to households. Aggregate profits Π_t are given by

$$\Pi_t = P_t^{int} Y_t^{total} - W_t N_t + \left[\frac{(1+\xi_t) P_t^{fin}}{1+\tau_t^v} - P_t^{fin} \right] C_t \quad , \tag{28}$$

where N_t is aggregate employment defined as $N_t = \int_0^1 n_t(i)\, di$, and Y_t^{total} is given by (35) below. Subtracting the aggregate wage bill from aggregate revenues of intermediate good firms (the first two terms) yields total profits in that sector. The third term denotes profits in the retail sector: the square bracket represents average profits per unit sold (after-tax revenues minus expenses to buy one unit of the final good) and is multiplied by total consumption.

3.3 Unions and wage setting

Nominal wage rigidity is modeled as in Erceg et al. (2000).[20] Households exert market power on the labor market because differentiated labor services are imperfect substitutes in (8). Each household j is represented by its own labor union that sets the household-specific wage rate $w_t(j)$ subject to a Calvo constraint, so each period only a random share $1 - \theta^w$ of unions can re-adjust.

Aggregating demand equation (9) over all intermediate good firms yields

$$\int_0^1 n_t(i,j)\, di = \int_0^1 \left(\frac{w_t(j)}{W_t} \right)^{-\epsilon_w} n_t(i)\, di \tag{29}$$

which, using the definition for total type-j labor $N_t(j)$ (see (2)) and the definition of aggregate employment, can be written as:

$$N_t(j) = \int_0^1 \left(\frac{w_t(j)}{W_t} \right)^{-\epsilon_w} N_t \quad . \tag{30}$$

A union maximizes the expected present value of the household it represents, which is governed by

$$\max_{w_t(j)} \mathbb{E}_t \left[\sum_{k=0}^{\infty} (\beta \theta^w)^k\, U\left(c_{t+k|t}(j), n_{t+k|t}(j) \right) \right] \quad , \tag{31}$$

where $c_{t+k|t}(j)$ and $n_{t+k|t}(j)$ are period $t + k$ consumption and hours, given that the newly set wage is still valid. Maximization is subject to demand schedule (30). The optimal wage w_t^*

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[20]Wage rigidity is a standard feature in the institutions' models and matters for the short-run pass-through of tax changes because it affects producer price dynamics. It is included to bring the implicit pass-through of the consumption tax in line with the institutions' models. Flexible wages are considered as a robustness exercise.

satisfies the following FOC that (jointly with (10)) governs the evolution of aggregate wages:

$$\mathbb{E}_t \sum_{k=0}^{\infty} (\beta \theta^w)^k MU_{t+k|t} n_{t+k|t} \left[\frac{w_t^*}{(1 + \tau_t^c) P_{t+k}} - \frac{\epsilon_w}{\epsilon_w - 1} MRS_{t+k|t} \right] = 0 \quad , \tag{32}$$

where $n_{t+k|t} = (w_t^*/W_{t+k})^{-\epsilon_w} N_{t+k}$ is period $t + k$ total demand for type-j labor, provided that w_t^* is still valid. $MU_{t+k|t}$ and $MRS_{t+k|t}$ denote household j's period $t + k$ marginal utility and marginal rate of substitution, also conditional on w_t^*. For w_t^*, it holds that after-tax real wages are a markup over an expected weighted average of marginal rates of substitution.

3.4 Government

Government consumption G is constant and defined as plain waste. It consists of domestic intermediate goods, aggregated by the same technology as in (17). The government issues bonds to domestic households, and $A_t = \int_0^1 a_t(j)\, dj$ denotes aggregate bond holdings. The period budget (for all $t \geq 0$) reads as

$$P_t^{int} G + R_{t-1} A_{t-1} = A_t + T_t + \tau_t^c P_t C_t + \frac{\tau_t^v}{1 + \tau_t^v} P_t C_t \quad , \tag{33}$$

where $P_t^{int} G$ are consumption expenditures (the government does not pay taxes and is not dependent on the retail sector). The last two terms on the RHS are revenues from the consumption tax and from the European VAT. Depending on the model version, one of the exogenous tax rates τ_t^c and τ_t^v is set to zero, so revenues only stem from one source. The non-zero tax rate is calibrated such that revenues equal expenditures in the zero-debt steady state[21] and subjected to a shocks that represents discretionary fiscal policy.

Lump-sum taxes T_t are introduced as technical device to make A_t stationary. T_t depends positively on the government's indebtedness:

$$T_t = \phi^A A_t \quad . \tag{34}$$

The responsiveness parameter is set to $\phi^A = 0.0125$, which is marginally larger than the (quarterly) steady state interest rate. Consequently, T_t only reacts very mildly to deviations of A_t from zero, but forces A_t to asymptotically revert to its steady state value of zero after a shock.[22]

The public sector is highly stylized[23], but rich enough to obtain consumption tax and VAT multipliers from a fiscal consolidation. In either model version, the respective tax rate is shocked such that revenues increase by 1% of steady state GDP. The induced surplus leads to an accumulation of government assets ($A_t < 0$), because G is constant and T_t is effectively constant (in the short and medium term) due to the small value of ϕ^A. Note that the obtained multipliers would be the same for a debt-financed fiscal stimulus because the model is symmetric in its approximation around the steady state.

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[21] Allowing for steady state government debt would only affect the model's adjustment properties (and thereby the results) if it significantly affected the real allocation in the steady state. However, steady state interest payments to households would not affect the real allocation if they were financed by lump-sum taxes. If they were financed by distortionary taxes, they would mildly affect the steady state allocation, but not enough to significantly change the model's adjustment properties.

[22] If ϕ^A were equal to the steady state interest rate, T_t would balance interest payments (revenues) for a given deviation $A_t > 0$ ($A_t < 0$). A_t would thus have unit root. A marginally higher value of ϕ^A ensures that T_t increases by enough to also redeem a positive fraction of the principle in the case of $A_t > 0$. Vice versa, in the case of $A_t < 0$, T_t declines by enough to pay out a positive fraction of the principle as lump-sum transfer.

[23] A more realistic public sector that also features labor taxes is considered as robustness exercise in Section 7. It does not significantly change the results.

3.5 Aggregate demand

Demand for the domestic goods bundle stems from domestic consumption (Y_t^H in (20)), government consumption, and exports. Assuming market clearing for final goods ($Y_t = C_t$), it is governed by

$$Y_t^{total} = (1 - \omega) \left(\frac{P_t^{int}}{P_t^{fin}} \right)^{-\sigma} C_t + \omega^{RoU} \left(\frac{P_t^{int}}{P^{fin,RoU}} \right)^{-\sigma} C^{RoU} + G \quad , \qquad (35)$$

where the second term is export demand. The price of the foreign final good in the RoU ($P^{fin,RoU}$) as well as RoU consumption (C^{RoU}) are constant and equal to the steady state values of the respective variables in the home country. The home bias parameter in the RoU (ω^{RoU}) is the same as in the home country, which implies balanced trade in the steady state.

3.6 Monetary policy

Monetary policy targets zero union-wide average inflation. It is described by the following standard Taylor Rule:

$$R_t = \beta^{-1} \left[n \left(\pi_t - 1 \right) + (1 - n) \left(\pi_t^{RoU} - 1 \right) \right]^{\alpha^\pi} \quad , \qquad (36)$$

where α^π governs the responsiveness of monetary policy and n is the weight of the home country in the monetary union. n is set on a negligibly small value in the baseline calibration, so the nominal rate is virtually constant. This corresponds to the current monetary policy environment in the Eurozone – policy rates can effectively not be lowered further and are not expected to increase in the face of an overall depressed economy. A robustness exercise in Section 7 considers "normal times" and calibrate n to match HICP country weights of highly indebted Eurozone countries. The domestic inflation measure $\pi_t = (1 + \tau_t^c) P_t / (1 + \tau_{t-1}^c) P_{t-1}$ accounts for tax-inclusive consumers prices. $\pi_t^{RoU} = 1 \ \forall \ t$ is inflation in the RoU.

3.7 Calibration

Table 1 shows the baseline calibration of the quarterly model. It largely follows Evers (2012) who calibrates a related model to members of the EMU. Calvo probabilities for prices and wages correspond to the empirical findings of Druant et al. (2009), who report for the Euro Area an average lifetime of prices and wages of 9.6 and 12.5 months respectively (excluding the outlier Italy). Elasticities of substitution between different good varieties and labor types match 11% price markup and 15% wage markup, as estimated in Basu & Kimball (1997) and Chari et al. (2002). The steady state import share is 0.33 as in Evers (2012).

The steady state tax rate in the European VAT model τ^v is set to 20%, which Lipinska & Von Thadden (2012) report to be the Eurozone average. In the consumption tax model, the steady state tax rate τ^c is 21.3%, which leads to the same revenues (so the steady state is the same in both model versions).[24] Government consumption $G = 0.165$ (corresponding about 18%

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[24]The European VAT rate is defined as a tax-inclusive rate, so the effective tax rate is $20\% / (1 + 20\%) = 16.67\%$, which is way below the effective consumption tax rate of 21.3%. It nevertheless generates the same revenues as the consumption tax (despite its smaller effective rate) because the tax base is higher under a European VAT. Revenues from the European VAT and from the consumption tax are given by $\left(\tau_t^v / \left(1 + \tau_t^v\right) \right) P_t C_t$ and $\tau_t^c P_t C_t$ respectively (see (33)). That is, effective tax rates ($\frac{\tau_t^v}{1 + \tau_t^v}$ and τ_t^c) are multiplied by the tax base $P_t C_t$. Substituting (23), $P_t C_t$ can be written as $(1 + \xi_t) P_t^{fin} C_t$. While P_t^{fin} and C_t are the same in both model versions, the aggregate markup ξ_t is higher in the steady state of the European VAT model, because retail firms use it to roll over the tax burden to consumers.

Table 1: Baseline parameters

Parameter		Value	Motivation / target
β	Discount factor	0.99	Annual risk-free rate of 4%
γ	Relative risk aversion	1	Log-utility
ϕ^{-1}	Frisch elasticity of labor supply	1	Kimball (2008)
ϵ	Elasticity of substitution goods varieties	10	11% price markup, Basu (1997)
ϵ_w	Elasticity of substitution types of labor	7.4	15% wage markup, Chari et al. 2002
θ	Calvo probability firms	0.6875	Avg. lifetime 9.6 months, Druant et al. 2009
θ^w	Calvo probability unions	0.76	Avg. lifetime 12.5 months, Druant et al. 2009
α^π	Inflation coefficient in Taylor Rule	1.5	Standard
n	Weight of home country in Taylor Rule	0.01	Passive monetary policy
ω	Steady state import share	0.33	Evers (2012)
τ^v	Steady state tax rate European VAT model	20% (0%)	Eurozone avg., Lipinska & Von Thadden (2012)
τ^c	Steady state tax rate cons. tax model	21.3% (0%)	Same revenues as in European VAT model
G	Government spending	0.165	Balanced budget in steady state
θ^r	Calvo probability of retail firms	0.75	Avg. lifetime markup: 1 year
ϵ_r	Substitution elasticity retail varieties	30	Retailers' profits 20% of total profits

of steady state GDP) is chosen such that it equals the revenues from the respective tax in the steady state. As robustness exercise, we also consider a larger government (corresponding to 45% of GDP) that also levies labor taxes.

The elasticity of substitution between retail varieties $\epsilon_r = 30$ implies that about one fifth of total profits accrue in the retail sector, in line with data for the US.[25] Retail markup rigidity θ^r is 0.75 in the baseline calibration, implying an average lifetime of a markup of one year. The resulting pass-through dynamics are discussed in the following subsection.

3.8 Model pass-through

This section illustrates tax pass-through in the two model versions. Figure 2 shows pass-through of the VAT as well as the implicit pass-through when the VAT is represented by a consumption tax. Analog to Benedek et al. (2015), the cumulative pass-through at a given time after a VAT change is defined as the cumulative proportionate response of consumer prices to an increase in the respective tax factor.[26] The upper (lower) panel depicts pass-through for an anticipated (unanticipated) tax increase by 1% of steady state GDP. Horizontal axes denote time in quarters, and both policies are implemented in t=0. For the anticipated reform, the two-year time window shown in Figure 2 begins at the time of the announcement in t=-4, while it begins at the time of the implementation for the unanticipated reform.

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[25]Using different values of ϵ_r is virtually irrelevant for the model's adjustment properties. The calibration data comes from the 2014 National Income and Product Accounts (NIPA) of the U.S. Bureau of Economic Analysis, which provides corporate profits by industry. Retail trade and wholesale trade (both sectors that distribute final goods) make about one fifth of total profits of non-financial firms.

[26]Formally, cumulative pass-through after t periods is given by $\frac{P_t^{cpi} - P^{cpi}}{P^{cpi}} / \frac{\tau_t - \tau}{1+\tau}$, where τ is the respective tax rate (either τ^c or τ^v), and $P_t^{cpi} = (1+\tau_t^c)P_t = (1+\tau_t^c)(1+\xi_t)P_t^{fin}$ corresponds in both model versions to the CPI. Steady state values have no time subscript.
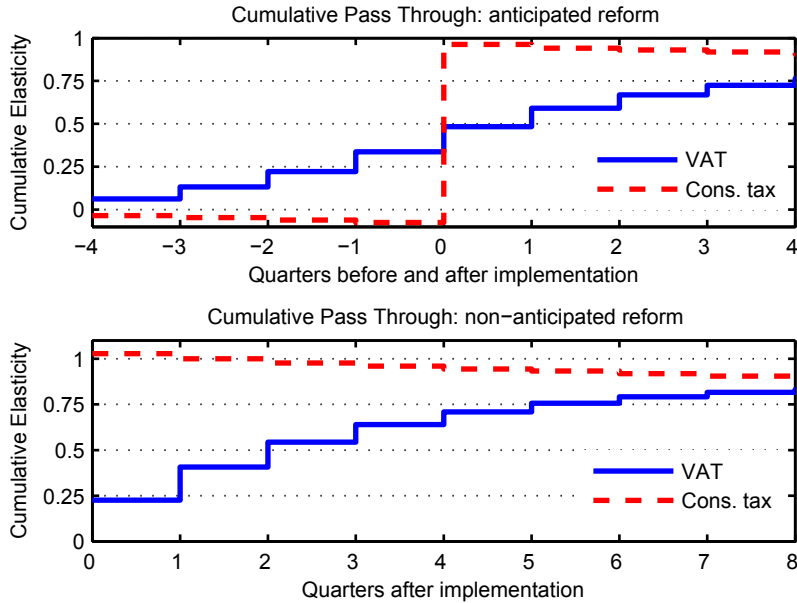
Figure 2: Cumulative pass-through in both models.

In the consumption tax model, changes in τ_t^c directly enter consumer prices (see budget (2)), so the implicit full pass-through subsides only due to general equilibrium price adjustments. However, as we can see in the lower panel, this happens only slowly, because price adjustments are mitigated by price and wage rigidity. Recall that the only purpose of the consumption tax is to represent the implementation of the VAT in standard models. It is thus not claimed that its pass-through is realistic for any kind of consumption tax.

In the European VAT model, in contrast, changes in τ_t^v affect the CPI only via adjustments in the aggregate markup ξ_t. Since the latter is sticky and set by forward-looking retail firms (see Section 3.2.3), we observe a gradual pass-through and significant anticipation effects (in line with Carare & Danninger (2008), see Section 2). The model pass-through corresponds to the estimate by Benedek et al. (2015): Figure 3 is taken from that study and shows the cumulative VAT pass-through (measured as in Figure 2) for an estimation that includes all VAT changes in their sample. Comparing the upper panel of Figure 2 with Figure 3 shows that VAT pass-through in the model is broadly in line with the upper end of the 95% confidence interval of the estimate.[27] Targeting the upper end of the confidence interval makes the parametrization conservative because a weaker pass-through would further reduce short-run multipliers and thereby enlarge differences to their values in the consumption tax model.[28]

Pass-through in either model version converges to roughly 80% in the long run, and differences between pass-through dynamics are only significant for about two years after a tax change (recognizable in the lower panel of Figure 2). This is desirable for the sake of conservative modeling, because reliable empirical evidence of partial pass-through exists only for the short-run after a VAT change: The studies mentioned in Section 2 typically document pass-through in a time window ending one or two years after a VAT change, while no study explicitly addresses pass-through in the long run.[29] We therefore only deviate from the (implicit) pass-through dy-

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[27]The anticipated VAT change is the suitable exercise for a comparison because Benedek et al. (2015) estimate pass-through in the period from one year prior to a VAT change to one year thereafter.

[28]The main results are reported for different variations of pass-through dynamics.

[29]This is not surprising, since it is easier to attribute price changes to a recent VAT change than to a VAT change that occurred long ago.

namics in the institutions' models when it is supported by strong empirical evidence, that is, in the short-run after a VAT change.
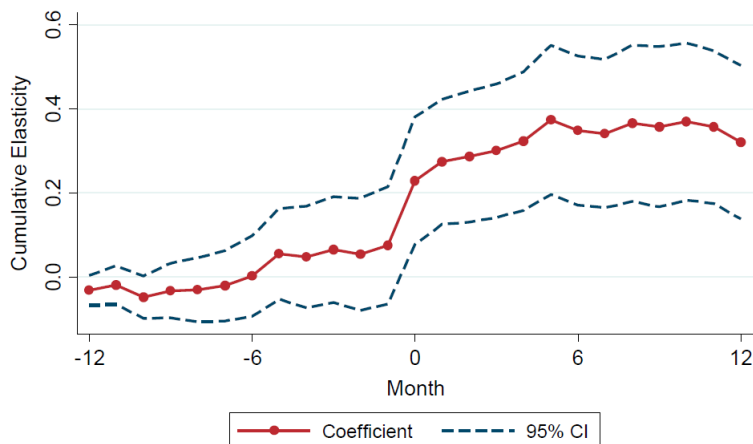

Figure 3: Estimated cumulative pass-through in the Eurozone. Source: Benedek et al. (2015).

4 Dissecting multipliers

This section builds the economic intuition for differences in multipliers between both model versions. We consider an exemplary fiscal consolidation exercise in which the respective tax rate (τ_t^c or τ_t^v) increases exogenously such that quarterly tax revenues rise by 0.25% of steady state GDP for three years, and the additional revenues are used to buy assets.[30] Both model versions are considered separately. The following impulse responses were obtained using a standard perturbation method in Dynare and depict tax rates, interest rates and inflation rates in annualized units.

4.1 Consumption tax model

Figure 4 shows the impact of the exemplary fiscal consolidation when it is implemented by a higher consumption tax – which represents the impact of a VAT increase in standard models. Since the tax base (consumption) is smaller than output in the steady state (due to the public sector), the tax rate has to increase by about 1.4% to elevate revenues by 1% of steady state GDP (1,4)[31]. Since the government lends additional revenues back to households, the tax hike ceteris paribus does not affect households' financial means. In the course of the adjustment, households reduce consumption by about 0.22% of steady state GDP (1,1). This only lowers aggregate demand and output by roughly 0.15%, because households also reduce imports (1,2) and because government consumption is constant. The overhang of the reduction in consumption expenditures over the reduction in income is lent to foreign households and leads to an accumulation of foreign bond holdings (1,3).

The nominal rate (not shown) is virtually constant due to the home country's small weight in the union. In line with the institutions' models, intermediate good prices are very stable (2,1), because wages paid by firms (3,3) – and thereby marginal costs (3,2) – are remarkably steady

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[30]As argued in Section 3.4, we would obtain the same multipliers for fiscal stimulus.

[31]Parentheses indicate the relevant panel. They read as (row, column).

due to nominal wage rigidity.[32] The adjustment of the real interest rate is thus dominated by changes in the consumption tax, and exhibits a sharp peak in period 12 when the tax rate reverts to its initial level (2,2). This corresponds to an increase in the long real rate already at the onset of the consolidation (2,2), and explains the immediate decline in consumption (1,1). Intuitively, households anticipate that consumer prices will drop when the fiscal consolidation comes to an end and postpone consumption until then.

A further consequence of the small adjustment in intermediate goods prices is that the depreciation in the terms of trade (2,3), and the resulting expenditure switching (1,2), is negligible.
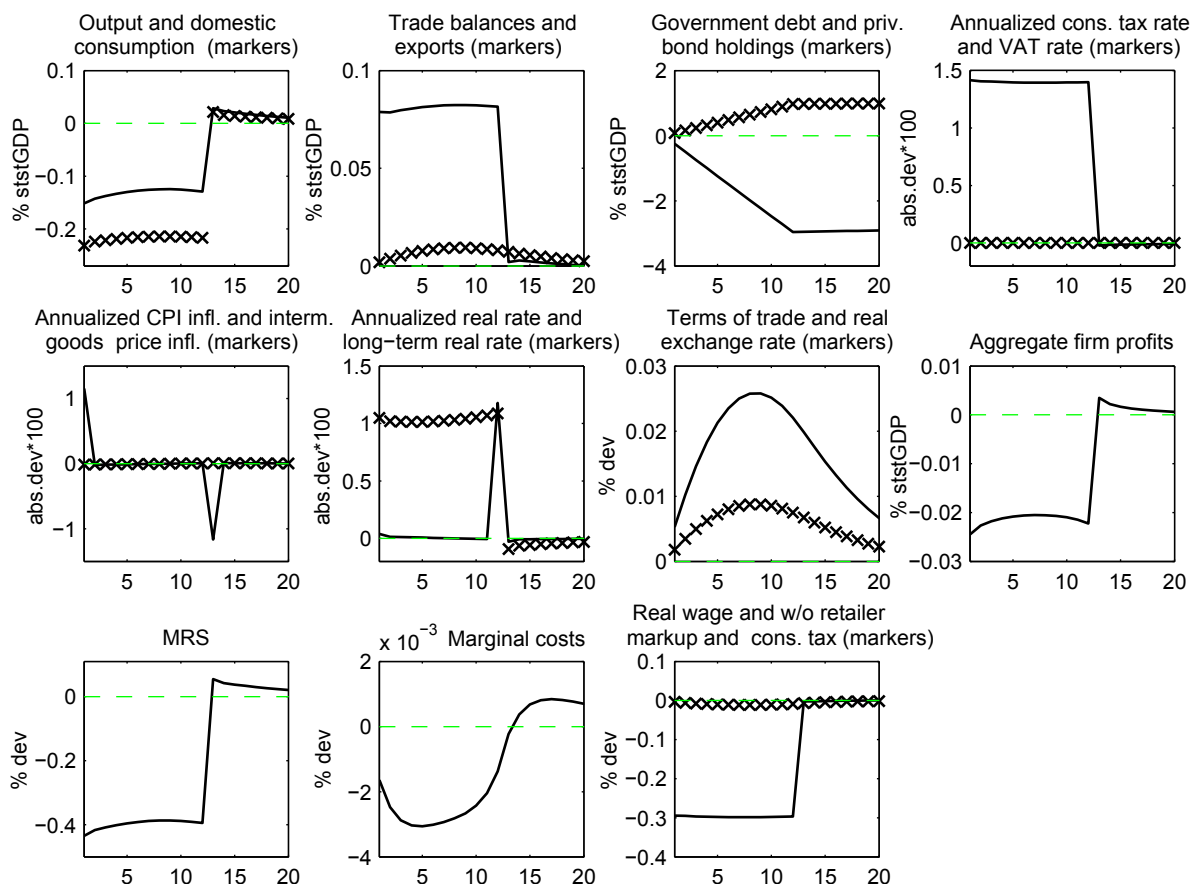
Figure 4: Three-year consolidation in the consumption tax model.

4.2 European VAT model

Figure 5 depicts the adjustment to the fiscal consolidation in the European VAT model. To facilitate a comparison with the consumption tax model, the adjustment in the latter is replicated

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[32]Flexible wages are examined in the robustness analysis. A further reason for the mild wage adjustment is that the MRS (3,1) declines in line with effective real wages (accounting for the consumption tax) (3,3). (Effective real wages decline for a given nominal wage due to the hike in the consumption tax, while the MRS drops because of lower consumption and hours.) As a result, no substantial adjustment of nominal wages is required in order to maintain the optimal proportion $\frac{\epsilon_w}{\epsilon_w - 1}$ between effective real wages and the MRS.

in dashed blue lines (and with circles as markers). As in the consumption tax model, the tax rate has to rise by about 1.4% to improve the primary balance by 1% of steady state GDP (1,4). We begin by examining the aggregate retail markup, which increases as retailers roll over the additional tax liability to consumers (3,4). It peaks roughly two years after the VAT hike sets in (in t=8), but its deviation remains below the deviation of the tax factor throughout the adjustment. The aggregate markup is still elevated after five years, i.e. for two more years after the tax hike has ended. This is because Calvo-rigidity forbids some retailers who increased their markup during the time of the tax hike to undo this action as soon as the policy comes to an end. The peak occurs at t=8 because some retailers begin to lower their markup in anticipation of the near reversal of the tax rate in t=12.

As in the previous exercise, inflation in intermediate good prices is very weak (2,1), so CPI inflation is dominated by inflation in retailer markups.[33] Since the nominal rate is virtually constant, the deviation of the real rate (2,2) mirrors CPI inflation and is negative when the aggregate retail markup rises (until t=8), and positive when it reverts downward. This gives rise to the observed hump-shaped deviation of the long-term real rate (2,2), which is a forward-looking average of one-period real rates. From the standard Euler equation, consumption adjusts accordingly (1,1).

In both model versions, households reduce consumption because the fiscal consolidation causes a transitory increase in consumer prices – either directly via a higher consumption tax or indirectly via higher retail markups. However, the short-run decline of consumption is dramatically weaker in the European VAT model. The reason is that markup rigidity prevents retailers to instantaneously roll over the full increment in the tax liability to consumer prices, whereas it directly falls on consumer prices in the consumption tax model. The second difference between consumption adjustment in both models is that the European VAT model predicts a gradual reversal of consumption to its initial level – lasting beyond the reversal of the tax hike – and not, as the consumption tax model, a jump that occurs at the moment when the tax hike ends. This is because consumer price changes caused by adjustments in retail markups exhibit inertia (since markups are Calvo-sticky), which does not apply for consumer price changes driven by a change in consumption taxes.

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[33]It is not surprising that retail firms carry out the lion's share of the nominal adjustment, as they are directly affected by the change in the tax rate.
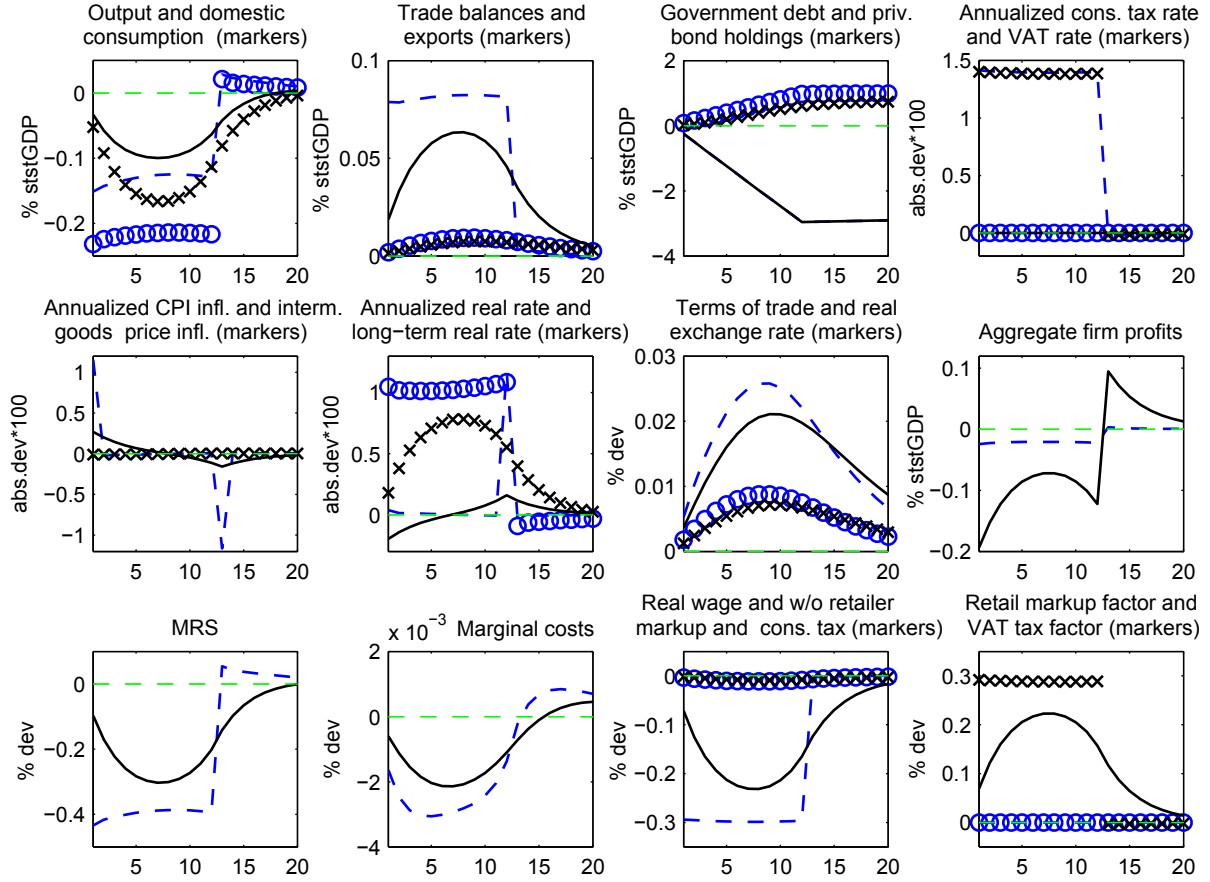
Figure 5: 3-year consolidation in the European VAT model.

5 Comparing multipliers

This section systematically compares multipliers across both models. Multipliers are derived for consolidations of various durations, and under various calibrations of pass-through dynamics in the European VAT model. In particular, Table 2 considers four different fiscal consolidation scenarios, which improve the primary balance by 1% of steady state GDP for one, two, five, and 20 years respectively.[34] The following multiplier statistics are computed: impact multiplier (percentage change of GDP when the VAT hike sets in), peak multiplier (peak percentage deviation of GDP), as well as average multipliers for one, two, five, and 20 years (average percentage deviations of GDP). In addition, the table reports the average GDP adjustment during the time from the beginning of the consolidation until two years after it has ended (last column).[35] Statistics are computed for the consumption tax model, as well as for the European VAT model in the following six calibrations of retail markup setting: for the rigidity parameter θ^r, values

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[34]The 20-year consolidation symbolizes a permanent VAT hike.

[35]This statistic is not a multiplier in the strict sense, because periods succeeding the consolidation are included in the average. It is nevertheless useful to measure the total impact of a consolidation, which requires to account for the sustained GDP decline in the European VAT model (that persists after the consolidation ended, see Figure 5), as well as for the modest post-consolidation expansion of GDP in the consumption tax model (see Figure 4).

0.67, 0.75 (baseline), and 0.85 are considered, while we use 0.85 and 0.99 (baseline) for the time-discount factor β^r.[36] The table also provides statistics to quantify pass-through dynamics for the respective calibration of θ^r and β^r: columns one, two, and three respectively show the instantaneous pass-through, as well as cumulative pass-through after one and two years.[37] To facilitate the comparison of multipliers between both model versions, parentheses next to European VAT multipliers report the percentage difference to their value in the consumption tax model.

Table 2: VAT multipliers in both model versions

	Cumulative PT			Impact multiplier	Peak multiplier	Average multipliers				Avg. adjustment duration +2 yrs.
	impact	1 year	2 years			1 year	2 years	5 years	20 years	
One-year consolidation										
Cons. tax model	100%	98%	–	0.16	0.16	0.15	–	–	–	-0.05
$\theta^r = 0.67$ β^r=0.85	29%	49%	–	0.05 (-71%)	0.08 (-48%)	0.07 (-55%)	–	–	–	-0.03 (-32%)
— β^r=0.99	26%	41%	–	0.04 (-73%)	0.07 (-55%)	0.06 (-61%)	–	–	–	-0.03 (-41%)
$\theta^r = 0.75$ β^r=0.85	20%	38%	–	0.03 (-80%)	0.06 (-61%)	0.05 (-67%)	–	–	–	-0.03 (-42%)
— β^r=0.99	17%	29%	–	0.03 (-83%)	0.05 (-69%)	0.04 (-73%)	–	–	–	-0.02 (-54%)
$\theta^r = 0.85$ β^r=0.85	10%	22%	–	0.02 (-90%)	0.03 (-78%)	0.03 (-82%)	–	–	–	-0.02 (-60%)
— β^r=0.99	7%	14%	–	0.01 (-93%)	0.02 (-86%)	0.02 (-88%)	–	–	–	-0.01 (-74%)
Two-year consolidation										
Cons. tax model	99%	95%	95%	0.15	0.15	0.15	0.14	–	–	-0.06
$\theta^r = 0.67$ β^r=0.85	31%	73%	60%	0.05 (-69%)	0.11 (-26%)	0.08 (-43%)	0.09 (-34%)	–	–	-0.05 (-18%)
— β^r=0.99	30%	69%	52%	0.05 (-70%)	0.11 (-31%)	0.08 (-45%)	0.09 (-38%)	–	–	-0.05 (-25%)
$\theta^r = 0.75$ β^r=0.85	23%	59%	54%	0.03 (-78%)	0.10 (-38%)	0.06 (-56%)	0.08 (-46%)	–	–	-0.05 (-26%)
— β^r=0.99	21%	53%	44%	0.03 (-79%)	0.08 (-46%)	0.06 (-59%)	0.07 (-52%)	–	–	-0.04 (-36%)
$\theta^r = 0.85$ β^r=0.85	13%	38%	41%	0.02 (-88%)	0.06 (-58%)	0.04 (-74%)	0.05 (-65%)	–	–	-0.04 (-43%)
— β^r=0.99	10%	29%	28%	0.02 (-90%)	0.05 (-70%)	0.03 (-79%)	0.04 (-74%)	–	–	-0.03 (-58%)
Five-year consolidation										
Cons. tax model	99%	92%	87%	0.15	0.15	0.14	0.13	0.12	–	-0.08
$\theta^r = 0.67$ β^r=0.85	31%	72%	83%	0.04 (-71%)	0.11 (-26%)	0.08 (-44%)	0.09 (-27%)	0.10 (-15%)	–	-0.07 (-8%)
— β^r=0.99	31%	72%	83%	0.04 (-71%)	0.11 (-25%)	0.08 (-44%)	0.09 (-26%)	0.10 (-17%)	–	-0.07 (-11%)
$\theta^r = 0.75$ β^r=0.85	23%	61%	78%	0.03 (-80%)	0.10 (-29%)	0.06 (-56%)	0.08 (-38%)	0.09 (-22%)	–	-0.07 (-12%)
— β^r=0.99	23%	60%	77%	0.03 (-79%)	0.10 (-30%)	0.06 (-56%)	0.08 (-38%)	0.09 (-25%)	–	-0.06 (-17%)
$\theta^r = 0.85$ β^r=0.85	13%	41%	61%	0.02 (-89%)	0.09 (-38%)	0.04 (-73%)	0.05 (-57%)	0.07 (-37%)	–	-0.06 (-22%)
— β^r=0.99	13%	40%	58%	0.02 (-89%)	0.08 (-45%)	0.04 (-74%)	0.05 (-58%)	0.07 (-44%)	–	-0.05 (-32%)
20-year consolidation										
Cons. tax model	99%	93%	88%	0.14	0.14	0.13	0.12	0.10	0.09	-0.08
$\theta^r = 0.67$ β^r=0.85	31%	74%	85%	0.03 (-77%)	0.10 (-25%)	0.07 (-47%)	0.08 (-28%)	0.09 (-11%)	0.09 (-3%)	-0.08 (-1%)
— β^r=0.99	32%	74%	85%	0.03 (-76%)	0.10 (-25%)	0.07 (-47%)	0.08 (-28%)	0.09 (-12%)	0.09 (-4%)	-0.08 (-2%)
$\theta^r = 0.75$ β^r=0.85	23%	63%	80%	0.02 (-86%)	0.10 (-29%)	0.05 (-60%)	0.07 (-40%)	0.08 (-17%)	0.09 (-6%)	-0.08 (-2%)
— β^r=0.99	23%	63%	80%	0.02 (-86%)	0.10 (-29%)	0.05 (-60%)	0.07 (-40%)	0.08 (-18%)	0.08 (-7%)	-0.08 (-4%)
$\theta^r = 0.85$ β^r=0.85	14%	44%	65%	0.01 (-96%)	0.09 (-33%)	0.03 (-78%)	0.05 (-60%)	0.07 (-31%)	0.08 (-10%)	-0.08 (-5%)
— β^r=0.99	14%	44%	64%	0.01 (-96%)	0.09 (-36%)	0.03 (-78%)	0.05 (-60%)	0.07 (-31%)	0.08 (-12%)	-0.07 (-8%)

Before we consider the different calibrations of pass-through dynamics, we discuss two main insights of Table 2. First, regardless of a consolidation's duration, short-run multipliers (i.e. impact multipliers and one-year and two-year average multipliers) are dramatically smaller in the European VAT model. The explanation directly follows from the discussion in Section 4: delay in the pass-through dampens the short-run GDP adjustment because it defers the incentive to postpone consumption. Second, multipliers averaging over the entire duration of a

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[36]Time-discounting specific to the retail sector is discussed in Section 3.2.3.

[37]As in Section 3.8, pass-through is defined as cumulative proportionate response of consumer prices to an increase in the VAT tax factor.

consolidation (as well as the average GDP decline reported in the last column) are also smaller in the European VAT model, but differences become weaker in a consolidation's duration. For short consolidations, retail firms anticipate the near reversal of the tax rate already at the onset of the policy. This weakens the incentive to raise markups, which dampens total tax pass-through and thereby the present value of the decline in output. These anticipation effects become weaker in the duration of a consolidation, and they play a minor role for the five-year and 20-year consolidation. For these consolidations, differences in long-run multipliers are driven by the fact that the adjustment in both models is virtually identical once pass-through has converged to 80% in both model versions (see Section 3.8). The weight of the early phase – when the adjustment is different between both models – is smaller for multipliers that average over a longer time horizon.

Regarding the different calibrations of markup rigidity, we observe that β^r is of minor importance for multipliers. For θ^r, we find that more rigidity in the markup (a higher value) increases the differences in multipliers. The explanation is straightforward: differences are driven by delayed tax pass-through in the European VAT model, and this delay becomes stronger in the degree of markup rigidity.

The general picture is that differences between both models are striking for impact multipliers, one-year and two-year average multipliers, and peak multipliers. By and large, incorporating realistic pass-through dynamics reduces the first-year (two-year) average GDP decline by roughly 50%-80% (30%-60%), relative to the projections in the model that implements the VAT as a consumption tax paid by households. Even for the weakest calibration of retail markup rigidity ($\theta^r = 0.67$, corresponding to an expected markup lifetime of three quarters), the first-year multiplier declines by at least 45%. Since this calibration of VAT pass-through is extremely conservative – in the sense that it overstates VAT pass-through[38] and thereby understates differences in multipliers – the results strongly suggest that neglecting pass-through dynamics leads to a severe overestimation of the short-tun impact of VAT changes.

6 Policy implications

Overestimation of the short-run impact of VAT changes in workhorse models used at policy-making institutions can significantly affect policy advice derived from those models. As example, consider Coenen et al. (2008), who apply the ECB's New Area-Wide Model (NAWM) to analyze fiscal consolidation strategies that reduce the debt ratio in the euro area from 70% to 60%. Figure 6 is taken from the paper and compares the impact of increasing labor income taxes with the impact of increasing consumption taxes, which represent the VAT.

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[38]$\theta^r = 0.67$ implies a more comprehensive short-run pass-through than the baseline calibration, for which tax pass-through is already stronger than what is estimated by Benedek et al. (2015) (see Section 3.8).
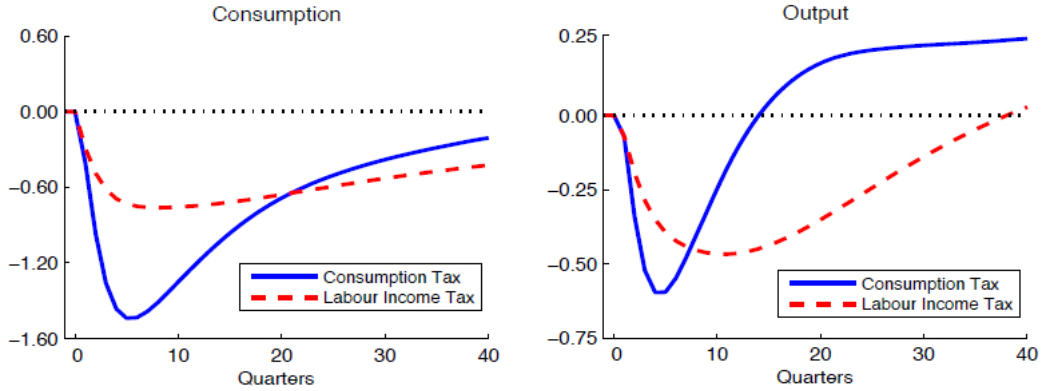
Figure 6: Impact of a fiscal consolidation in Coenen et al. (2008)

In the first eight quarters following the tax hike, the consumption tax (the stand-in for the VAT) has a significantly stronger adverse impact on output than the labor income tax (right panel). This can weaken the case for the use of the VAT as fiscal instrument, especially for countries that are in severe recession. However, the results of the paper at hand suggest that the short-run impact of the VAT hike would be significantly weaker if the NAWM accounted for empirically plausible VAT pass-through. This would presumably make the VAT the superior fiscal instrument also in the short run, and thereby allow for a more clear-cut policy advice.

The findings of this paper are also potentially relevant for the quantification of the impact of fiscal devaluations in theoretical models. Since the literature treats the VAT as a consumption tax (see Lipinska & Von Thadden, 2012; Hohberger & Kraus, 2016, Engler et al.,forthcoming), the VAT increase that is part of a fiscal consolidation has an immediate negative impact on private consumption. Under empirically plausible pass-through dynamics this impact would be significantly weaker, and the stimulus from a fiscal devaluation would presumably be stronger.

Finally, the results of this paper are important for the choice between using the standard VAT rate or reduced VAT rates as fiscal instrument. Benedek et al. (2015) report that tax pass-through is considerably faster and more comprehensive for the standard rate than for reduced rates. In light of the findings of this paper, reduced rates appear thus more suitable for fiscal consolidation, as they can be expected to have a weaker adverse impact on economic activity in the short run. By the same token, the standard rate is more appropriate to be lowered in order to stimulate the economy: as the benefit is more quickly passed on to consumers, the induced GDP expansion is stronger in the short run.

7 Robustness analysis

To examine the robustness of the results, Tables 3 and 4 (p. 26 and p. 27 in the appendix) report the same statistics as Table 2, but for variations in parameters and in the model specification. Rows labeled "European VAT model" depict the results for the baseline parameters $\theta^r = 0.75$ and $\beta^r = 0.99$. As in Table 2, parentheses indicate the percentage difference between multipliers in both models.

7.1 Exercise A: Introducing Rule-of-Thumb households

In this exercise, 40% of households are credit-constrained "Rule-of-Thumb" consumers, introduced by Galí et al. (2004).[39] This in general increases multipliers and also slightly raises their differences across the two models. The reason is that changes in disposable income of Rule-of-Thumb households translate to their full extent into changes in consumption. The reduction in hours worked and labor income induced by the consolidation thus lead to a further decline in Rule-of-Thumb consumption, and the emerging adverse feedback loop increases multipliers.

7.2 Exercise B: Flexible wages

To obtain wage flexibility, the rigidity parameter of wages θ^w (see equation (31)) is set to a negligibly small value, which slightly reduces the overall size of multipliers. Under wage flexibility, nominal wages decline in the short-run as response to the fall in the MRS between consumption and leisure. This reduction in marginal costs leads to lower producer prices. The latter stabilizes output in the face of the consolidation, because it offsets some of the increase in consumer prices (the driver of the reduction in consumption), and because the implied deterioration in the terms of trade induces more export demand. However, the implications for the differences in multipliers between both model versions are very modest.

7.3 Exercise C: Weaker elasticity of intertemporal substitution

This exercise considers $\gamma = 2$ instead of $\gamma = 1$ in the utility function (1), which lowers the elasticity of intertemporal substitution. We observe that multipliers are significantly smaller, but differences between both model versions decrease only slightly. The reason why multipliers are smaller is that weaker intertemporal substitution dampens the main channel by which the consolidation affects output – the postponement of consumption until the tax hike is over.

7.4 Exercise D: Larger public sector and labor taxes

As of 2014, general government expenditure as share of GDP is on average as high as 49% in the Euro Area (source: Eurostat). To replicate this figure, the model is extended by a constant labor tax rate of 32%, and government consumption G is increased by the amount of the additional revenues.[40] This has a mild impact on the level of multipliers in both model versions, but does not significantly change differences between both models.

7.5 Exercise E and F: Higher country weights in Taylor Rule

The baseline value $n = 0.01$ roughly matches the 2016 HICP country weights of Ireland, Greece and Portugal (1.4%, 2.4% and 2.2% respectively) and implies that the home country has a negligible weight in the union-wide inflation measure. Hence there is no significant reaction of monetary policy to inflation in the home country. To study the implications of higher country weights, exercise E considers $n = 0.11$ (which is in line with the HICP weight of Spain), and exercise F uses $n = 0.2$ (which roughly corresponds the weight of Italy and France, 17.6% and 20.7% respectively).[41] We observe that a higher country weight leads to smaller multipliers. To

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[39]The model description is available upon request.

[40]The model description is available upon request.

[41]All of these countries have a high debt-to-GDP ratio. In 2015, it is 93.8% in Ireland, 176.9% in Greece, 129% in Portugal, 99.2% in Spain, 132.7% in Italy, and 95.8% in France. Source: Eurostat.

see why, recall that the decline in consumption is driven by the positive deviation of the long-term real rate from the onset of the consolidation, and that this deviation results from the fall in consumer prices when the consolidation comes to an end. Responsive monetary policy means that this downward-reversion of consumer prices goes along with a decline in the nominal rate, which dampens the positive deviation in the real rate. Regarding the differences in multipliers between both model versions, a higher value of n does not significantly affect the results.

8   Conclusion

This paper analyzes the implications of empirically plausible tax pass-through dynamics for VAT multipliers. The focus on tax pass-through is motivated by the fact that standard models in academic research as well as workhorse models of leading policy-making institutions implement the VAT as a consumption tax, which dramatically exaggerates the speed of VAT pass-through. I use a standard DSGE model to quantify the resulting bias in short-run VAT multipliers, which is defined as as the difference between multipliers when the VAT is implemented as a consumption tax and multipliers when the VAT is thoroughly modeled in the sense that it has realistic pass-through dynamics. The analysis shows that the standard modeling strategy greatly overestimates the short-run impact of VAT changes: depending on the duration of the discretionary fiscal policy, one-year average multipliers and two-year average multipliers decline by about 50%-80% and 30%-60% respectively once the model accounts for realistic VAT pass-through.

In doing so, this paper proposes a modeling strategy that allows to align VAT pass-through with empirical estimates. Provided that a model features country-specific pricing equations, a technically inexpensive alternative to the proposed strategy is to implement the VAT as a tax paid by intermediate good firms on their sales (discussed at the end of Section 3.2.1).[42] This would make the model substantially better suited to derive tax multipliers for countries that use a European-style VAT rather than a US-style sales tax.

Since the relative size of multipliers associated with different fiscal instruments is crucial for the design of discretionary fiscal policy packages, the accuracy of VAT multipliers obtained from theoretical models is highly relevant for policy advice. This is particularly true on the backdrop of the high debt levels in many developed countries, which make it necessary to assess alternative fiscal consolidation strategies. The results of this paper also draw attention to the distinction between the VAT standard rate and VAT reduced rates as fiscal instruments. Since both are reported to differ in their pass-through dynamics, a more thorough analysis of their suitability as instrument for macroeconomic stabilization is a promising direction for further research. Finally, revisiting the implementation of the VAT could potentially overturn the results from the theoretical literature on the effectiveness of fiscal devaluations.

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[42]If the Calvo-parameter for intermediate good firms equals the Calvo-parameter for retailers ($\theta^r = \theta$), the model at hand generates the pass-through dynamics that one would obtain under the alternative modeling strategy. Since the standard Calvo-parameter 0.75 for retail markup rigidity leads to empirically plausible pass-through dynamics (see Section 3.8), the alternative modeling strategy would constitute a significant improvement on the standard approach.

Appendix

Table 3: Robustness analysis (1/2)

		Impact multiplier	Peak multiplier	1 year	Average multipliers 2 years	5 years	20 years	Avg. adjustment duration +2 yrs.
Baseline model (for comparison)								
One year duration	Cons. tax model	0.16	0.16	0.15	–	–	–	-0.05
—-	Euro. VAT model	0.03 (-83%)	0.05 (-69%)	0.04 (-73%)	–	–	–	-0.02 (-54%)
Two years duration	Cons. tax model	0.15	0.15	0.15	0.14	–	–	-0.06
—-	Euro. VAT model	0.03 (-79%)	0.08 (-46%)	0.06 (-59%)	0.07 (-52%)	–	–	-0.04 (-36%)
Five years duration	Cons. tax model	0.15	0.15	0.14	0.13	0.12	–	-0.08
—-	Euro. VAT model	0.03 (-79%)	0.10 (-30%)	0.06 (-56%)	0.08 (-38%)	0.09 (-25%)	–	-0.06 (-17%)
20 years duration	Cons. tax model	0.14	0.14	0.13	0.12	0.10	0.09	-0.08
—-	Euro. VAT model	0.02 (-86%)	0.10 (-29%)	0.05 (-60%)	0.07 (-40%)	0.08 (-18%)	0.08 (-7%)	-0.08 (-4%)
Exercise A: Including Rule-of-thumb consumers								
One year duration	Cons. tax model	0.20	0.20	0.20	–	–	–	-0.06
—-	Euro. VAT model	0.03 (-83%)	0.06 (-71%)	0.05 (-75%)	–	–	–	-0.03 (-57%)
Two years duration	Cons. tax model	0.20	0.20	0.19	0.18	–	–	-0.08
—-	Euro. VAT model	0.04 (-79%)	0.10 (-50%)	0.07 (-60%)	0.08 (-54%)	–	–	-0.05 (-38%)
Five years duration	Cons. tax model	0.19	0.19	0.17	0.15	0.13	–	-0.08
—-	Euro. VAT model	0.04 (-79%)	0.11 (-41%)	0.07 (-57%)	0.09 (-39%)	0.10 (-27%)	–	-0.07 (-18%)
20 years duration	Cons. tax model	0.19	0.19	0.17	0.14	0.11	0.09	-0.09
—-	Euro. VAT model	0.04 (-80%)	0.12 (-37%)	0.07 (-58%)	0.09 (-41%)	0.09 (-20%)	0.09 (-8%)	-0.09 (-4%)
Exercise B: Flexible wages								
One year duration	Cons. tax model	0.12	0.12	0.11	–	–	–	-0.03
—-	Euro. VAT model	0.02 (-85%)	0.03 (-74%)	0.03 (-75%)	–	–	–	-0.01 (-56%)
Two years duration	Cons. tax model	0.12	0.12	0.09	0.09	–	–	-0.04
—-	Euro. VAT model	0.02 (-81%)	0.05 (-55%)	0.04 (-59%)	0.04 (-53%)	–	–	-0.03 (-36%)
Five years duration	Cons. tax model	0.12	0.12	0.09	0.09	0.08	–	-0.06
—-	Euro. VAT model	0.02 (-81%)	0.07 (-36%)	0.04 (-55%)	0.05 (-36%)	0.06 (-24%)	–	-0.05 (-16%)
20 years duration	Cons. tax model	0.11	0.11	0.09	0.09	0.08	0.08	-0.08
—-	Euro. VAT model	0.02 (-82%)	0.08 (-25%)	0.04 (-53%)	0.06 (-34%)	0.07 (-14%)	0.08 (-5%)	-0.07 (-2%)
Exercise C: Weaker elasticity of intertemporal substitution								
One year duration	Cons. tax model	0.07	0.07	0.07	–	–	–	-0.02
—-	Euro. VAT model	0.01 (-82%)	0.02 (-67%)	0.02 (-72%)	–	–	–	-0.01 (-52%)
Two years duration	Cons. tax model	0.07	0.07	0.06	0.06	–	–	-0.03
—-	Euro. VAT model	0.02 (-77%)	0.04 (-42%)	0.03 (-56%)	0.03 (-49%)	–	–	-0.02 (-33%)
Five years duration	Cons. tax model	0.06	0.06	0.06	0.06	0.05	–	-0.04
—-	Euro. VAT model	0.02 (-77%)	0.05 (-24%)	0.03 (-52%)	0.04 (-34%)	0.04 (-22%)	–	-0.03 (-14%)
20 years duration	Cons. tax model	0.06	0.06	0.06	0.05	0.05	0.05	-0.04
—-	Euro. VAT model	0.01 (-80%)	0.05 (-22%)	0.03 (-54%)	0.04 (-35%)	0.04 (-14%)	0.04 (-4%)	-0.04 (-1%)
Exercise D: Larger public sector and payroll taxes								
One year duration	Cons. tax model	0.13	0.13	0.13	–	–	–	-0.04
—-	Euro. VAT model	0.02 (-83%)	0.04 (-68%)	0.04 (-73%)	–	–	–	-0.02 (-53%)
Two years duration	Cons. tax model	0.13	0.13	0.13	0.13	–	–	-0.06
—-	Euro. VAT model	0.03 (-78%)	0.08 (-42%)	0.05 (-58%)	0.06 (-51%)	–	–	-0.04 (-35%)
Five years duration	Cons. tax model	0.13	0.13	0.12	0.12	0.12	–	-0.08
—-	Euro. VAT model	0.03 (-77%)	0.11 (-16%)	0.06 (-53%)	0.08 (-36%)	0.09 (-24%)	–	-0.07 (-16%)
20 years duration	Cons. tax model	0.12	0.12	0.12	0.11	0.11	0.11	-0.10
—-	Euro. VAT model	0.02 (-82%)	0.11 (-12%)	0.05 (-55%)	0.07 (-36%)	0.09 (-16%)	0.10 (-8%)	-0.09 (-6%)

Appendix

Table 4: Robustness analysis (2/2)

		Impact multiplier	Peak multiplier	1 year	Average multipliers 2 years	5 years	20 years	Avg. adjustment duration +2 yrs.
Baseline model (for comparison)								
One year duration	Cons. tax model	0.16	0.16	0.15	–	–	–	-0.05
—-	Euro. VAT model	0.03 (-83%)	0.05 (-69%)	0.04 (-73%)	–	–	–	-0.02 (-54%)
Two years duration	Cons. tax model	0.15	0.15	0.15	0.14	–	–	-0.06
—-	Euro. VAT model	0.03 (-79%)	0.08 (-46%)	0.06 (-59%)	0.07 (-52%)	–	–	-0.04 (-36%)
Five years duration	Cons. tax model	0.15	0.15	0.14	0.13	0.12	–	-0.08
—-	Euro. VAT model	0.03 (-79%)	0.10 (-30%)	0.06 (-56%)	0.08 (-38%)	0.09 (-25%)	–	-0.06 (-17%)
20 years duration	Cons. tax model	0.14	0.14	0.13	0.12	0.10	0.09	-0.08
—-	Euro. VAT model	0.02 (-86%)	0.10 (-29%)	0.05 (-60%)	0.07 (-40%)	0.08 (-18%)	0.08 (-7%)	-0.08 (-4%)
Exercise E: 11% weight and different inflation measure								
One year duration	Cons. tax model	0.16	0.16	0.13	–	–	–	-0.04
—-	Euro. VAT model	0.03 (-83%)	0.04 (-73%)	0.04 (-73%)	–	–	–	-0.02 (-53%)
Two years duration	Cons. tax model	0.16	0.16	0.13	0.13	–	–	-0.06
—-	Euro. VAT model	0.03 (-78%)	0.07 (-52%)	0.06 (-57%)	0.06 (-51%)	–	–	-0.04 (-35%)
Five years duration	Cons. tax model	0.15	0.15	0.12	0.12	0.11	–	-0.07
—-	Euro. VAT model	0.03 (-78%)	0.10 (-35%)	0.06 (-53%)	0.08 (-35%)	0.08 (-24%)	–	-0.06 (-15%)
20 years duration	Cons. tax model	0.14	0.14	0.12	0.11	0.10	0.09	-0.08
—-	Euro. VAT model	0.03 (-82%)	0.09 (-34%)	0.05 (-55%)	0.07 (-36%)	0.08 (-16%)	0.09 (-6%)	-0.08 (-3%)
Exercise F: 20% weight and different inflation measure								
One year duration	Cons. tax model	0.16	0.16	0.12	–	–	–	-0.04
—-	Euro. VAT model	0.03 (-83%)	0.04 (-77%)	0.03 (-72%)	–	–	–	-0.02 (-52%)
Two years duration	Cons. tax model	0.16	0.16	0.12	0.11	–	–	-0.05
—-	Euro. VAT model	0.04 (-78%)	0.07 (-58%)	0.05 (-55%)	0.06 (-50%)	–	–	-0.03 (-34%)
Five years duration	Cons. tax model	0.16	0.16	0.11	0.11	0.10	–	-0.07
—-	Euro. VAT model	0.04 (-77%)	0.09 (-40%)	0.06 (-50%)	0.07 (-33%)	0.08 (-23%)	–	-0.06 (-14%)
20 years duration	Cons. tax model	0.15	0.15	0.11	0.10	0.10	0.10	-0.09
—-	Euro. VAT model	0.03 (-79%)	0.10 (-34%)	0.05 (-51%)	0.07 (-33%)	0.08 (-14%)	0.09 (-5%)	-0.09 (-3%)

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